**International Journal of Electrical and Computer Engineering (IJECE)**
Vol. 14, No. 1, February 2024, pp. 1048~1057
ISSN: 2088-8708, DOI: 10.11591/ijece.v14i1.pp1048-1057


# Pedestrian level of service for sidewalks in Tangier City

**Marwane Benhadou[1], Amina El Gonnouni[2], Abdelouahid Lyhyaoui[2]**
[1]Laboratory of Research in Management and Development, Faculty of Economics and Management, Hassan First University, Settat, Morocco
[2]Laboratory of Innovative Technologies, National School of Applied Sciences, Abdelmalek Essaâdi University, Tangier, Morocco

**Article Info**

***Article history:***

Received Jul 2, 2023
Revised Aug 9, 2023
Accepted Oct 9, 2023

***Keywords:***

Artificial neural network
Morocco
Pedestrian level of service
Pedestrian walking
Self-organizing map
Unsupervised learning

**ABSTRACT**

The pedestrian level of service (PLOS) is a measure that quantifies walkway comfort levels. PLOS defined into six categories (A, B, C, D, E, and F) each level defines the range of values, for example, a good level (best traffic condition) is defined with the letter A until reaching the worst level, F (high congestion). This article aims to define the PLOS on sidewalks considering walking conditions in Tangier City (Morocco). Sidewalks are analyzed using video recording in the urban center of Tangier City. The collected data are pedestrian flow and effective sidewalk width. Each level contains a range of values that corresponds to the pedestrian flow that defines the level of service. Clustering techniques are used to identify the threshold of each level using a self-organizing map (SOM). The results are different from those obtained with other methods because pedestrian traffic differs from country to country.



***Corresponding Author:***

Marwane Benhadou
Laboratory of Research in Management and Development, Faculty of Economics and Management, Hassan First University
Km3, Casablanca, Settat higway, 26000 Settat, Morocco
Email: marwane.feg.info@gmail.com

## 1. INTRODUCTION

Pedestrian mobility takes on a fundamental role in urban environment planning, however walking on foot is practicable for most necessary urban journeys and it is the most sustainable way [1]. Pedestrian mobility is done in shared resources, such as sidewalks, for this reason, shared use is directly related to the capacity of that resource to support a certain 'pedestrian traffic'. Fruin [2] introduced the concept of capacity pedestrian analysis and formulate that if the number of pedestrians increases in a specific space, the comfort and freedom of movement decrease resulting in high congestion of this particular space (like vehicles on the roads and highways). Vuchic [3] defined the level of service as the basic element that attracts potential users to the system. So, the pedestrian level of service (PLOS) is a measure to evaluate walking conditions and the factors affecting pedestrians' safety, comfort, and satisfaction with the facility [4].

The PLOS model is determined following two methods, the first method is to assess the walkway's ability to sustain an adequate level of pedestrians, and the parameters taken into account are flow, speed, and density (quantitative method). The second method is through quantifying the comfort level, safety, and convenience and studying the different characteristics of the sidewalk (qualitative method), we can also use both quantitative and qualitative methods [5]. Most research uses questionnaires and video recordings to collect data for their PLOS models. Those models were developed considering a system of scales (point system) or through regression techniques, creating a mathematical relationship of measurable factors to reflect the study participants' reactions, and simulations.

To get a first idea of the meaning of PLOS we introduce the highway capacity manual (HCM) method [6]. The HCM guide, elaborated on considering mobility conditions based on quantitative measures, such as pedestrian flow, sidewalk space, and pedestrian density, as explained in Table 1, developing PLOS levels (A, B, C, D, E, and F). Each letter represents an interval of values, defining a level of service considered. For example, we consider the third column (flow rate (pedestrian/min/meter)), if the pedestrian flow is $\leq 16$, we assign the letter A (best traffic condition), in other words, there is enough space (no congestion) for each pedestrian on the sidewalk. The other levels are determined in the same way until reaching the last level F (high congestion), the pedestrian flow $> 75$. To see in a very clear way what was explained before, Figure 1 shows each pedestrian traffic situation graphically.

Table 1. PLOS criteria HCM guide

| LOS | Space ($m^2/p$) | Flow Rtae (p/min/m) | Speed (m/s) |
|---|---|---|---|
| A | >5.6 | ≤ 16 | >1.3 |
| B | >3.7-5.6 | >16-23 | >1.27-1.30 |
| C | >2.2-3.7 | >23-33 | >1.22-1.27 |
| D | >1.4-2.2 | >33-49 | >1.14-1.22 |
| E | >0.75-1.4 | >49-75 | >0.75-1.14 |
| F | ≤ 0.75 | variable | ≤ 0.75 |

