

Constructing pedestrian level of service based on the perspective of visual impairment person

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Abstract. Comfortability level of pedestrian facilities is practically implied by the pedestrian level of service (i.e., PLOS), which defines the performance level of pedestrian facilities. The level is set by applying certain criteria, which may influence by the heterogeneity and the pedestrian behavior. On the other side, the growth attention is given to the inclusive pedestrian environment that pay a great consideration to the persons with disabilities (PWDs), including the visual impairment person (i.e., VIP). Moreover, the universal design of the public facilities, which has minimum barriers for the PWDs needs to be promoted more, to attain better accessibility for the public. This paper then proposes a method for calculating of PLOS by taking into account the VIP perspective to the pedestrian facilities performance.

1 Introduction

Pedestrian is considered as an essential element to be accommodated because almost all movements are committed on foot. However, in some countries, particularly developing ones, walking by foot is often overlooked in a transportation system. Society at large tend to assume that transport infrastructures are constructed only for motor vehicles. The existing standards, rules, norms, and habits are provided to accommodate motor vehicles only. As a result, pedestrian facilities are mostly below acceptable standard. Therefore, pedestrian facilities needs to be a top priority when planning and designing transport infrastructures. Proper pedestrian facilities will bring forth a lot of benefits such as comfortability for pedestrian themselves.

Comfortability level of pedestrian facilities is practically implied by the pedestrian level of service (i.e., PLOS). A level of service can be defined as an assessment of the quality of service or an overall measure of current conditions of streets including facilities, situations, equipment and infrastructures [1]. It can also be described as a quantitative stratification of a performance measure or measures that represent quality of service [2]. Most of the PLOS standards that have developed so far to assess the service quality of pedestrian facilities have been estimated using experts' opinion and not from pedestrians' perceptions [3]. Meanwhile, pedestrian input can be used for determining adequate levels of service from the user's perspective [4].

On the other side, the growth attention is given to the inclusive pedestrian environment that pay a great

consideration to the persons with disabilities (PWDs), including the visual impairment person (i.e., VIP). PWDs is a group of people which is prone to social exclusion in the society. Social exclusion happens when individuals or people are systematically blocked from (or denied full access to) various rights, opportunities and resources that are normally available to members of a different group. It is contradictory to a general statement that is every human being should be treated equally. According to the International Labour Organization, about 15% of world population are PWDs, or more than a billion. They are considered as the largest minority group in the world and most likely experience social exclusion. Accessibility provision is one of the efforts needed to create an inclusive pedestrian environment mainly for PWDs. If PWDs can get to a public places and pathways easily, it means that other people also have easy to use public places and public transportation [5].

For VIP, walking is a stressful experience as they negotiate the sidewalks trying to avoid painful collisions [6]. The effect of vision loss is being uncomfortable about safety while moving around or traveling independently [7, 8]. Limited knowledge of building design and engaging with disabled people in order to understand their perspective of accessible needs are also become another reason of inattentive design for PWDs. Therefore, this paper presents a method for calculating of PLOS by taking into account the VIP perspective to the pedestrian facilities performance.

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2 Literature review

Pedestrians and cyclists have received less attention in LOS studies than motorized vehicles. Furthermore, only one research that addressed disabled pedestrians in LOS studies. Asadi-Shekari *et al.* constructed the disabled pedestrian level of service (DPLOS) for different street hierarchies that has not been addressed previously to ensure inclusive walking conditions. An analytical point system comparing existing pedestrian facilities to a standard is proposed to estimate the DPLOS [9].

Fruin constructed the basis for six levels of service for the design of walkways and stairways. These levels of service provided a qualitative method of designing new or evaluating existing pedestrian environments [10]. Kang *et al.* studied how pedestrians perceive LOS on sidewalks shared with bicycles under various urban-street conditions [2]. Mori *et al.* described a way to evaluate ordinary sidewalks, and proposed two different methods: an evaluation based on pedestrian behaviour and an evaluation based on pedestrian opinion [11]. Asadi-Shekari *et al.* constructed a foundation for evaluating and improving campus streets for pedestrians. They presented pedestrian design indicators based on different guidelines that consider various pedestrian needs. They also introduced the pedestrian level of service (PLOS) for campuses, which is a measure to evaluate campus street facilities and infrastructure for pedestrians. An analytical point system comparing existing pedestrian facilities to a standard is proposed to estimate this PLOS [12].

