Proceedings of 10th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: October Volume: 10

Evaluation of Pedestrian LOS for Footpath by Cluster Analysis and Questionnaire Survey: A case Study of Kathmandu

Ajeya Acharya [a], Anil Marsani [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] ajeya.arya@gmail.com, [b] anilmarsani@ioe.edu.np

Abstract
This study comprises defining Pedestrian level of service ranges from LOS A to F for footpath by k-means cluster analysis based on parameters speed, flow rate and space that were extracted from video graphic survey of different footpath of Kathmandu and Quality of Service (QOS) ranges by questionnaire survey. PLOS ranges based upon space from A to F were found to be >12.28, 12.28-9.24, 9.24-7.54, 7.54-6.02, 6.02-4.25 and <4.25 m2/ped respectively. PLOS ranges based upon flow rate from A to F were found to be <9, 9-12.12, 12.12-15.91, 15.91-19.67, 19.67-23.07 and >23.07 ped/min/m respectively. PLOS ranges based upon speed from A to F were found to be >79.8, 79.8-75.6, 75.6-70.8, 70.8-66.6, 66.6-62.4 and <62.4 m/min respectively. Importance and Satisfactory ratings of different physical and user characteristics for footpath were collected from user perception through questionnaire survey and walkability index was determined to define QOS ranges from A to E. QOS categories of walkability for footpath ranges from A to E were found to be >130, 130-105, 105-86, 86-67 and <67 respectively. The PLOS ranges defined in this study are significantly different from that mentioned in HCM 2010 due to different land use pattern, illegal parking, vendors activities and different obstructions.

Keywords
Pedestrian Level of service, Quality of Service, average pedestrian space, speed, flow rate, K means clustering

1. Introduction

Pedestrian Level of Service (PLOS) is the qualitative measure that describe the operational characteristics of pedestrian based upon service measures like speed, comfort, convenience, interruptions and freedom to maneuver. Highly heterogeneous traffic movement, negligence of traffic rules and regulations, illegal parking, poor surface condition, obstructions, unauthorized vendors activities, etc. are some of the major factors that affect PLOS of footpath in urban areas. In addition, footpath in low-income and developing countries are much different compared to that of high income and developed countries. Therefore, analysis of PLOS based upon models of developed country may not suite in low-income country like Nepal. In Nepal, there is no proper procedure to evaluate PLOS of footpath of their own. International codes of developed countries are used for evaluation of PLOS which may not be appropriate. The suitable methodologies need to be developed that can help in proper planning, design, construction and operation phase of road projects. An attempt was made in this study to define and evaluate PLOS of footpath in urban areas of Nepal. Both qualitative and quantitative methods were used to define and classify PLOS. Qualitative method was based upon pedestrian perception analysis by questionnaire survey and field observation. Quantitative method was based upon flow parameters like speed, flow and space to classify ranges of level of service by k-means cluster analysis algorithms.

2. Literature Review

2.1 PLOS ranges model

Level of Service (LOS) is done for the evaluation of the effectiveness of transport facility. HCM 2000 [1] defined PLOS into two broad segments, which are uninterrupted and interrupted pedestrian facility. HCM 2010 [2] analyzed PLOS by measurement of speed, density and volume of pedestrian and space of footpath. Six level of service are defined ranging from

A to F in which LOS A represents the condition where pedestrian is able to move in any desired path without any need of altering their movement and LOS F is worst condition where all walking speeds are severely restricted and there is frequent contact with other pedestrians.HCM defined PLOS ranges based on speed, density and volume of pedestrian and sidewalk space as shown in Table 1.

Table 1: PLOS categories in HCM 2010

LOS	Average Space sq.m/p	Flow rate p/min/m	Average speed m/s	V/c ratio
A	>5.6	<=16	1.27-1.3	<=0.21
B	3.7-5.6	16-23	1.22-1.27	0.21-0.31
C	2.2-3.7	23-33	1.14-1.22	0.31-0.44
D	1.4-2.2	33-49	0.75-1.14	0.44-0.65
E	0.75-1.4	49-75	<= 0.75	0.65-1
F	<0.75	Variable	<=0.75	variable

Indo HCM (2017) [3] defined PLOS based upon fundamental flow parameters like space, speed and flow rate for footpath of five different land uses (Commercial, Institutional, Terminal, Recreational, Residential). Six LOS are also defined starting from LOS A to F for each land use in Indian context. PLOS ranges from LOS A to F based upon flow rate (p/min/m) for footpaths at different land use are showed in Table 2.