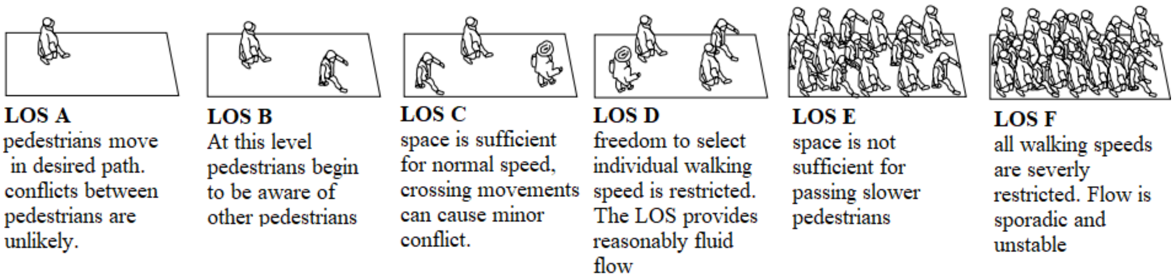



Figure 1. Pedestrian walkway LOS

Previous studies reported in the literature review related to the development of PLOS models use qualitative, quantitative, or both methods. Khisty [7] follows the method proposed by Sarkar [8], developing a PLOS model based on qualitative measures such as security, safety, and comfort to evaluate performance factors using a 5-point scale LOS $A = 5$ to LOS $F = 0$ and then assigning weight to each factor using a weighting factor methodology. Dixon [9] evaluates roadway corridors using PLOS performance measures with a point system of 1 to 21 and LOS rating from A to F. Landis *et al.* [10] describe objectively pedestrians' perception of safety and comfort as a qualitative measure of effectiveness. Developed a PLOS model using stepwise regression analysis, they construct a stratification of levels based on the standard US educational systems letter grade structure. Sisiopiku *et al.* [11] compare 5 methods: the HCM method, the Australian method, the trip quality method, the Landis model, and conjoint analysis techniques. Estimates sidewalks LOS applying each method. As observations have noted that the same sidewalk segment receives multiple LOS ratings. Kim *et al.* [12] based on the social distance theory and the concept of personal space using subjective and objective data, authors evaluate PLOS for sidewalks and examine the relationship between personal space, evasive movement, and PLOS using multiple regression analysis. Kim and Kang [13] developed a novel approach based on travel time to determine PLOS, where pedestrian comfort can be better addressed with this approach. Sahani and Bhuyan [14] apply affinity propagation algorithm to classify PLOS ranging from off-street with heterogeneous traffic considering pedestrian space, flow rate, speed, and v/c ratio following the HCM method. Ghani *et al.* [15] evaluate pedestrian facilities using the P-index method in function of, mobility, safety, facility, and accessibility. 5 stars format is developed to rate streets. Kadali *et al.* [16] study the behavior of pedestrians depending on the type of area (residential, shopping, and business area) and its effect on PLOS using an ordered probit model. Zhao *et al.* [17] investigate pedestrian safety and comfort on sidewalks. Propose a model that relates pedestrian satisfaction and influencing factors using a fuzzy neural network. Also, the authors used the image edge detective method, to quantify the integrality of the environment landscape on sidewalks. Marisamynathan and Lakshmi [18] suggest a method to evaluate PLOS on sidewalks in the Indian mixed traffic context, using stepwise regression analysis. This research is based on qualitative and quantitative data. LOS rating is determined using Khistys' relationship chart. Wicramasinghe and Dissayanake [19] study pedestrian behavior to evade sidewalks by developing a pedestrian sidewalk index, the PLOS ranking is represented through conjoint analysis. Marisamynathan and Vedagiri [20] study PLOS at signalized intersections through a delay model and factors affecting PLOS. The fuzzy linear regression (FLR) model is used and shows best results. To determine the range of values for PLOS, authors use fuzzy C-means. Cepolina *et al.* [21] apply the HCM method to determine the effect of social groups (friends, couples, …) on pedestrian travel behavior. Defining 2 zones: $Zone\ 1 = Acceptable = LOS\ A + B + C$ and $Zone\ 2 = not\ acceptable = LOS\ D + E + F$. Cepolina *et al.* [22] apply the local density based on the Voronoi diagram to evaluate the comfort level of walking and pedestrian interactions. Given that individual comfort can relate to available space and required space. Sahani and Bhuyan [23] studied pedestrian behavior on sidewalks, signalized and unsignalized intersections, to investigate the parameters that affect PLOS. Satisfaction levels are measured with discriminant analysis. Thresholds of the PLOS model is determined with GA-fuzzy clustering (LOS A, to LOS F). Shu *et al.* [24] model PLOS through traffic state and pedestrian flow rate using a Fuzzy clustering algorithm. Spearman rank was used to extract the significant factors and Fuzzy c-means to determine ranges of PLOS (LOS A to LOS F). Kaur *et al.* [25] use the HCM method and the Australian method to evaluate pedestrian congestion using qualitative parameters such as sidewalk, surface, and sidewalk width, rating each parameter with a 5-point scale.