Sisiopiku *et al.* reviewed and compared the existing methods (Highway Capacity Manual 2000 method, Australian method, Trip Quality method, Landis model, and conjoint analysis approach) for establishing the quality of operations of pedestrian sidewalks in urban settings. The findings from the study can assist with the determination of appropriate improvements to the pedestrian LOS approach that is currently included in HCM 2000 [13]. Dixon developed a point system to evaluate the PLOS of a street, which is useful for rating street conditions. The weights of the various indicators in this model are arbitrarily chosen. In addition, there are no separate score categories for various situations. Therefore, appropriate weight was not given to the intermediate conditions [14]. Christopoulou *et al.* developed a model, applicable to the Greek urban environment, for the estimation of pedestrian level of service, since available methodologies usually refer to quite different conditions than the prevailing ones in Greek cities. The model was then applied in parallel with other five methodologies along a sidewalk in the city of Thessaloniki [15].

Rastogi *et al.* presented the LOS criteria under two conditions, one for pedestrian movements along the carriageway on or at its side and other for the movement on a pedestrian facility. The LOS criteria were developed using two different approaches and the two data sets. One approach is based on the rate of change of curvature of the pedestrian flow-area module curve and another is based on speed ratio-density plot. It is observed that the pedestrian space criterion is more uniform and stable than the pedestrian flow criterion in defining the LOS of a facility [16]. Zhao *et al.* proposed a comprehensive multi-

factor evaluation method for pedestrian level of service on sidewalks based on the quantification of environmental factors. The fuzzy neural network method was used to establish the comprehensive evaluation model for pedestrian level of service on sidewalks [17]. Kadali and Vedagiri proposed the evaluation of the quality of service of such crossing facilities with respect to different land-use type under mixed traffic conditions. Pedestrian perceived LOS were collected with respect to different land-use type such as shopping, residential and business areas. The ordered probit (OP) model was developed by using NLOGIT software package, with number of vehicles encountered, road crossing difficulty as well as safety considered as primary factors along with pedestrian individual factors (gender and age), land-use type and roadway geometry [18].

Sahani and Bhuyan carried out an indepth study to define PLOS criteria of urban off-streets facilities in developing countries having heterogeneous traffic flow conditions. Affinity Propagation (AP) is used in order to defined LOS classification problem. Inventory details and speed data are collected from two important cities (Bhubaneswar and Rourkela) of Odisha state, India through the application of video camera [19]. Cepolina *et al.* presented methodology for evaluating the quality of operation of pedestrian facilities: the methodology is based on the individual level of comfort perceived by each pedestrian that moves in the area [20]. Tanaboriboon and Guyano developed a set of LOS criteria for planning pedestrian walkways in Bangkok and to compare these criteria with those based on Western standards [21].

Marisamynathan and Lakshmi proposed a method for the evaluation of PLOS at sidewalk, based on quantitative and qualitative data. The required model parameters were collected from videographic and questionnaire surveys conducted at selected nine sidewalks in Chennai, India. Significant parameters were identified and PLOS model was developed using stepwise regression analysis method. The developed model was validated using the field data and the results showed that the performance level of the proposed model was more precise and produced reliable solutions. The model applications were proposed and analyzed theoretically with three improvement measures. The developed model can be used by road designers to find the wellness of a particular sidewalk that accommodates pedestrian travel mode [22]. Marisamynathan and Vedagiri developed a suitable method for estimating the PLOS model under mixed traffic conditions and also to define threshold values for PLOS classification at signalized intersections [23].

