Towards The Design of a Comprehensive PLOS Index

Eleni Andrikopoulou*[1], Ioanna Spyropoulou[2]

[1] PhD candidate, School of Rural, Surveying and Geoinformatics Engineering, National Technical University of Athens, Greece

[2] Professor, School of Rural, Surveying and Geoinformatics Engineering, National Technical University of Athens, Greece

SHORT SUMMARY

This study proposes an innovative methodology for evaluating sidewalk efficiency through the assessment of the Pedestrian Level of Service (PLOS) as experienced by pedestrians. The approach is structured around four key pillars: infrastructure accessibility, convenience of movement, safety and security. It also aims to capture pedestrians' preferences regarding their walking experience in order to estimate weighting coefficients and develop an index for quantifying pedestrian service levels. A questionnaire survey was conducted to examine factors influencing pedestrian experience, considering built environment characteristics, infrastructure and traffic conditions and user demographics. The findings indicate that gender affects the factors that pedestrian prioritise, with women placing greater importance on security as well as convenience. Regarding age, convenience becomes increasingly important as pedestrians grow older. Overall, the results contribute to the development of a standardized framework for assessing sidewalk performance and identifying critical factors affecting pedestrian experience.

Keywords: Pedestrian Level of Service (PLOS), pedestrian infrastructure assessment, sidewalk performance, walking, active mobility

1. INTRODUCTION

Walking is the most sustainable and environmentally friendly transport mode. It plays a central role in nearly every trip, acting as the key first- and last-mile link between land use and motorised travel (Wigan, 1995). Because of its importance, it is vital to design pedestrian networks that ensure walking is safe, reliable, comfortable and efficient. The design of transport infrastructure requires an ex-ante assessment of its operational performance to determine the characteristics that ensure satisfactory conditions and address user needs. The measure commonly employed for this purpose is the Level of Service (LOS), applicable to both vehicular and pedestrian facilities.
The concept of LOS was first introduced in 1965 for vehicular traffic on highways (HRB, 1965). It was later extended for pedestrian facilities by Fruin (1971), who defined the Pedestrian Level of Service (PLOS) as a measure of pedestrian comfort and mobility. According to the Highway Capacity Manual (HCM, 2022), LOS, regardless of whether it involves motorised or non-motorised traffic, is defined as a qualitative measure derived from the quantitative stratification of performance indices that represent service quality from the traveler's perspective, typically using a scale from A to F. In particular, the PLOS describes the operational quality of relevantfacilities and the comfort experienced by users, indirectly reflecting their satisfaction (Sahani and Bhuyan, 2017). Over time, numerous methods have been proposed for estimating PLOS. However, most are adapted from vehicular flow models and therefore fail to capture the distinct characteristics

and dynamics of pedestrian movement. Nevertheless, the significant variation among these methods indicates that a standardised evaluation framework is still lacking (Bivina and Parida, 2024). A review of relevant studies reveals various approaches related to the concept of PLOS (Andrikopoulou and Spyropoulou, 2026). Some focus on developing methodologies for its calculation based on pedestrian traffic quantities, while others propose analytical techniques that incorporate environmental and built environment parameters that influence service quality. The former are rather simplistic, as they overlook important factors that affect pedestrian experience, whereas the latter approximate walkability indicators rather than measuring infrastructure performance. The main objective of the present study is to identify and interpret the factors that affect the walking experience as perceived by pedestrians, with the aim of proposing a new PLOS index that incorporates the needs of all users, which are often overlooked.

2. METHODOLOGY

The proposed framework defines the pedestrian LOS around four fundamental dimensions: infrastructure accessibility, movement convenience, safety and security. The first step is to identify all relevant parameters that shape these four dimensions, ensuring that they function as operational performance factors. To this end, a comprehensive literature was conducted to identify potential relevant factors. The review highlighted several categories of factors: commonly used variables (e.g. pedestrian speed), newly introduced factors reflecting a more pedestrian-centred approach that incorporates prevailing priorities (e.g. safety), walkability-related factors that do not directly represent PLOS (e.g. streetscape design, presence of trees, shade) and factors not typically incorporated as a function of pedestrian flow, although they should be (e.g. security). Last, additional underreported or missing factors were also identified. Based on these findings, a questionnaire was developed for a large-scale questionnaire survey, the analysis of which could inform a framework of the factors that should be incorporated into a PLOS index and their relative importance across different population groups. This first step has been partially completed, as the questionnaire has been designed and disseminated yielding 1470 responses, while data analysis is still ongoing.