Table 2: PLOS categories in Indo HCM 2017

LOS	Commercial	Institutional	Terminal
A	<=13	<=13	<=15
B	13-19	13-19	15-26
C	19-30	19-27	26-32
D	30-47	27-36	32-68
E	41-69	36-42	<= 68-78
F	Variable	Variable	Variable

Indo HCM [3] also evaluate qualitative assessment for the evaluation of footpaths. This method uses the perception of the pedestrians. Quality of Service (QOS) is used for assessing the characteristics of footpath in a qualitative manner based upon walkability index (WI). WI is used for determining quality of service of footpath considering the Physical and user characteristics/parameter and importance weight and satisfaction rating of individual parameter. QOS for footpath based upon Indo HCM 2017 is shown in Table 3.

Table 3: QOS categories in Indo HCM 2017

QOS	WI
A	>=124
B	124-106
C	106-70
D	70-52
E	<52

Sahani and Bhuyan (2013) [4] studied footpath in mid-sized city in Bhubaneswar and Rourkela of India and determined PLOS category by using Affinity Propagation Clustering. In this study PLOS ranges from LOS A to F were lower than that mentioned in HCM 2010 which was because of low volume of pedestrian movement in footpath and highly heterogeneous traffic flow.

Prativa Gywali (2014) [5] developed PLOS model in context of Kathmandu city of Nepal. The model was developed through stepwise multi-variable regression analysis of data observed based upon Flow rate, F_r (ped/15min), Density, D(ped/m^2), width, W(m) and Buffer,B (m).

$$y = 1.76 + 0.0048F_r + 1.005D - 0.25W - 0.67B \quad (1)$$

2.2 Fundamental Relationship between flow parameters of footpath

Indo HCM [3] also determined fundamental relationships between speed, flow rate, density and space for footpath for different land use patterns. The models and macroscopic diagrams of fundamental parameters were developed by HCM. According to the manual, parabolic, linear, parabolic and inverse parabola relationship were obtained between flow-density, speed- density, speed- flow and flow- space respectively.

2.3 K-means clustering and Validation

K-means clustering [6] is an unsupervised learning technique used to group the data which are unlabelled. Unlabelled data are the data in which group are not well defined. This method classifies into k-number of cluster groups. The algorithm of this cluster analysis uses various iterations steps to assign each data point to one of the k groups which is based upon the similarity of the groups. The k-means algorithm minimizes the sum of the distances from each observed data to the centroid of clusters and moves the observed data between clusters until there is no

further decrease of the sum of the distances [7]. This algorithm also determines a vector of indices indicating the assignment of each observation to the particular k cluster.

The elbow method is used to analysis the data for selecting the optimal number of clusters. This elbow method finds the optimal cluster numbers by fitting the model with a range of values for k. The k-means clustering method defines clusters by minimizing the total intra cluster variation also known as total within-cluster sum of square (WSS). WSS defines how well there is compactness of the clustering and it must have preferable lower value. In the Elbow method, total WSS is a function of the number of range of clusters. For each value of k, total WSS is calculated and so final elbow plot is obtained and the location of a bend in the plot shows the optimal cluster groups.

Cluster validation is done to check the quality of clustering outcomes. Silhouette is a method used for the interpretation and validation of consistency of observed data that are clustered by clustering algorithm. This technique provides the pictorial representation about how well each object has been organized within the group. Rousseeuw (1987) [8] proposed the silhouette width index to evaluate the outcome of clustered data. Silhouette width index (S_i) is used to explain the compactness and separation of the clusters based upon both cohesion and separation measures. Cluster cohesion measures how well the data are closely related within a cluster and cluster separation measure how well the data are separated from one cluster to other clusters. If the silhouette index value is high, then the data is closely related to its own cluster group and poorly related to the neighboring clusters but if the silhouette index value is low or negative value, then the clustering is said to be bad clusters. The value of S_i must be greater than 0.5 for good cluster.