Jaskiewicz proposed a process by which such factors can be used to analyze pedestrian systems. Nine specific evaluation measures are described, followed by an account of their application in Winter Park, Florida [24]. Petritsch *et al.* developed a level-of-service (LOS) model that represents pedestrians' perceptions of how well urban arterials with sidewalks (a combination of roadway segments and intersections) meet their needs [25]. Asadi-Shekari *et al.* constructed the pedestrian safety index (PSI), which evaluates facilities along the streets for pedestrians. To estimate this PSI, a point system method is proposed that compares existing conditions to a

standard. This method can be used to identify existing problems and to propose improvements [26]. Talavera-Garcia and Soria-Lara developed an alternative walking index, the Quality of Pedestrian Level of Service (Q-PLOS) method. This novel method is based on the quality of urban design for pedestrian and its relationship with walking needs. The city of Granada (Spain) provided the empirical focus [27]. Tan *et al.* studied the methods of assessing pedestrian level of service by analyzing the relationship between the pedestrians' subjective perceptions and the quality of the road physical facilities as well as the traffic flow operation [28].

3 VIP LOS development

Pedestrian level of service is generally represented using an alphabet rating, which is derived from the numeric rating of sidewalk performance. The numeric rating composes several aspects, which is standardly formulated as follows:

$$VIPLOS = \sum_{i=1}^I a_i \left(\sum_{j=1}^J b_i^j c_i^j \right) \quad (1)$$

where:

- $VIPLOS$: VIP level of service
- a_i : weight value for component criteria- i
- b_i^j : performance level of indicator- j , which construct component criteria- i
- c_i^j : weight value of indicator- j , which construct component criteria- i

Based on the above formulation, at least three questions exist for developing PLOS based on the perspective of VIP, such as:

- What the component criteria that influence the perspective of service level?
- How the infrastructure and built environment of sidewalk affect the component criteria?
- How to assess the performance level of infrastructure and built environment for satisfying the VIP requirement?

Such questions are possible to be answered by reviewing the current stream of PLOS, and by interviewing the VIP relating those issues. PLOS is firstly developed based on the criteria of capacity and pedestrian traffic [10, 11], though, literatures currently record an extensively growth of criteria. For instance, researchers put their attention on the criteria of comfort, convenience [31], security, safety [32], and system coherence [14, 15]. This paper then simply utilizes such criteria for constructing the PLOS based on the VIP perspective. In addition, to acquire the important level of criteria, the pair wise-based interview is conducted by involving 30 VIP respondents.

Table 1. Importance level of component criteria.

Component Criteria	Weight of Importance (a_i)
Capacity	0.106
Comfort	0.154
Safety	0.222
Security	0.232
System Coherence	0.135
Traffic	0.152

Table above resumes the interview result concerning on the importance level of component criteria, in which VIP places the safety and security components as the most important factor. In addition, the capacity component is interestingly located in the last positioned, which may be different from that previously available for the non-VIP [35]. In fact, the criteria are constructed by the apparent indicator of sidewalk, which can be interpreted as the infrastructure and built environment of sidewalk. Table below then tries to identify the related indicators, which may build the VIP perspective relating to the component criteria.

Table 2. Indicator candidates.

Component Criteria (i)	Indicators (j)
Capacity	Total width of sidewalk Effective width of sidewalk
Comfort	Tactile pavement condition Potholes Street furniture Number of trees
Safety	Tactile pavement existence Warning tile existence Crossing facilities Audible crossing facilities
Security	Number of nearby houses Number of nearby commercials Presence of other Lighting Criminalities record/news
System Coherence	Number of public transports Number of intermediaries Change in elevation
Traffic	Vehicle traffic Pedestrian traffic

The indicator candidates are filtered based on the VIP perspective by rating the current performance of sidewalk indicators. The correlation between rating criteria and indicator is then investigated, in which the strongest correlation may implied the beneficial level of indicator.

Table 3. Correlation between sidewalk capacity rating and infrastructure indicators.

	Capacity rating	Total width	Effective width
Capacity rating	1,00		
Total width	0,02	1,00	
Effective width	0,03	0,99	1,00

Table 3 shows the example of selection for determining the vital indicator that govern the capacity criteria. It indicates that the capacity criteria from the VIP perspective may relate to the total width and effective width. Although, the correlation between effective and

total width is statically strong, it thus cannot be united into a single formulation. Therefore, in the further step, the capacity criteria are only managed by the effective width indicator, which has a largest correlation with capacity criteria.

After the indicators have been selected, the weight value is estimated by conducting the linear regression between the rating criteria and indicators. The resulted coefficient of regression is then regarded as the comparable pattern for determining the indicator weight. To ensure the fair comparison, each indicator value is firstly adjusted in the similar value of range. In addition, since the coefficient may be composed the wide range of number, the normalized process is conducted for adjusting the indicator weight (see Table 4). The similar approaches are further implemented for determining the other indicators and its weight value, which is summarized as in Table 5.