The second step is to assign weighting coefficients to the identified variables for the development of a composite index quantifying PLOS. To achieve this, naturalistic data will be collected alongside responses from a short questionnaire, where participants will rate their walking experience. A field survey will be conducted on selected sidewalk segments to collect observational data under real-world conditions. Data collection will primarily rely on video recordings to capture pedestrian movement trajectories, walking speed and the spatial and functional characteristics of the surrounding environment. The resulting dataset will be used to develop a PLOS evaluation index that reflects actual infrastructure usage and prioritises user experience.

Moreover, the data will be further analysed to explore potential relationships between perceived PLOS and users' socio-demographic and economic characteristics, including age, gender, employment status, income level, physical ability and trip purpose.

Questionnaire survey

A large-scale online questionnaire survey is designed to explore how pedestrians perceive key parameters and how they can be measured. The survey systematically investigates pedestrians' opinions, preferences and experiences while walking in urban environments, focusing on accessibility, convenience, safety and security. The first part collects mobility characteristics (e.g., walking frequency, trip purpose) and perceptions of factors influencing the walking experience. The second part examines how specific features of the urban environment, such as obstacles, lighting, time of day and area characteristics, shape perceived safety, security and convenience

(Table 1). This includes elements often overlooked in prior research, such as whether pedestrians walk alone or in groups and the influence of pedestrian and vehicular traffic on perceived security. Regarding convenience, the analysis evaluates how different types of obstacles (based on size and position) alter the effective sidewalk width, resulting in deviations, discomfort and reduced mobility, especially under crowded conditions. The third section of the questionnaire collects socio-demographic characteristics, such as gender, age, walking ability and occupation, to assess how individual and social attributes interact with pedestrian preferences. By analyzing the responses, the objective is to identify the parameters that most significantly influence pedestrians' perceptions of the walking experience, while also considering individual and social characteristics such as gender, age and walking ability, as well as other external factors, for example trip purpose.

Table 1: List of pedestrian parameters considered in the analysis

Sidewalk width
Sidewalk surface material
Condition of sidewalk surface (level of maintenance)
Sidewalk height (curb height)
Sidewalk gradient
Curb ramps on both sides of the sidewalk
Tactile paving (guidance path for visually impaired users)
Presence of other pedestrians
Vehicles on the sidewalk (e.g., motorcycles)
Fixed obstacles (e.g., signs, outdoor seating, trees, etc.)
Cleanliness / bad odor
Water accumulation due to poor drainage
Stray animals
Weather conditions
Poor lighting
Absence of other pedestrians
Absence of vehicles on the road
Area reputation (e.g., unsafe neighborhood)
Lack of active land use (closed shops, empty streets)
Lack of activity or human presence in surrounding buildings
Passage through underground crossings
Lack of separation between road traffic and sidewalk (railings, planters, etc.)
Vehicles driving very close to the sidewalk
High vehicle speeds
Wide road (multiple lanes)
Heavy vehicle traffic (e.g., buses, trucks)
Frequent intersections

Data collection

The questionnaire survey was conducted between November 2025 and March 2026. In total, 1.470 valid responses were collected, providing a sample size considered adequate for a margin of error of 5% at a significance level of $\alpha = 1\%$, based on the formulas proposed by Daniel (1999) and Naing et al. (2006). The sample mainly consisted of respondents from Athens, complemented by participants from other major urban centers such as Thessaloniki and Volos, in order to ensure

relatively homogeneous urban environments with comparable pedestrian infrastructure characteristics (e.g., sidewalk design and conditions). The questionnaire was developed and administered using the LimeSurvey platform and distributed online via social media platforms and email networks, while supplementary dissemination was conducted through posters and informational leaflets. Although the questionnaire was addressed to individuals with experience in urban walking, the final sample comprised participants with diverse walking habits, including those with low walking frequency.

Sample characteristics

The study sample size comprised 1470 completed questionnaires and consisted of a diverse group of respondents across key socio-demographic and travel-related characteristics, as shown in Table 2.