Kim and Yamashita (2005) [9] used k-means clustering method to analyze the crash pattern of the pedestrians. The locations and patterns of traffic accidents are examined by using k-means clustering algorithm. The study illustrated that k-means method is most appropriate method for the analysis of pedestrian safety.

Sahani (2017) [10] studied the appropriate methodology in Indian context to evaluate PLOS for the footpath for flow parameters speed, space, flow rate and v/c ratio. The PLOS ranges from LOS A to F were determined using six clustering algorithms which were K-means, Fuzzy c-means, Hierarchical Agglomerative Clustering, Self-Organizing MAP in Artificial Neural Network, Affinity Propagation and Genetic Algorithm. Among all the six clustering methods, k-means clustering method was found to be the most appropriate method for the classification of LOS in Indian context .

Lee Cronbach developed Cronbach's alpha (α) [11] in 1951 for measurement of the reliability or internal consistency of survey data which can be multiple-question like Likert scale. These questions describe about the latent variables. These variables are very difficult to measure in real life. The scale used in variables for questionnaire survey must be consistent giving same result over time and this is examined by such test. The internal consistency is considered excellent, good, acceptable, questionable, poor, unacceptable for α >0.9, 0.8- 0.9, 0.8-0.7, 0.7-0.6,0.6-0.5 and <0.5 respectively. If the value of α is acceptable, then the questionnaire data are reliable for further analysis purpose.

2.4 Research-objective

1. To determine PLOS ranges for footpath based on pedestrian space, speed and flow rate by the help of k-means clustering algorithms.
2. To determine PLOS ranges for footpath based on walkability index by the methods of questionnaire surveys and field observation.
3. To compare the obtained ranges of PLOS and QOS with other existing international widely used classification ranges.

3. Methodology

3.1 Study area and Sampling

The area under study included footpath of Kathmandu like Bagbazzar, Baneswor, New Road, Kalimati and Ratnapark. These footpaths considered various land use like institutional area, market area, office area, commercial area, hospital area etc.

3.2 Data collection and Processing

The data collection for this research were done by field measurement, video graphic technique and questionnaire survey. Field measurement was done for measurement of footpath width and identifying physical characteristics of footpath like surface

quality, crossing facilities, encroachment, obstructions at footpath such as bench, parking, tree, poles, etc. The effective width of footpath was obtained by deducting shy distance because of obstacle by using Indo HCM 2017. A stretch of certain length was marked in every sidewalk under study to find the flow and speed of pedestrian. Here stretch of length of 6,7 and 8m were chosen based upon reference length, camera location and other limitation conditions.

Video graphic technique involved use of camera and smart mobile for capturing videos in study area. About 34000 pedestrians were observed at various sidewalk mentioned in study area in both peak hour and off-peak hour of working days and non-working days from January 15, 2021 to February 15, 2021 and July 2, 2021 to July 30, 2021. After video collection the video clips was loaded in computer to extract data volume of flow every minutes and speed of 3-5 pedestrians every minute to obtain 15-min flow and average speed. Flow rate, density and average pedestrian space were then calculated based upon extracted flow and speed.

Questionnaire form technique was used to collect data based on pedestrian perception for qualitative assessment of footpath. Different parameters for questionnaire were based on Indo HCM 2017. Physical characteristics of footpath such as surface quality, width, obstructions, potential for vehicular conflict and continuity and User characteristics for footpath such as encroachment, crossing facilities, security, comfort and walking environment were assessed based on importance rating and satisfaction rating by interviewing 420 respondents walking from different footpath of study area. The minimum number of necessary sample size for unlimited population is 385 and for 34000 population size of the sample is 380. Satisfactory rating was given a score from 5 to 1 (Excellent to poor) and importance rating was given a score from 5 to 1 (Most important to immaterial). Walkability index was determined as the product of the importance and satisfactory rating.

4. Analysis of Data

4.1 Speed, Flow rate, Density and Space Relationship

Average Speed, Flow rate, Space and density were observed and determined by extracting data from videograph. To know about the kind of fundamental traffice flow relationships between speed, flow, density and spaces, Speed- Density, Speed-Flow rate, Flow rate-density and Spacing- flow rate was plotted as shown in Figure 1, Figure 2, Figure 3 and Figure 4.

