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Development of Landuse based Pedestrian Level of Service in Indian Context

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Abstract
Walking is a basic as well as environment friendly mode of transportation. Walking facilities require cautious design strategy consideration to promote walking which helps to reduce congestion, pollution, rate of accidents and other transport related problems from developing countries like India. Better facilities will encourage people for walking and will provide healthy environment for future. Design of these facilities ensure the precise forecast of pedestrian flows and realization of capacity. In this paper macroscopic stream flow characteristics of pedestrians were observed considering various land uses for urban areas. Five different types of land use such as terminal, institutional, recreational, commercial and residential were categorized for study purpose. Data were collected from 21 urban locations of eight cities including metropolitan cities in India. Pedestrian flow models were developed and macroscopic flow diagrams (MFD) were prepared separately for various land uses. Difference in fundamental flow parameters for instance flow, speed and density were observed for different land uses. Comparison between secondary flow parameters such as free flow speed, optimum density, optimum speed, space at capacity and capacity for different land uses are presented in this study. Estimated Mean free speed (MFS) varies from 60.81 to 85.14 m/min and capacity ranges vary from 42.22 to 91 P/min/m for different land uses. Pedestrian level of service (PLOS) criterion for sidewalk facilities have been proposed for different land uses. Study results will be useful for engineers, planners, practitioners and policy makers to provide economic and efficient sidewalk facilities for pedestrians in India.
Keywords: Macroscopic flow models, MFD, Capacity, PLOS.

1. Introduction

The importance of pedestrian movements is understood globally and cannot be overemphasized. In most of the developing countries, a high percentage of travel by walking or cycling. Foot traffic has been found to be influenced by psychological, social, and environmental factors. Walking is an activity which offers less risk of heart disease, weight control, less risk of high blood pressure, diabetes, less depression and anxiety, less risk of cancer and osteoporosis (Azmi et al., 2012). Non-motorized traffic motorizing programs are implemented in a Small Rural College Town (Blacksburg;VA; ~50,000people, 19.7 square miles)with the goal ofcharacterizing bicycle and pedestrian traffic on an entire transportation network (Lu et. al. 2017).
In India’s major cities, accident rates are highest for pedestrians. According to Central Road Research Institute, almost 80 per cent of the road fatalities involve pedestrians, with studies based on hospital records suggesting that 22-35% of road deaths are pedestrian deaths (MOUD, 2008). Increasing rate of motor vehicles in India cause environmental pollution, congestion and parking problems.

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These problems can be solved by promoting non-motorized transportation through providing better facilities. Better walking environment will encourage pedestrians and also encourage motorized traffic for shifting towards walking. People can adopt waling mode of transportation for last mile connectivity. It will also help to promote public transportation system.Pedestrian can move according to their convenience as they have different choices for movement which make them different from motorized users. Their movement is more flexible and complex. Every pedestrian requires sufficient space for their comfortable movement. In the urban scenario, a good number of trips up to 2-3 km are performed on foot but the kind of facility available for movement are not up to the mark. As per Tiwari, G. (2011), the shorter trip lengths and high percentage of low-income groups have resulted in the high modal share of NMT and the modal share of NMT is about 30% in cities with more than 1 million populations, which increases to nearly 60% in smaller cities. In a developing country like India, the importance of walking depends on size and nature of cities. Percentage share of walking and cycling is less in megacities due to high vehicle ownership and existence of superior transportation system.
Pedestrian facilities help in improving the built-up surroundings by making the residential and neighbourhoods safe and stimulating**.** The pedestrian friendly environment cannot be devolved just by laying of footpath or putting in signals. The appropriate guidelines and regulator of the facilities must be determined for providing better facilities. Pedestrian traffic (transport system) and land use (activity system) are closely related to each other. Pedestrian movement is directly affected by type and purpose of trip which is further depends on surrounding land use activities. The land use activities are affected by demographic and socioeconomic characteristics of a particular region. These comprise journeys to access crucial facilities like education, shopping and leisure trips inside neighbourhoods.
The land use activity system of a region defines the demand of pedestrians whereas the pedestrian transport system determines the capacity of pedestrian infrastructure while ensuring safe, comfortable and convenient movement. Maximum cities of India have varied patterns of land-use, high residential densities and low-income people living close to place of work by occupying public land. The above three characteristics contribute to generation of short trips and less dependency on motorized travel. Therefore, development of walking environment should consider integrated approach for interdependence between pedestrian movement and land-use.