Through the review of the studies carried out, there are several methods to develop a PLOS model, such as the HCM method, the Australian method, Landis method, among others, but each PLOS model is based on data from each country, HCM (USA) [6], Gallin (Australia) [4], and also the other articles develop their own model based on data from each country. In Morocco, there is no PLOS model to assess pedestrian mobility. That is why our model is developed considering data collected in Tangier City.

The objective of this article is to determine levels of service by identifying the threshold of each level that will allow us to evaluate sidewalks, and find a model for PLOS to use as a reference to evaluate other pedestrian areas in other Moroccan cities. The work will be divided as follows: an introduction presenting the objective of the study, previous studies carried out, limitations, and our contribution. Then a second section explains the method followed, this section in turn divided into 2 sections, the data collection procedure and the algorithm used in data processing (SOM). A third section presents the results obtained, a comparison with other methods, and finally a conclusion.

## 2. METHOD

The objective of this article is to determine the levels of service provided by sidewalks, considering data collected in Tangier City (Morocco). The steps followed for this are detailed in the following sections. These stages can be summarized in two essential points.

- Data collection: pedestrian flow and effective walkway width.
- Determination of the pedestrian level of service: data analysis applying the SOM algorithm.

### 2.1. Data collection

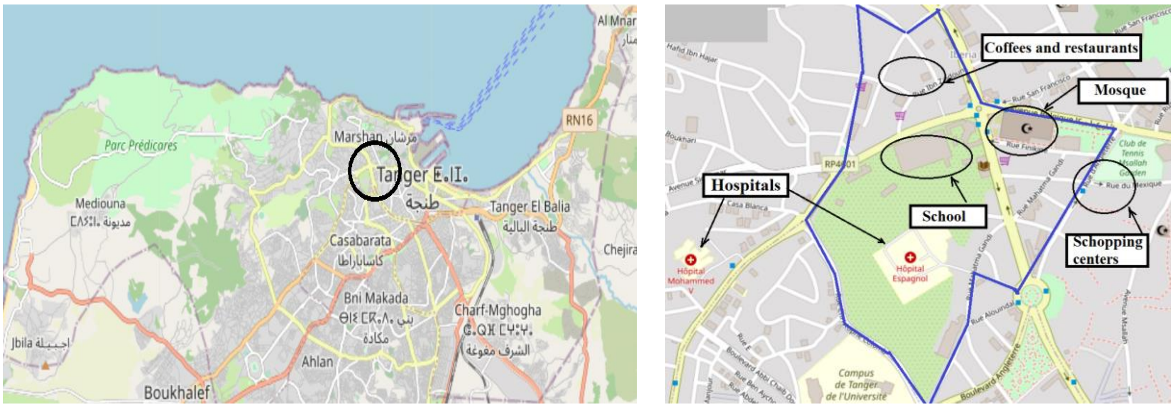
#### 2.1.1. Selection of the study area

The Tangier City, located at the junction of two seas, in the north of Morocco interface between two continents, is experiencing an accelerated rate of urban growth, exceeding 1 million inhabitants. The socio-economic and urban transformations of Tangier driven by major infrastructure projects aim to produce the conditions for the development of a competitive metropolis in the Mediterranean Basin. The study area is the center of the city, where we found several centers that generate pedestrian mobility, such as shopping centers, a concentration of bus stops, educational centers, hospitals, the great mosque, and schools.

All of these centers generate great pedestrian mobility. Which leads to a need for study, analysis, and therefore planning and development of new urban traffic models. As described in Figure 2, Figure 2(a) shows the location of the study area within the map of Tangier City, and Figure 2(b) shows in detail the delimitation of the study area indicating the centers of mobility generation.

#### 2.1.2. Procedure of data collection

To facilitate data collection on sidewalks as shown in Figure 3(a), first, model the area under study, as illustrated in Figure 3(b). The road digitization process consists of modeling the road using a directed graph where the vertices correspond to intersections and the arcs to sections of streets. Each vertex is identified by a unique letter and an arc by two vertices or nodes called origin and destination in the function of the direction of movement. The result of the digitization process is a background map with a superimposed graph that is the basis of the organization of data collection [26].




(a) (b)

Figure 2. Study area description: (a) location of the study area and (b) study area delimitation


(a) (b)

Figure 3. Digitalization of the road: (a) sidewalks, and (b) study area model

The pedestrian flow, described by (1), used in this research consists of the procedure followed in HCM [3], based on the high 15 min flow: is the number of pedestrians that pass per 15-minute on the sidewalk, divided by the effective sidewalk width, $W_E$. As explained by (2) and Figure 4.

$$P_f = \frac{F_{15}}{15.W_E} \quad (1)$$

where,
$P_f$ : pedestrians/min/meter,
$F_{15}$ : pedestrian 15 min flow.

$$W_E = W_T - W_0 \quad (2)$$

where,
$W_T$ : total sidewalk width,
$W_0$ : sum of fixed object effective widths and linear feature shy distances at a given point along the sidewalk.