Figure 1: Speed Vs Density

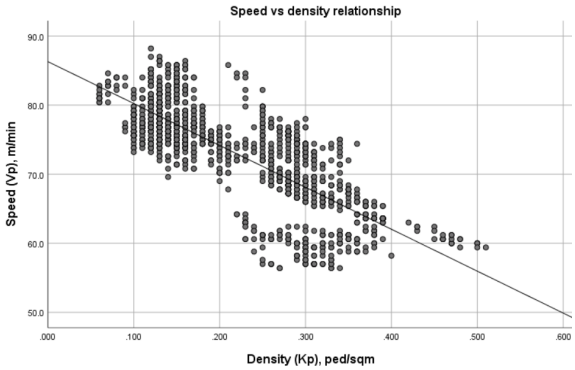


Figure 2: Speed vs Flow rate

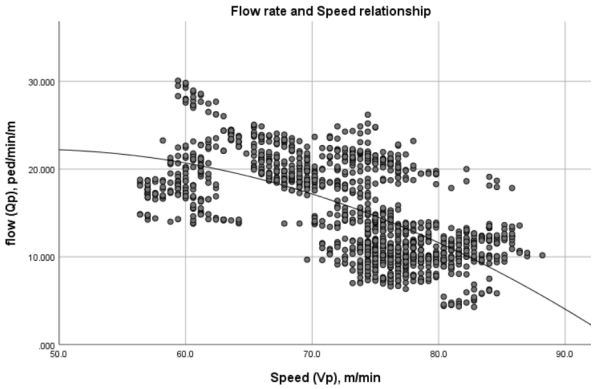
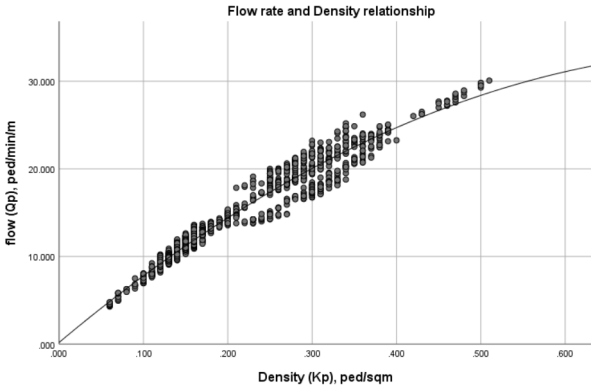
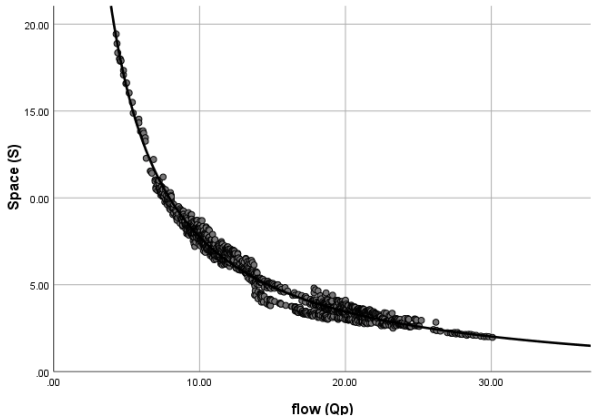


Figure 3: Density vs Flow Rate



From Figure 1, the linear relationship of reverse order exist between speed and density. There exist the non linear relationship between flow rate with speed and density as seeen in Figure 2 and Figure 3. From Figure 4, inverse parabolic relationship was observed between space and flow rate. The fundamental traffic flow relationship obtained in this study were found to be similar to that of study of Indo HCM 2017.

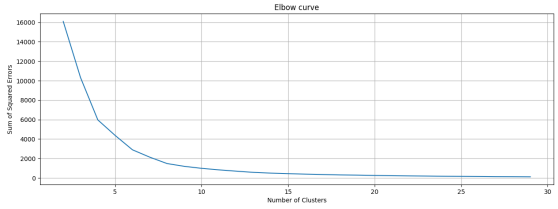
Figure 4: Spacing vs Flow Rate



4.2 PLOS categories Optimal Number by Elbow Plot method

To obtained optimal number of clusters Elbow plot was developed by using Python program where total WSS value were calculated for different values of k. The curve of WSS was obtained according to the cluster number, k which is shown in the Figure 5. Here in figure, there was bend at 6. So optimal number of clusters was found to be 6. Hence Six level of service categories (A to F) was determined which fitted well in context of this research as well.