2. Past studies

Pedestrian characteristics can be described studying relationships of walking speed, flow, density and space parameters for different type of facilities. Developed relationships basically represent the pedestrian traffic flow modelling concept which involves mathematical relationships among fundamental parameters of pedestrian traffic. Flow parameters such as speed, flow, density and space are basic inputs for pedestrian flow modelling. Hankin and Wright (1958), studied passenger flow in subways andobserved free flow speed in empty passage was 96.56 m/min and estimated capacity value was 90 P/m/min for design purposes on level passageway in London transport subway. Oeding (1963), observed average pedestrian speed 74.98 m/min and estimated speed at maximum flow 45.11 m/min at 1.96 P/m_2 density level for mixed traffic. Older observed pedestrian characteristics at three sites on shopping streets in London. He observed free flow speed was 78.64 m/min and optimum walking speed was 38.4 m/min. Fruin (1971) considered 1000 travelers without baggage at Port Authority Bus Terminal and Penn Station in New York City to study pedestrian characteristics. He found free speed of pedestrian was 81.0 m/min. It was also found from the study that females walk slower than males. Polus et al., developed three regime models for sidewalks in Israel, Halifa (Polus et al. 1983). The three regimes followed a linear trend between speed and density. The first regime was limited up to density of 0.6 P/m^2, the second regime was limited for densities range from 0.6 P/m^2 to 0.75 P/m^2 and the model for third regime was valid for densities greater than 0.75 P/m². Tanaboriboon et al. studied the flow of 519 pedestrians at three sidewalks beside the streets of Singapore and compared fundamental models between Singapore and Western Countries (Tanaboriboon et al. 1986). Tanaboriboon and Guyano (1989) recommended six set of LOScriterions for designing of walkways using volume/ capacity ratio and area occupancy for each pedestrian in Bangkok.

Morrall et al. (1991) observed that people carrying some baggage are likely to walk slower than the non-baggage-carrying pedestrians regardless of the dimensions and weight of the baggage. Koushki and Ali (1993) studied pedestrian flow characteristics in Kuwait City. They observed pedestrian walking speeds in Kuwait City Centre which was lower as compared with the United State and England and it was similar to observed pedestrian speed in Riyadh, Saudi. Al-Masaeid et al. (1993) established the pedestrian speed-flow relationship for the central business district (CBD) areas in Irbid, Jordan. They found quadratic polynomial regression relation as best fit for their study. Virkler and Elayadath (1994) developed various models considering single, two and three regime linear models to study the pedestrians' speed– density relationship near the entrance to a pedestrian tunnel. Edie's model was best fitted among the two regime models. Gerilla et al. (1995) conducted a detailed study to develop LOS standards for walkways around CBDs of metro in Manila. Three types of transportation survey techniques were performed for instance photographic technique survey, pedestrian behaviour questionnaire survey and pedestrian preference of facility survey. Linear speed-density model was observed as a best fitted model with 0.85 value of measured R^2. Lam et al. (1995) performed peak hour surveys for various types of walking facilities (indoor and outdoor walkway, crosswalk, stair, escalator and passageway etc.) in Hong Kong. They found that free-flow speed varied from 47.93 to 87.09 m/ min. Sarkar and Janardhan (2001) developed the relationships of speed, density, flow and space for transfer terminal in Calcutta and he reported the speed of a pedestrian as 87.59 m/min, maximum flow 92 p/m/min, and required space at maximum flow as 0.48 m²/P. Lam and Cheung (2000) estimated speed of pedestrians on different walking facilities and found that pedestrians on indoor walkways walk slower than those on outdoor walkways.