For data collection, each segment of 24 sidewalks (considering the two sidewalks of the avenue and collecting pedestrian opposing flow volumes at 15-minute intervals) of the graph is analyzed. It analyzed with video recording during (30 min) in 7 intervals of the day (07:45-08:15, 09:45-10:15, 11:45-12:15, 1:45-2:15, 3:45- 4:15, 5:45-6:15, 7:45-8:15) (p.m.) throughout the week and considering 3 months of the year: March, June, and November. The data collected are effective sidewalk width and pedestrian flow rate.

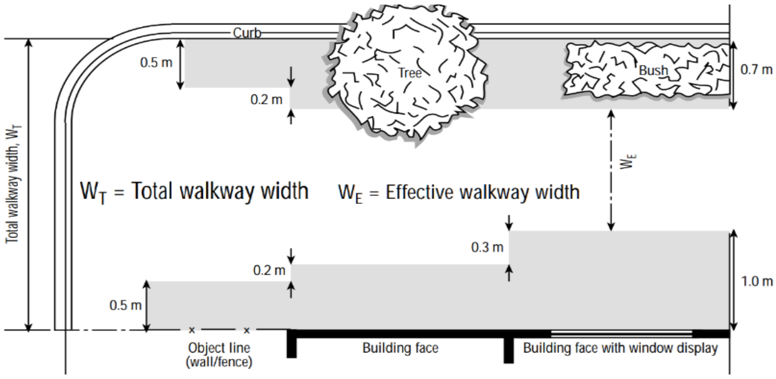



Figure 4. Effective sidewalk width

### 2.2. Data analysis

To determine the 6 levels of PLOS, the data analysis consists of determining the threshold for each interval that corresponds to each level service: A, B, C, D, E, and F. Now the question is: how do we find those limits that reflect the different data collected on pedestrian flow? Well, taking advantage of unsupervised learning algorithms and more precisely the SOM algorithm.

#### 2.2.1. Self-organizing maps

Machine learning ML is the ability of machines (computers) to use algorithms, learn from data, and use what is learned in decision-making [27]. ML can be applied in almost all situations: Object detection, classification, distribution of content on social networks, cyber security. In unsupervised learning, algorithms do not use any pre-organized data to indicate how the new information should be categorized, but they have to find a way to classify them themselves [27]. It is often used for clustering, segmentation, and reduction of dimensionality.

Clustering is used to split the observations into subgroups (clusters), such that the similarity between the observations belonging to the same cluster is greater than those in different clusters. Self-organizing maps (SOM), introduced by Kohonen, is a competitive unsupervised learning neural network model. The objective is to represent multidimensional data sets in a two- or one-dimensional network. As shown in Figure 5, SOM architecture is composed of two layers of neurons, the input layer made up of $N$ neurons ($N$ input data) and an output layer made up of $M$ neurons that is responsible for creating clusters, where each input neuron $i$ is connected to each of the output neurons $j$ by means of a weight $W_{ij}$ [28].

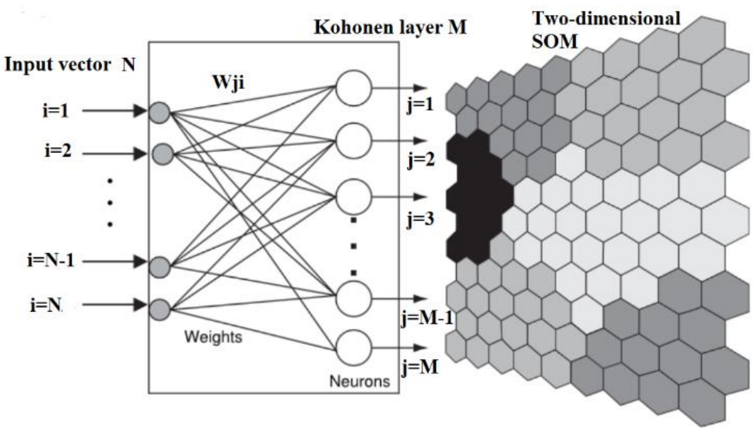



Figure 5. SOM architecture

Kohonen's algorithm takes into account the lateral interactions between neighbors to update the output weights and the differences between the weight vectors and the input vectors. We can describe Kohonen's algorithm in the following steps [29]:

– Initialization: assign to each node a vector of random weights $W_j$.
– Competition: for each input data $x_i$, the node $j$ to which it is close in terms of similarity is selected (best matching unit). The Euclidean distance from the data $x_i$ to each of the vectors is calculated, and the neuron at which this distance is minimum is chosen, as explained in (3).