Figure 5: Elbow Curve plotting Cluster number vs Sum of Squared Errors



4.3 PLOS for footpath by K-means clustering

K-means cluster algorithm was used in Python to find the range of pedestrian LOS based upon spacing, speed and flow rate. Six level of service categories ranging from LOS A to F were determined for flow rate, spacing and speed which are shown in Figure 6, Figure 7, Figure 8 and Table 4.

From PLOS ranges as presented in Table 4, it was found that PLOS based upon pedestrian average space for PLOS A $>$ 12.28 $m^2/pedestrian$, where pedestrians have the ability to move in their desirable path and there is no need to change their movement. This condition is also known as the free flow

Figure 6: Flow Rate of PLOS categories

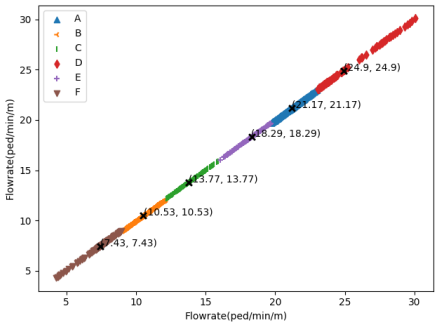
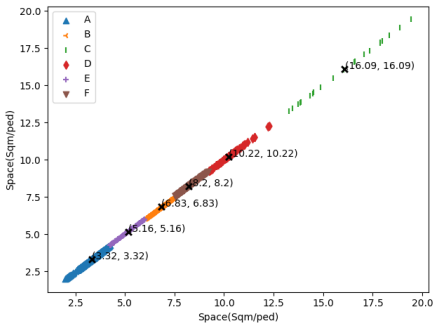


Figure 7: Spacing of PLOS categories



condition. In this level of service, flow rate is less than 9 ped/min/m. Here pedestrians at footpath can move with a speed of greater than 79.8 m/min. In case of LOS B pedestrians can also move easily but from time to time they need to change their path. In case of LOS C, path is often adjusted to avoid conflicts. LOS F, the worst condition for pedestrian movement is achieved when speed is severely restricted and there are frequent contact with other people in footpath. Using k-means clustering LOS range were thus classified from A to F where LOS A represented the best operating conditions and LOS F the worst. For parameter Space (unit: sqm/ped), PLOS ranges from A to F were found to be >12.28, 12.28-9.24, 9.24-7.54, 7.54-6.02, 6.02-4.25 and <4.25 respectively. Similarly, for parameter Flow Rate (unit: ped/min/m), PLOS ranges from A to F were found to be <9, 9-12.12, 12.12-15.91, 15.91-19.67, 19.67-23.07 and >23.07 respectively. Similarly, for parameter Speed (unit: m/min), PLOS ranges from A to F were found to be >79.8, 79.8-75.6, 75.6-70.8, 70.8-66.6, 66.6-62.4 and <62.4 respectively.

To know how well the clusters are formed, silhouettes plot for various clusters were developed. Silhouettes plot of studied footpath for six level of service of flow rate, space and speed by the help of k-means clustering is shown in Figure 9, Figure 10 and Figure 11. The

Figure 8: Speed of PLOS categories

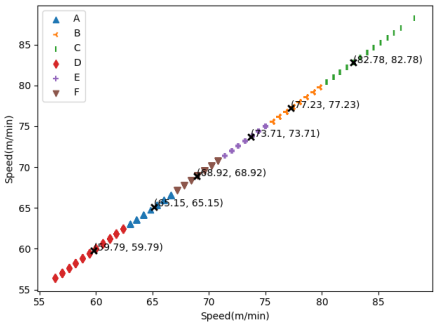
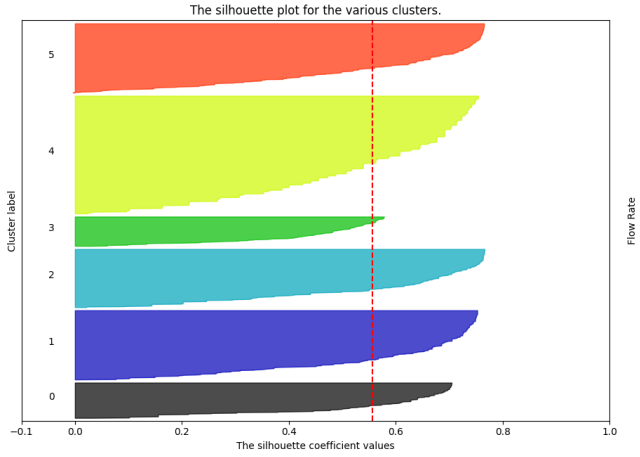