Table 4. Weight value of potholes and tactile conditions indicators.

Indicators (<i>j</i>)	Coefficients	Weight (c_i^j)
Potholes	0.12	0.07
Tactile pavement condition	1.64	0.93
Total	1.76	1.00

Table 5. Selected indicators and its weight value.

Component Criteria (<i>i</i>)	Indicators (<i>j</i>)	Weight (c_i^j)
Capacity	Effective width of sidewalk	1.00
Comfort	Tactile pavement condition	0.93
	Potholes	0.07
Safety	Tactile pavement existence	0.35
	Warning tile existence	0.26
	Crossing facilities	0.39
Security	Presence of other	0.57
	Criminalities record/news	0.43
System Coherence	Number of public transports	0.59
	Number of intermediaries	0.41
Traffic	Pedestrian traffic	1.00

Taking into consideration the previous process, it can be inferred that the performance level quantification of indicator is regarded as the remains parameters need to be adjusted. For ensuring the fair and accountable assessment, the level classification of indicator is then proposed, which is developed based on the performance level perspective of VIP. Moreover, the minimum requirement is derived from the sidewalk-related standard. For instance, Indonesian standard specified the minimum requirement for the sidewalk effective width is equal to 1.5 m. However, based on the interview survey, the VIP respondent gives a relatively small rating (i.e., 2.7 scale 6) for infrastructure with such width value (i.e., 1.5 m). Therefore, the minimum width stated in standard (i.e., 1.5 m) is placed at LOS D (see Table 6).

Table 6. Classification of level performance for effective width indicator.

Alphabet value	LOS		Effective width (m)
	Alphabet value	Numeric value	
A		6	>3
B		5	2.5-3
C		4	2.0-2.5
D		3	1.5-1.9
E		2	1.0-1.4
F		1	<1.0

Relating to the comfort criteria, the tactile pavement condition and number of potholes indicator are defined into six level, in which the LOS A regarded to the pedestrian facilities that pass all requirement of tactile and no potholes existed. On contrary, the tactile pavement which is not fitted to the requirement, and several number of potholes is appeared is then located in LOS F.

Table 7. Classification of level performance for tactile pavement condition and potholes indicators.

LOS	Tactile pavement condition *)	Sidewalk potholes
A	Pass all requirement	No potholes
B	Pass all requirement except uncoloured tactile	A little number of potholes existed on sidewalk (<5 per 100 m)
C	Only not passed width requirement	A little number of potholes existed on tactile (<5 per 100 m)
D	Only not passed distance from edge requirement	Several potholes existed on sidewalk (>5 per 100 m)
E	Not passed width and distance requirement	Several potholes existed on tactile (>5 per 100 m)
F	Not passed all requirement	Several potholes existed at tactile & sidewalk

*) Minimum requirements: 0.60 m distance from edge of footpath; minimum width 0.30 m; yellow coloured;

Table 8. Classification of level performance for existence of tactile, warning tile, and crossing facilities indicators.

LOS	Existence of tactile	Existence of warning tile	Number of crossing facilities (/km)
A	Tactile pavement existed	Warning tile existed	3
B	-	-	-
C	-	-	2
D	-	-	-
E	-	-	1
F	No tactile pavement existed	No warning tile existed	0

Table 8 shows the level classification for describing the performance of pedestrian facilities related to the existence of tactile, warning tile, and crossing facilities. As the existence of warning tile behaved as the binary

number, LOS A is obtained in case the tactile or warning tile is existed, and LOS F for the contrary conditions.

Table 9. Classification of level performance for the presence other and criminalities record indicators.

LOS	Presence other *)	Criminalities record (number/month)
A	5.6 m ² /ped.	No record
B	3.7–5.6 m ² /ped.	1
C	2.2–3.7 m ² /ped.	2
D	1.4–2.2 m ² /ped.	3
E	≤ 0.75 m ² /ped	4
F	< 5.6 m ² /ped	>4

The performance level of security criteria, which is constructed by presence other and criminalities record indicators, is also classified. The indicator of presence of other is simplified in Table 9. The lowest performance of security is given to the sidewalk with very crowded or very limited pedestrian, which is implied from the interview survey.