Table 2: Sample characteristics

Age (years)		Occupation	
17-30	289	University Student	136
31-40	314	Public Sector Employee	239
41-50	346	Private Sector Employee	527
51-60	330	Self-Employed	256
>60	191	Passive Income Recipient	10
Gender		Homemaker	57
Male	601	Retired	137
Female	866	Unemployed	78
Other	3	School Student	7
Main Transport Mode		Other	23
Private car (driver)	674	Level of Living	
Private car (passenger)	61	Low	70
Motorcycle	85	Lower-Middle	239
Public Transport	343	Middle	831
Taxi	9	Upper-Middle	284
Bicycle	27	High	46
Scooter	1	Highest Level of Education Completed	
Pedestrian	270	Primary education	6
Walking Frequency		Secondary education	327
Never	38	Bachelor's degree	664
Rarely	236	Master's degree	398
2-3 days/week	400	Doctorate	71
4-5 days/week	337	Other	4
6-7 days/week	459		

The majority of respondents are female (58,9%), while males represent a smaller proportion (40%) and only a negligible share identifies with other gender categories (0,1%). The age distribution is relatively balanced across working-age groups, with a slight concentration in middle

adulthood. Participation appears lower among older respondents, which may be attributed to reduced familiarity with digital technologies and online survey tools. In terms of mobility behaviour, private car use as a driver is dominant (46%), while public transport (23,3%) and walking (18,4%) are also significant. Walking frequency varies considerably, with a substantial proportion walk regularly, with 4-7 days/week accounting for the majority of responses (54%), while only 38 respondents (2,5%) report that they never really walk. Overall, the dataset reflects a heterogeneous population in terms of demographics, socioeconomic background, and mobility patterns, making it suitable for the analysis of transport behavior and related factors.

3. RESULTS AND DISCUSSION

ANOVA analysis

A series of one-way analysis of variance (ANOVA) tests was conducted to examine whether perceived PLOS dimensions differ significantly across gender and age groups. The results indicate that for the safety dimension, no statistically significant differences were observed with respect to either gender ($F = 0.014$, $p = 0.986$) or age ($F = 1.105$, $p = 0.352$). In contrast, for the security dimension, a statistically significant effect of gender was identified ($F = 14.43$, $p < 0.001$), while age showed a marginally non-significant effect ($F = 2.238$, $p = 0.0628$). Similarly, for the convenience dimension, gender was found to have a statistically significant influence ($F = 6.544$, $p = 0.00148$), whereas age was marginally significant ($F = 2.351$, $p = 0.0523$). Finally, for the accessibility dimension, neither gender ($F = 1.953$, $p = 0.142$) nor age ($F = 0.374$, $p = 0.827$) demonstrated statistically significant effects. Overall, findings suggest PLOS dimensions are evaluated differently across pedestrian sub-populations.

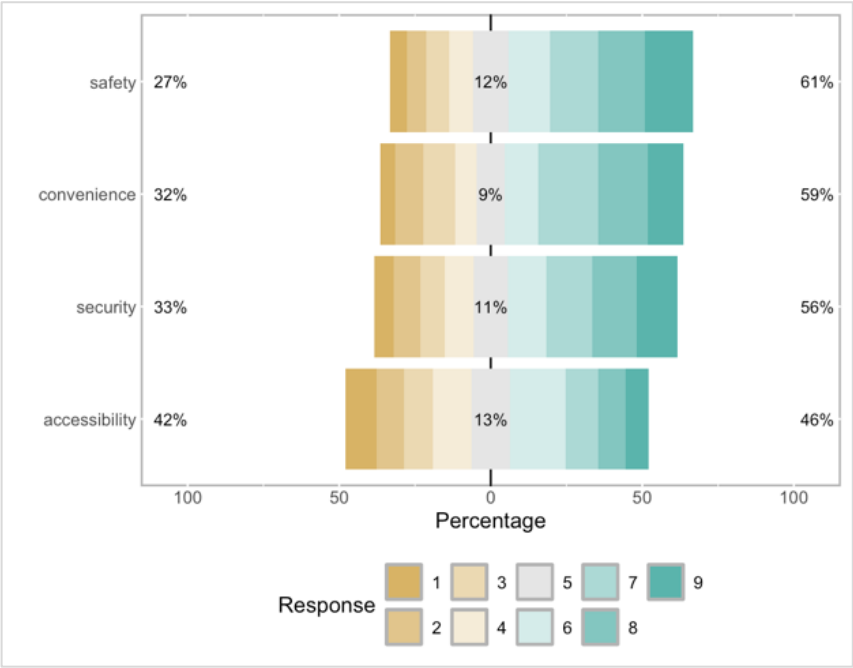


Figure 1: Distribution of respondents' ratings (1–9 Likert scale) for factors influencing pedestrian sidewalk experience

The Likert plot (Figure 1) presents the distribution of responses across the four factors. Each bar shows the proportion of responses on a 1–9 scale, where higher values indicate greater perceived importance. The central reference line serves only as a visual midpoint for comparison between lower and higher ratings. Overall, the results indicate that safety-related factors are the most important, with both traffic safety (62%) and security (56%) receiving the highest proportion of high importance ratings. Convenience is also considered highly important (59%), while accessibility shows comparatively lower importance, with a more balanced distribution of responses. In general, respondents prioritise safety and convenience over accessibility when evaluating sidewalk quality.