Table 4: PLOS categories for footpath using K-means Clustering

P-LOS	Space m^2/ped	Flow rate (p/min/m)	Speed (m/min)
A	>12.28	<9	>79.8
B	12.28-9.24	9-12.12	79.8-75.6
C	9.24-7.54	12.12-15.91	75.6-70.8
D	7.54-6.02	15.91-19.67	70.8-66.6
E	6.02-4.25	19.67-23.07	66.6-62.4
F	<4.25	>23.07	<62.4

average Silhouette score for flow rate, space and speed of this study were found to be 0.56, 0.63 and 0.56 respectively. Thus, cluster groups of this study were good clusters as silhouette score were greater than 0.5.

Figure 9: Silhouette Plot Categories of Flow Rate



4.4 QOS Based upon Pedestrian Perception

After interviewing, the score for each respondents on various parameters were entered in an excel and Cronbach's alpha test was computed by the help of SPSS software. The value of Cronbach's Alpha was 0.731 which is acceptable and reliable. Based on questionnaire survey and field observation, the

Figure 10: Silhouette Plot Categories of Spacing

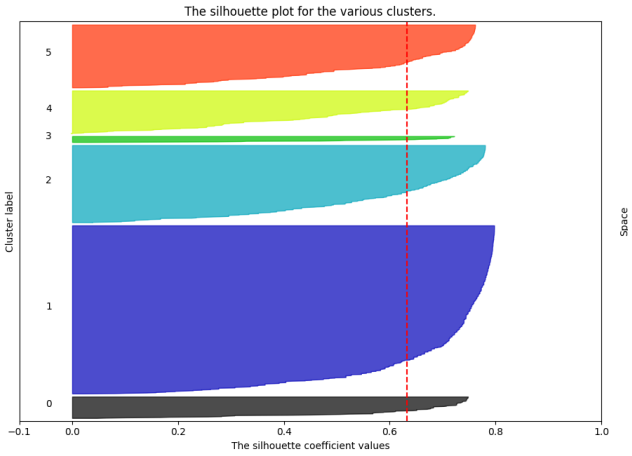
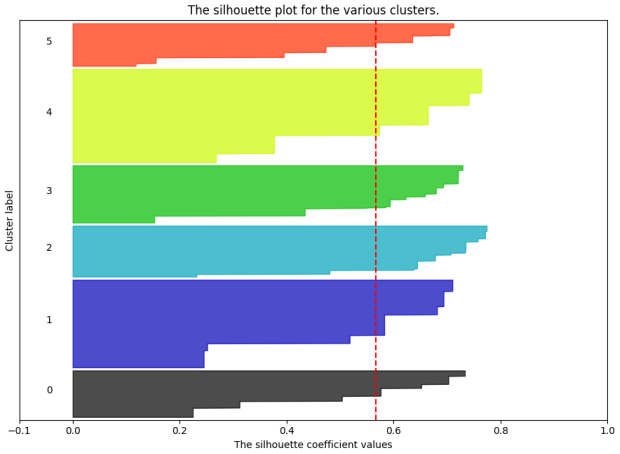


Figure 11: Silhouette Plot Categories of Speed



importance and satisfaction rating on physical and user characteristics of footpath were determined and finally the walkability index value was computed based on the importance and satisfaction rating on the physical and user characteristics of footpath.

Result of cluster analysis by the help of K-means algorithm was used in Python to find the range of QOS based upon walkability score. Five quality of service categories (A to E) was determined. The different ranges of QOS categories are shown in Figure 12 and Table 5. From k-means cluster analysis presented in Table 5, it was found that QOS categories of walkability for footpath ranges from A to E were found to be >130, 130-105, 105-86, 86-67 and <67 respectively where QOS A represented the excellent walkable footpath and QOS E represented poorly walkable footpath.