$$j = arg\,min\|x - W_k(t)\|^2 \quad (3)$$

– Cooperation: calculate the learning and neighborhood coefficients. neighbor nodes $W_k$ whose distance to $W_j$ is small, we use the kernel neighborhood function, and it can be of different types, in our case we use a Gaussian function, this function assigns more or less weight to the neighboring nodes depending on the distance, as shown in (4).

$$h_{ik} = \exp\left(\frac{d.(r_i - r_k)^2}{2\sigma^2}\right) \text{ where } h_{ik} \in (0,1) \quad (4)$$

where $r_i\ and\ r_k$ are the positions of cells $i$ and $k$ in the grid and $\sigma$ is the neighborhood radius. The Gaussian kernel determines that the magnitude of the weight changes decreases as the neighborhood grids are further away from the one that received the new object. On the other hand, the learning rate $\alpha \in (0.1)$ is defined, which depends on the number of iterations that are previously specified in the argument of the SOM function, such that in each iteration $\alpha$ decreases linearly from 1 to 0.
– Updating: update the weights of nodes in the neighborhood of K using Kohonen's learning rule (5).

$$W_k(t+1) = W_K(t) + \alpha . h_{ik} . (x - W_k(t)) \quad (5)$$

– Check: return to step 2 if there is no more data or the maximum number of iterations or that after several iterations the change of weight vectors is not significant (the weights stabilize).

Algorithm SOM is one of the most popular neural network architectures. Its simplicity and its data processing power provide very satisfactory results, and the Kohonen neural network integrates the hierarchical clustering of complete patterns and the least-mean-square method for classifying incomplete patterns. SOM is one of the clustering methods used to classify the ranges of different measure of effectiveness in this regard [30].

#### 2.2.2. Data description and treatment

Our input data is a matrix of month, day, and time. Each element of this matrix is expressed as:
- For the month we consider the values of 1, 2, ..., 12 to identify the months, January, February, ..., December.
- For the day we used the numbers 1, 2, …, 7 to identify Monday, …, Sunday.
- For hours we used (6).

$$Time = \frac{hours + \frac{minutes}{60}}{24} \quad (6)$$

Each avenue is divided into segments, Figure 3(b), and the input data of each segment is a matrix of a month, day, time, and the pedestrian flow in the previous segment. Then we used neural network architecture to resolve an unsupervised learning problem. For our clustering problem, we used a self-organizing map. The network is trained with unsupervised weight and bias learning rules with batch updates.

## 3. RESULTS AND DISCUSSION

The objective is to classify the service levels of pedestrian flow per minute and meter. Treat this problem from a machine-learning point of view as a clustering problem using SOM algorithm. This classification is determined by intervals, and each interval is identified by a letter since the idea will be to determine the lower and upper limits of each interval. Cluster analysis works by organizing items into groups (in our case intervals) on the basis of how similar they are. According to the HCM method, the different parameters taken into consideration to determine PLOS are: space, flow rate, average walking speed and volume to capacity ratio. In this article taking in consideration the pedestrian flow, because it gives us an idea of the occupied space, and the average walking speed. Figure 6 represents the execution result of the algorithm obtaining the 6 PLOS ranges (A to F). The ordinate axe presents the levels A, B, C, D, E and F, and the coordinate axis represents the range (expressed in pedestrian flow per min and per meter) that corresponds to each level.