Daamen et al. (2005) found the effect of various factors like width, type of facility, and environmental factors on walking speed of pedestrians. McDonald (2007) proposed social environment as a vital factor short-distance walking trips as it affected the walking behaviour of child pedestrians in their study. Wells and Yang (2008) found that land-use mix also affects walking, and pedestrians in non-residential areas walk less than those in other areas.

Finnis and Walton (2008) observed higher walking speeds for New Zealanders as compared to past studies. The pedestrian walking speed is found greatly affected by individual and locational factors.

Paridaet al. (2007), analyzed the existing sidewalk facilities in Delhi using quantitative and qualitative approach. They observed the exponential relationship was best fitted between the speed-density relationships. Maximum flow rate and optimum speed were reported as 11.63-38.01 P/min/m and 31-35 m/min. Six levels of service were defined by this study from A (flow < 12 P/min/m and available space >4.9 m²/P) to F (available space < 0.6 m²/P) based on space and flow. Kotkar et al. (2010) found the pedestrian flow characteristics at four locations under mixed traffic condition. Free-flow speed was found quite high, 84 m/min or 1.4 m/s and jam density was ranging from 2.59-4.17 P/m². Nazir. et al. (2012) studied the pedestrian movement on three walkways in Khulna Metropolitan City, Bangladesh and found the effect of location on pedestrian flow parameters. They reported the value of free flow speed as 64.14 m/min, jam density as 7.50 P/m², maximum flow rate as 114.71 P/m-min and required space as 0.13-.31 m²/P.

Rastogi et al. (2013) observed pedestrian behaviour for different type of walking facilities available i.e. sidewalks, wide sidewalks, and precincts at nineteen locations in five cities of India. They analyzed pedestrians flow characteristics under different conditions i.e. unidirectional and bidirectional flow, restrained and normal flow condition, exclusive and non- exclusive pedestrian facility. Rastogiet al.

(2014) developed LOS for sidewalks andwide-sidewalks and observed that the pedestrian space criterion is more uniform and stable in defining the LOS for a facility. Singhet al. (2015) found that the shy distance of pedestrians decreases as number of pedestrians along the width increases. The body ellipse value for Indian human is found as 34.76 cm × 50.82 cm. As per the above study, required space for Indian pedestrian without luggage is0.17 m^2.Das et al. (2015) observed that three regime model was best fitted to establish speed-density relationship for sidewalks and carriageways around transport terminal areas in India. Estimated free flow speed was 83.49 m/min and maximum flow rate was 86.93 P/min/m at 2.94 P/m^2density level for carriageways. For sidewalks estimated values were 92.50 P/min/m, 3.45 P/m^2 and 80.74 m/min for capacity, optimum density and free flow speed. Lammel et al. (2016) developed pedestrian modelingusing cellular automata for urban street segments with high pedestrian tripgenerators.They evaluated pedestrianoperations at urban street segments considering heavy pedestrian trip generators as an alternative analysistool of the HCM pedestrian analysis methodology.Kim et al. (2017) developedpath planning model which includes the planning level after thedeparture time and the destination are confirmed under dynamic and stochastic environment.Blumenberg et. al. (2017) examined the determinants of walking using Tobit regression considering changes in walking mode choice and changes in other neighborhood characteristics. Vanumu et. al. (2017) stated that after establishing behavior of pedestrians in terms of speed and density with respect to the environment, pedestrian flow characteristics can be modelled by simulations. They reviewed fundamental diagrams of pedestrian flow characteristics developed for various flow types and geometric elements.

At international level and national various studies have been done in this area. Very few studies have been done at national level using wide range of data sets from different cities to define service levels using quantitative approach. Here we have collected data from eight different cities to capture wide range of data for developing PLOS for Indian context.