To know how well the clusters were formed, silhouettes plot for various clusters were developed shown in Figure 13. The average Silhouette score for

WI of this study was found to be 0.55. Thus, cluster groups of this study were good clusters as silhouette score were greater than 0.5.

Figure 12: QOS of WI

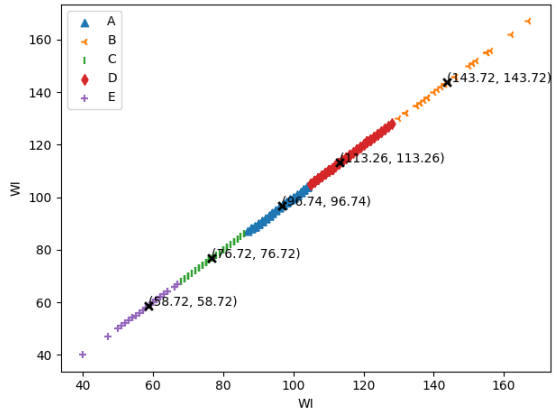


Figure 13: Silhouette Plot of WI

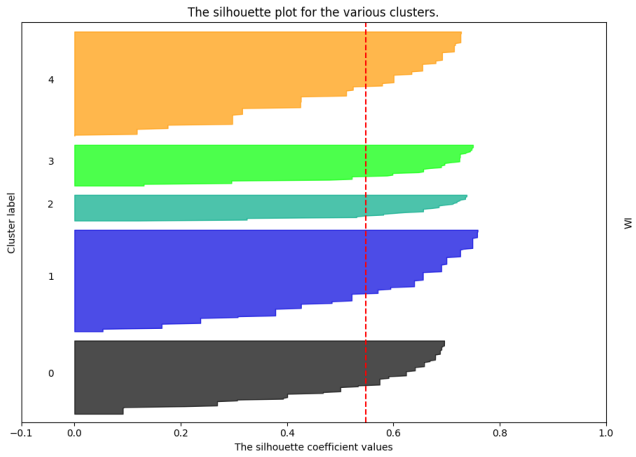


Table 5: QOS for footpath by K means Clustering Method

QOS	WI
A	>=130
B	130-105
C	105-86
D	86-67
E	<67

4.5 PLOS and QOS comparison with international model

The classification of PLOS ranging from A to F by HCM 2010 of US, Indo HCM 2017 of India and by k-means clustering in this study based upon flow parameters like flow rate, speed and spacing are presented in Table 1, Table 3 and Table 4. It was found that the ranges of PLOS is different in context of Nepal. The PLOS ranges found from this study were significantly different from HCM 2010. This could happen because in cities of Nepal traffic flow is highly heterogenous in nature. Different vehicle like car, bus, taxi, bike, cycle, truck, tempo all move in main road at similar time frame. These conditions directly influence movement of pedestrian in footpath. Also, poor enforcement of rules and regulation on both road and footpath are seen in cities of Nepal where there is strict rules and regulations are enforced in developed countries. Social and cultural aspects make people walk in groups to form platoons mostly which is less observed in developed country. The other reasons are poor surface conditions of footpath, vendor obstructions, illegal parking, improper design of road and footpath, unplanned location of poles, trees at footpath that affect the ranges of PLOS in Nepal from that of other developed countries. The ranges of PLOS based upon flow rate from this study is also proportionally lower than that of other country. It is due to decrease of movement of pedestrian at footpath and public places due to Covid19 pandemic. The classification of QOS ranging from A to E by Indo HCM 2017 of India and by k-means clustering in this study based upon walkability index are presented in Table 3 and Table 5. It was found that the ranges of QOS were slightly different in context of Nepal.

5. Conclusion

Quantitative and Qualitative methods have been used to evaluate Pedestrian level of service for footpath using k means clustering algorithms. In quantitative methods video graphic technique was used to find flow rate, space and speed and their PLOS range are thus classified from A to F. Here, LOS A represents the best operating conditions and LOS F as the worst operating conditions. For parameter Space (unit: sqm/ped), PLOS ranges from A to F were found to be >12.28, 12.28-9.24, 9.24-7.54, 7.54-6.02, 6.02-4.25 and <4.25 respectively. Similarly, for parameter Flow Rate (unit: ped/min/m), PLOS ranges from A to F were found to be <9, 9-12.12, 12.12-15.91, 15.91-19.67, 19.67-23.07 and >23.07 respectively. Similarly, for parameter Speed (unit: m/min), PLOS ranges from A to F were found to be >79.8, 79.8-75.6, 75.6-70.8, 70.8-66.6, 66.6-62.4 and <62.4 respectively. For cluster validation of consistency within clusters of data Silhouette Width Index is calculated and the average score for flow rate, space

and speed were found to be 0.56, 0.63 and 0.56 respectively. The silhouette score more than 0.5 is said to be good cluster.