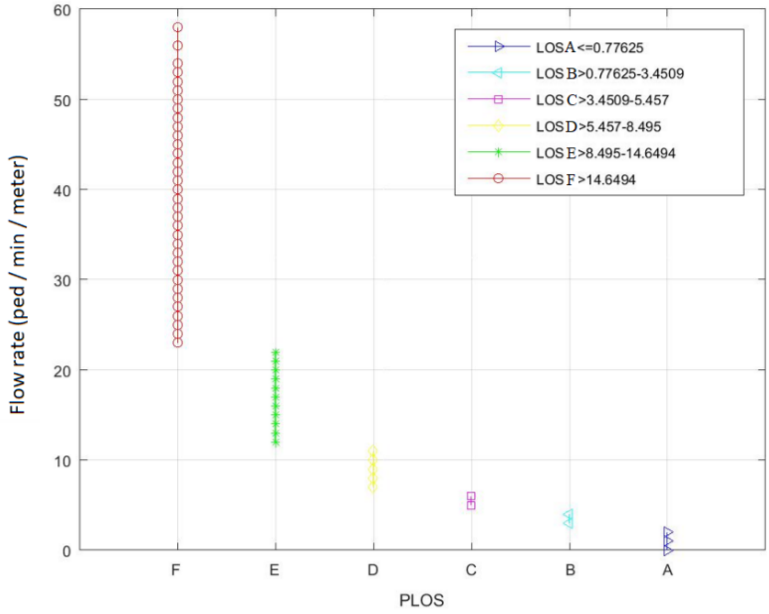



Figure 6. PLOS scores based on flow rate

According to the results obtained by applying the SOM algorithm, Table 2 summarizes the 6 PLOS levels (A to F) of flow rate, grouping them in intervals, and adding a description for each level of service. First, explain the results obtained through the use of the SOM clustering algorithm. In this algorithm according to the results observed in Figure 5, each range of values is identified by a letter; well, to classify a level of service as level A, the pedestrian flow must not exceed 0.77625 or the same, on that avenue we must have at most one-person walking. An avenue is classified as service level B if the pedestrian flow is between 1 and 4 pedestrians, and it is classified as level C if there are between 4 and 6 pedestrians. For a level D if there are between 6 and 9 pedestrians, a level E if there are between 9 and 15 pedestrians, and finally a level of service F if there are more than 15 pedestrians passing per minute. To better interpret these results, comparing what was obtained with HCM and our method summarized in Table 3.

Table 2. Pedestrian level of service (PLOS) description

| Level of Service | Flow Rate (p/min/m) | Comments |
|---|---|---|
| A | ≤ 0.77625 | Pedestrians move in the desired path |
| B | > 0.77625 – 3.4509 | There is no great need to adjust the trajectory |
| C | > 3.4509 – 5.457 | Space is sufficient for normal pedestrian speed |
| D | > 5.457 – 8.495 | Speed is restricted |
| E | > 8.495 – 14.6494 | Space is not sufficient for passing slower pedestrians |
| F | > 14.6494 | Frequent contact with other pedestrians |

Table 3. Comparison of the results obtained with the HCM method

| PLOS | Flow rate (pedestrian/min/meter) | |
|---|---|---|
| | Proposed classification | HCM |
| A | ≤ 0.77625 | ≤ 16 |
| B | > 0.77625 – 3.4509 | >16-23 |
| C | > 3.4509 – 5.457 | >23-33 |
| D | > 5.457 – 8.495 | >33-49 |
| E | > 8.495 – 14.6494 | >49-75 |
| F | > 14.6494 | variable |

Table 3 shows a high difference between the results obtained and the values found using HCM method. These differences are due to several factors, firstly the geometric characteristics of the study area, the small value of the effective width of the sidewalks, and also the non-homogeneity of flows in the studied area. To classify the service levels in the different sidewalks in the study area, Figure 7 represent the levels of flows in the sidewalks studied, identifying these flows in 3 levels using 3 colors, the green stripes representing low flow (no more than one pedestrian per minute), the orange color with circles representing medium flow (no more than 4 pedestrians per minute), and the red color with dashed line representing high flow (at least 14 pedestrians per minute). In statistical terms: 24 sidewalks studied, where 9 sidewalks with green stripes color, 10 orange color with circles and 5 with red color with dashed line. Respectively 37.5% low flow, 41.66% medium flow and 20.83% high flow. As we can see, it is an area with low-medium pedestrian flow. The high pedestrian flow is concentrated on some sidewalks, these avenues have a high flow of pedestrians: first because they are main avenues, second because they have a larger effective width than other avenues, which is why they are more comfortable for walking. So, that is why the service levels are so different from those obtained with the HCM method, due to heterogeneous pedestrian flow.

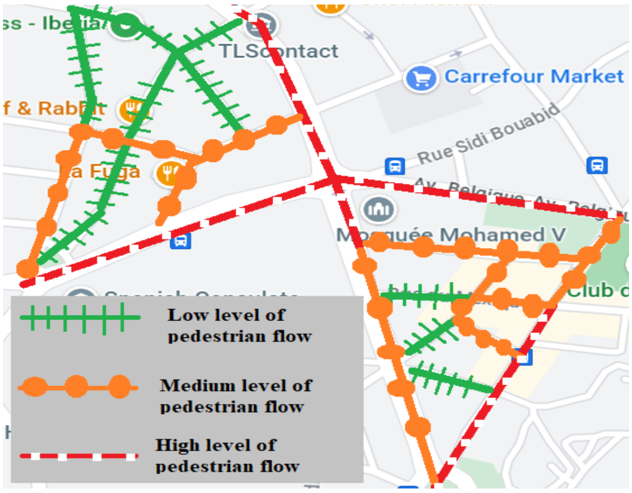



Figure 7. Distribution of pedestrian flow in the study area

Some sidewalks are less attractive than others due to the existence of obstacles or a very small effective width. This analysis corresponds to the urban center of Tangier City, the result obtained is represented in Figure 5, it gives us a first idea of the division of pedestrian service levels (6 levels). We can use that result to determine the level of service in other areas or cities.

## 4. CONCLUSION

This work is the first attempt to model PLOS taking into account Moroccan walking conditions. We have to determine the levels of service by taking data directly from pedestrians' flow in the center of Tangier City, following the method proposed in HCM, and we have determined 6 levels A, B, C, D, E, and F using the SOM algorithm. Through this new classification of service levels, we can apply it to estimate the PLOS on the sidewalks of the Tangier City and other cities. The area has a low-medium flow of pedestrians, there are sidewalks that are more attractive than others, the levels obtained differ from those obtained in HCM and this is due to the geometric characteristics and also due to the pedestrians' walking habits. In future work, we are going to take more data in other environments and also in other cities, applying other classification techniques, and compare it with the results obtained in this study.