Confirmatory factor analysis

A confirmatory factor analysis (CFA) was conducted to validate the proposed PLOS measurement model using RStudio software. The results demonstrated an acceptable overall fit across all constructs. Specifically, the Security showed a very good fit (CFI = 0.990, TLI = 0.971, RMSEA = 0.081, SRMR = 0.021) although the RMSEA value was slightly above the recommended threshold. The accessibility construct exhibited an excellent model fit (CFI = 0.996, TLI = 0.987, RMSEA = 0.040, SRMR = 0.016), followed by safety, which also demonstrated excellent fit indices (CFI = 0.988, TLI = 0.977, RMSEA = 0.044, SRMR = 0.018). Similarly, convenience showed a strong model fit (CFI = 0.979, TLI = 0.958, RMSEA = 0.039, SRMR = 0.021), indicating a well-specified latent structure. All observed indicators loaded significantly on their respective latent constructs ($p < 0.001$), confirming the robustness of the measurement model. Table 3 presents the parameter estimates of CFA models for all respondents. Among the four dimensions, accessibility and safety demonstrated the strongest and most consistent factor loadings, indicating high construct validity. The security construct also showed strong loadings overall, although slight variability was observed in some indicators. In contrast, convenience exhibited comparatively lower loadings for certain items, suggesting a somewhat less consistent representation of this construct.

Table 3: CFA models for Safety, Convenience, Security and Accessibility

		Estimate	Std. Err	z-value	Std. all
Safety	Frequent intersections	1.176	0.049	24.160	0.736
	Vehicles on the sidewalk (e.g., motorcycles)	0.780	0.029	26.803	0.961
	Lack of separation between road traffic and sidewalk (railings, planters, etc.)	0.837	0.045	18.596	0.530
	Vehicles driving very close to the sidewalk	0.478	0.044	10.799	0.334

	High vehicle speeds	0.649	0.026	24.610	0.765
Convenience	Sidewalk gradient	1.156	0.056	20.785	0.755
	Fixed obstacles	0.865	0.034	25.327	0.913
	Presence of other pedestrians	1.231	0.058	21.296	0.770
	Weather conditions	0.967	0.057	16.958	0.657
	Stray animals	1.676	0.073	22.893	0.820
Security	Passage through underground crossings	0.647	0.025	25.965	0.647
	Absence of vehicles on the road	0.673	0.035	19.246	0.673
	Absence of other pedestrians	0.382	0.030	12.910	0.382
	Lack of active land use (closed shops, empty streets)	0.569	0.028	20.241	0.589
Accessibility	Sidewalk height	1.015	0.046	22.015	0.641
	Curb ramps on both sides of the sidewalk	0.534	0.066	8.106	0.284
	Tactile paving	1.044	0.056	18.752	0.550
	Fixed obstacles	0.926	0.034	26.950	0.978

4. CONCLUSIONS

The present study contributes to a more comprehensive understanding of sidewalk performance through a multidimensional approach to the Pedestrian Level of Service (PLOS), incorporating key dimensions such as accessibility, convenience, safety and security. The findings highlight that pedestrians place greater emphasis on factors related to safety and convenience, while demographic characteristics affect pedestrians' priorities. Moreover, specific less explored variables associated with traffic interaction, such as vehicles encroaching on sidewalks, high vehicle speeds and insufficient separation between pedestrian and vehicular space, emerge as critical determinants of perceived safety. At the same time, factors affecting movement continuity, including fixed obstacles, play a key role in shaping convenience. The confirmatory factor analysis validated the proposed measurement model, supporting its suitability for the development of a composite evaluation index. Overall, the research underscores the need for more user-centered and

inclusive approaches towards the estimation of PLOS. Future research will focus on the development of Structural Equation Models (SEM) to further explore the relationships between the identified PLOS dimensions, the contributing factors and pedestrians' characteristics, enabling a deeper understanding of both direct and indirect effects influencing sidewalk PLOS.

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