In qualitative method, importance and satisfactory ratings of different physical and user characteristics for footpath are were collected from user perception through questionnaire survey. Reliability test was done by using Cronbach's Alpha method to determine the reliability of different parameters of questionnaire survey and the value of Cronbach's Alpha was found to be 0.731 which was acceptable and reliable. After reliability test, walkability index was determined based upon importance and satisfactory rating and based on WI QOS ranges from A to E were obtained. QOS categories of walkability for footpath ranges from A to E were found to be >130, 130-105, 105-86, 86-67 and <67 respectively.

The PLOS ranges from LOS A to F obtained in this study are significantly different from that of HCM 2010. Traffic flow of cities in Nepal is highly heterogenous in nature. Different vehicle like car, bus, taxi, bike, cycle, truck, tempo all move in main road at similar time frame. These conditions also influence movement of pedestrian in footpath. Poor enforcement of rules and regulation on both road and footpath are seen in cities of Nepal where there is strict rules and regulations are enforced in developed countries. Social and cultural aspects make people walk in groups to form platoons mostly which is less observed in developed country. The other reasons are poor surface conditions of footpath, vendor obstructions, illegal parking, improper design of road and footpath, unplanned location of poles, trees at footpath that affect the ranges of PLOS in Nepal from that of other developed countries. The ranges of PLOS based upon flow rate from this study is also proportionally lower than that of other country. It is due to decrease of movement of pedestrian at footpath and public places due to Covid19 pandemic. QOS range from A to E obtained was also compared with Indo HCM 2017 of India based upon walkability index. It was found that the ranges of QOS were slightly different in context of Nepal.

6. Recommendation

Following are the limitations in this study. There are remaining tasks for future studies to overcome these limitations.

1. This study was conducted in footpath of some areas of Kathmandu. Similar studies could be carried out in many areas of Kathmandu and other cities for better results.
2. Further study can be done to evaluate PLOS ranges considering the effect of Platoon flow, cross flow and queening area.
3. This study is done during covid 19 pandemic outbreak and due to pandemic condition flow of pedestrian is much lower than norman condition. So further study can be carried out after ending of pandemic.

References

[1] *Highway Capacity Manual*, 2000.

[2] *Highway Capacity Manual*, 5th edition, 2010.

[3] *Indo- HCM 2017*, 2017.

[4] Rima Sahani and P.K. Bhuyan. Level of service criteria of off-street pedestrian facilities in indian context using affinity propagation clustering. *Procedia - Social and Behavioral Sciences*, 104:718–727, 2013. 2nd Conference of Transportation Research Group of India (2nd CTRG).

[5] P Gyawali. Pedestrian level of service at sidewalk (a case study in kathmandu valley). Master's thesis, Tribhuwan University., 2014.

[6] A.K. Jain and R.C Dubes. Algorithms for clustering data. *Prentice Hall Inc., Englewood Cliffs, New Jersey.*, (1988).

[7] Shehroz Khan and Amir Ahmad. Cluster center initialization algorithm for k-means clustering. *Pattern Recognition Letters*, 25:1293–1302, 08 2004.

[8] Peter J. Rousseeuw. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics*, 20:53–65, 1987.

[9] Karl Kim and Eric Y. Yamashita. Using a k-means clustering algorithm to examine patterns of pedestrian involved crashes in honolulu, hawaii. *Journal of Advanced Transportation*, 41(1):69–89, 2007.

[10] Rima Sahani and Prasanta Kumar Bhuyan. Pedestrian level of service criteria for urban off-street facilities in mid-sized cities. *Transport*, 32(2):221–232, 2017.

[11] Lee J. Cronbach. Coefficient alpha and the internal structure of tests. *Psychometrika, The Psychometric Society*, 16(3):297–334, 1951.