## REFERENCES

[1] L. M. B. S. Rupprecht, L. Brand, S. B. Baedeker, *The concept of sustainable urban mobility plans*, Second Edition. 2019.
[2] J. J. Fruin, "Designing for pedestrians: a level-of-service concept," *Highway Research Record*, vol. 377, no. 355, pp. 1–15, 1971, Accessed: Oct. 16, 2023. [Online]. Available: http://onlinepubs.trb.org/Onlinepubs/hrr/1971/355/355-001.pdf
[3] V. R. Vuchic, *Urban public transportation*. Englewood Cliffs, N. J.: Prentice Hall, Inc., 1981.
[4] N. Galinn, "Quantifying pedestrian friendliness- guidelines for assessing pedestrian level of service," in *Walking the 21st Century, Perth*, 2001, pp. 119–128.
[5] A. Banerjee, A. K. Maurya, and G. Lämmel, "Pedestrian flow characteristics and level of service on dissimilar facilities: A critical review," *Collective Dynamics*, vol. 3, Jul. 2018, doi: 10.17815/cd.2018.17.
[6] T. R. B., "Urban street segments," in *Highway Capacity Manual, chapter 17, The fifth edition, National Research Council Washington, D.C., TRB, Transportation Research Board*, pp. 17–44, 2010.
[7] C. J. Khisty, "Evaluation of pedestrian facilities: Beyond the level of service concept," *Transportation Research Record*, no. 1438, pp. 45–50, 1994.