Table 10. Classification of level performance for the number of public transport and intermediaries' indicators.

LOS	Number of Public Transport Route	Number of intermediaries' (/100 m)
A	>5	0
B	5	2
C	3	3
D	2	4
E	1	5
F	0	>5

The performance level of system coherence and traffic-related indicator is classified in Table 10 and 11. The classification for the system coherence indicator is mainly developed based on the performance rating by the VIP from the interview surveys. Meanwhile, the traffic indicator classifications are inspired from HCM LOS by taking into consideration that VIP does not comfort with the crowded or less number of traffic flow (i.e. LOS E and F).

Table 11. Classification of level performance for the vehicle traffic and pedestrian density indicators.

LOS	Pedestrian traffic
A	16–23 ped./min/m
B	23–33 ped./min/m
C	33–49 ped./min/m
D	49 – 75 ped./min/m
E	>75 ped./min/m
F	<16 ped./min/m

Putting together the criteria, indicator, its weight, and performance assessment, the VIP LOS thus can be calculated, where the rating explains the quality of sidewalk based on the perspective of VIP (see Table 12).

Table 12. VIP LOS interpretation.

VIP LOS		Interpretation
Alphabet	Numeric	
A	5.00-6.00	Very pleasant
B	4.00-4.99	Acceptable
C	3.00-3.99	Rarely acceptable
D	2.00-2.99	Uncomfortable
E	0.99-1.99	Unpleasant
F	0.00-0.99	Very unpleasant

To ensure the applicability of proposed method, an actual sidewalk is assessed based on the framework of VIP LOS. The existing information relating to the sidewalk is illustrated in Table 13.

Table 13. Infrastructure and environmental built information of tested sidewalk.

Indicators (j)	Unit	Value
Effective width of sidewalk	m	7.8
Tactile pavement existence	-	yes
Warning tile existence	-	yes
Tactile colour	-	yellow
Tactile width	m	0.3
Distance of tactile from edge of footpath	m	0.6
Number of potholes on tactile	unit/100 m	no
Number of potholes on sidewalk	unit/100 m	no
Number of crossing facilities	unit/1 km	2
Ave. sidewalk density	m ² /ped.	2.8
Criminalities record	unit/month	1
Number of public transports route	unit	3
Number of intermediaries	unit/100 m	7
Pedestrian traffic	ped./min/m	35

Based on the sidewalk-related information, the method is firstly implemented by categorizing the information to the performance classification of indicators (see Table 6 to Table 11).

Table 14. Infrastructure and environmental built information of tested sidewalk.

Component Criteria (i)	Indicators (j)	LOS Value (Numeric)
Capacity	Effective width of sidewalk	6
	Tactile pavement condition	6
Comfort	Sidewalk potholes	6
	Tactile pavement existence	6
Safety	Warning tile existence	6
	Crossing facilities	4
Security	Presence of other	4
	Criminalities record/news	5
System Coherence	Number of public transports	4
	Number of intermediaries	1
Traffic	Pedestrian traffic	4

$$\begin{aligned}
 VIPLOS &= 0.106(1*6) + 0.154(0.93*6 + 0.07*6) \\
 &+ 0.222(0.35*6 + 0.26*6 + 0.39*4) \\
 &+ 0.232(0.57*4 + 0.43*5) \\
 &+ 0.135(0.59*4 + 0.41*1) + 0.512(1*4) \\
 VIPLOS &= 4.72
 \end{aligned}$$

In addition, Eq. (1) is invoked for calculating the LOS rating, in which the tested sidewalk is thus regarded as an acceptable performance for VIP (i.e., LOS A).

4 Conclusion

This paper presents a method for estimating the pedestrian level of service, which is constructed from the perspective of visual impairment person. The deep interview is conducted for elaborating the important criteria of pedestrian performance. In order to investigate the critical indicator that forms the criteria, the comparison between performance rating and infrastructure condition is implemented. The performance classification is also proposed corresponds to the existing sidewalk standard and the interview result. The applicability of method is also tested in a single segment of sidewalk.

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