[8] S. Sarkar, "Determination of service levels for pedestrians, with European examples," *Transportation Research Record*, no. 1405, 1993.
[9] L. B. Dixon, "Bicycle and pedestrian level-of-service performance measures and standards for congestion management systems," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1538, no. 1, pp. 1–9, Jan. 1996, doi: 10.1177/0361198196153800101.
[10] B. W. Landis, V. R. Vattikuti, R. M. Ottenberg, D. S. McLeod, and M. Guttenplan, "Modeling the roadside walking environment: Pedestrian level of service," *Transportation Research Record*, vol. 1773, no. 1773, pp. 82–88, Jan. 2001, doi: 10.3141/1773-10.
[11] V. P. Sisiopiku, J. Byrd, and A. Chittoor, "Application of level-of-service methods for evaluation of operations at pedestrian facilities," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2002, no. 1, pp. 117–124, Jan. 2007, doi: 10.3141/2002-15.
[12] S. Kim, J. Choi, S. Kim, and R. Tay, "Personal space, evasive movement and pedestrian level of service," *Journal of Advanced Transportation*, vol. 48, no. 6, pp. 673–684, Mar. 2014, doi: 10.1002/atr.1223.
[13] I. Kim, H. Kang, "A study of delay-based level of service on pedestrian facility," in *Australasian Transport Research Forum*, 2013, pp. 2–4.
[14] R. Sahani and P. K. Bhuyan, "Pedestrian level of service criteria for urban off-street facilities in mid-sized cities," *Transport*, vol. 32, no. 2, pp. 221–232, Sep. 2017, doi: 10.3846/16484142.2014.944210.
[15] N. A. Ghani, T. Shimizu, and S. Mokhtar, "Assessment of pedestrian facilities in Malacca world heritage site, Malaysia using P-index method," *Journal of the Eastern Asia Society for Transportation Studies*, vol. 11, no. 0, 2015, doi: 10.11175/EASTS.11.1535.
[16] B. R. Kadali and P. Vedagiri, "Evaluation of pedestrian crosswalk level of service (LOS) in perspective of type of land-use," *Transportation Research Part A: Policy and Practice*, vol. 73, pp. 113–124, Mar. 2015, doi: 10.1016/j.tra.2015.01.009.
[17] L. Zhao, Y. Bian, J. Rong, X. Liu, and S. Shu, "Evaluation method for pedestrian level of service on sidewalks based on fuzzy neural network model," *Journal of Intelligent & Fuzzy Systems*, vol. 30, no. 5, pp. 2905–2913, Jan. 2016, doi: 10.3233/IFS-151753.
[18] S. Marisamynathan and S. Lakshmi, "Method to determine pedestrian level of service for sidewalks in Indian context," *Transportation Letters*, vol. 10, no. 5, pp. 294–301, Dec. 2018, doi: 10.1080/19427867.2016.1264668.
[19] V. Wicramasinghe and S. Dissanayake, "Evaluation of pedestrians' sidewalk behavior in developing countries," *Transportation Research Procedia*, vol. 25, pp. 4068–4078, 2017, doi: 10.1016/j.trpro.2017.05.327.
[20] S. Marisamynathan and P. Vedagiri, "Modeling pedestrian level of service at signalized intersection under mixed traffic conditions," *Transportation Research Record*, vol. 2634, no. 1, pp. 86–94, Jan. 2017, doi: 10.3141/2634-13.
[21] E. M. Cepolina, F. Menichini, and P. Gonzalez Rojas, "Pedestrian level of service: The impact of social groups on pedestrian flow characteristics," *International Journal of Sustainable Development and Planning*, vol. 12, no. 4, pp. 839–848, May 2017, doi: 10.2495/SDP-V12-N4-839-848.
[22] E. M. Cepolina, F. Menichini, and P. Gonzalez Rojas, "Level of service of pedestrian facilities: Modelling human comfort perception in the evaluation of pedestrian behaviour patterns," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 58, pp. 365–381, Oct. 2018, doi: 10.1016/j.trf.2018.06.028.
[23] R. Sahani and P. K. Bhuyan, "Modelling pedestrian perspectives in evaluating satisfaction levels of urban roadway walking facilities," *Transportation Research Procedia*, vol. 48, pp. 2262–2279, 2020, doi: 10.1016/j.trpro.2020.08.289.
[24] S. Shu, Y. Bian, L. Zhao, J. Rong, and X. Liu, "Modelling pedestrian level of service on sidewalks with multi-factors based on different pedestrian flow rates," *Transport*, vol. 36, no. 6, pp. 486–498, Jan. 2022, doi: 10.3846/transport.2021.16276.
[25] H. Kaur, P. Singh, G. R. Bivina, and A. Nawani, "Qualitative evaluation of pedestrian facilities using the PLOS model," *IOP Conference Series: Earth and Environmental Science*, vol. 775, no. 1, Art. no. 12004, Jun. 2021, doi: 10.1088/1755-1315/775/1/012004.
[26] M. Benhadou and A. Lyhyaoui, "Toward sustainable mobility in streets, problems and solutions-case study Tangier-," in *International Conference on Automation, Control Engineering and Computer Science (ACECS), Proceedings of Engineering and Technology – PET*, vol. 21, pp. 75-81, 2018.
[27] B. Mahesh, *Machine learning algorithms: A review*, *International Journal of Science and Research (IJSR)*, vol. 9, no. 1, pp. 381-386, 2020. doi: 10.21275/ART20203995.
[28] M. Begum, B. C. Das, M. Z. Hossain, A. Saha, and K. A. Papry, "An improved Kohonen self-organizing map clustering algorithm for high-dimensional data sets," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 1, pp. 600–610, Oct. 2021, doi: 10.11591/ijeecs.v24.i1.pp600-610.
[29] R. Widayanti, S. Madenda, E. P. Wibowo, and K. Anwar, "SOM-SIS approach to auto summary of clustering results on university academic performance," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 21, no. 1, pp. 104–112, Feb. 2023, doi: 10.12928/TELKOMNIKA.v21i1.24238.
[30] P. K. B. R. Sahanii, "Pedestrian level of service criteria for urban off-street facilities on mide-size cities using SOM in ANN," *Indian Highways*, vol. 43, pp. 5–15, 2015.


## BIOGRAPHIES OF AUTHORS

**Marwane Benhadou** is an assistant professor of informatics, Hassan first University. His research interest includes telecommunications, mathematical modeling and computing, traffic engineering and sustainable mobility. He can be contacted at email: marwane.feg.info@gmail.com.

**Amina El Gonnouni** received a computer science degree from the Science and Technology Department, Abdelmalek Essaadi University, Tangier, Morocco, the D.E.S.A. degree in telecommunications systems from the Faculty of Science of Tetouan, Morocco, and the Ph.D. degree in telecommunications and informatics from the Faculty of Science of Tetouan, Morocco. Her research interests include artificial intelligence, machine learning, and statistical learning for signal processing, cognitive radio, and sensor networks. She can be contacted at email: amina_elgo@yahoo.fr.

**Abdelouahid Lyhyaoui** is a full professor at the National School of Applied Sciences of Tangier. He holds the PhD degree in telecommunications engineering from the Escuela Politecnica Superior, Universidad Carlos Iii de Madrid. His research interests include data science, artificial intelligence, and smart cities. He is the founder and president of the Moroccan Society for Technological Development and Innovation. He has participated in several national and international research projects and has more than 150 scientific publications. He is a member of scientific committees of several national and international conferences and journals. He is strongly involved in university life, having served as director of the Innovative Technologies Laboratory, head of the Telecom & Electronics Department, elected member of the Scientific Council, the Board of Directors, the Pedagogical Commission of the university, and a member of the jury for the recruitment contest for doctoral students at Abdelmalek Esaadi University. He can be contacted at email: lyhyaoui@gmail.com.