3. Need of the study

Most of the past studies focused on qualitative assessment of pedestrian infrastructures. In some of the past studies focused on basically analyzing the speed chracteristics. Summarized mean walking speed of pedestrians are given in Table 1 based on different land uses but in different time variations. Also,observed variation of pedestrians' speed by Parida (2006) in Delhi are provided in Table 2. PLOS was developed for integrated land use in most of the past studies.There is need to develop service quality based on different land uses which will be economical and efficient. Here from quantitative view point, it was observed that not only speed,flow, space and capacity also varied with the land uses. Developedcapacity norms for different land use patterns, will be more realistic as flow characteristics have noticeable difference with regard to prevailing land use. Developed models and service levels of pedestrian facilities (sidewalks) will be useful for policy makers andpractitioners to provide better facilities for pedestrians. Study results will provide asimple path for them to measure PLOS. Better infrastructure will also encourage people to shift from motorized traffic towards non-motorized traffic and it will promote sustainable transportation system.

Table 1: Mean walking speed of pedestrians considering land uses

Land use	Author	Country	Mean walking Speed (m/min)
Commercial	Older (1968)	London	79.0
	Koushki and Ali (1988)	Kuwait	71.0
	Lam and Cheung(2000)	Hong kong	74.0
	Parida et.al.(2006)	India	68.64

Residential	Parida et.al.(2006)	India	86.0
	Ilango et. al.	India	88.77
Institutional	Navin and Wheeler (1969)	USA	79.0
	Parida et.al.(2006)	India	76.0
Terminal	Fruin (1971)	USA	81.0
	Sarkar et al (2001)	India	87.6
	Parida et.al. (2006)	India	76.0
	Kotkar et al. (2010)	India	83.4

Table 2: Land use wise Pedestrian Speed Variation

Location	**Land use**	**Speed** (m/min)
Ashram	Residential/ Interchange	86.4
AIIMS	Public /semi public	81.12
ITO	Public/semi public	86.70
CP	Commercial	68.64
ISBT	Terminal	76.0

Source: Parida et.al 2007

4. Details of Study area

In present study, eight Indian cities i.e. New Delhi, Kolkata, Mumbai, Roorkee, Ahmedabad, Vadodara, Chandigarh and Chennai were selected as suitable study area. The land use of these sidewalks has been determined on basis of surrounding activities. The various locations of these cities are considered for observing the characteristics of pedestrian flow on sidewalks under different land use, which are further used to develop pedestrian flow models. All these locations are in built-up area with significant pedestrian activities. The details of these study locations are provided in Table 3.

Table 3: Details of study locations for present study

City	**Name of the Road Section**	**Width (m)**	**Land-use**
Delhi	North Campus	3.14	Institutional
	In front of Akshardham Temple	2.03	Recreational
	Near Akshardham metro	3.2	Terminal
	Connaught Place towards LIC	8.7	Commercial
	Maharani Bag	3.2	Residential
Chennai	Beach Road	5.0	Recreational
Bombay	CST	2.6	Commercial
	Church gate	5.0	Terminal
Roorkee	Railway Station Roorkee	3.2	Terminal
Kolkata	College Street	2.6	Institutional
	BBD Bag	4.4	Commercial
	Howrah Bridge	4.4	Terminal
	Girish Avenue	4.2	Residential
Ahmedabad	Income Tax Road (AR)	2.5	Institutional

	University Road (AR)	3.0	Institutional
Vadodara	Nyay Mandir to Mandvi Road	2.59	Commercial
	Nyay Mandir to Mandvi Road	2.59	Commercial
Chandigarh	Rose Garden	1.55	Recreational
	Sukhna lake	2.0	Recreational
	Punjab University	2.1	Institutional
	PGI Hospital	2.0	Institutional

5. Data collection and extraction Methodology

Video Observation Technique (VOT) was used for data collection. The data was collected by CSIR-Central Road Research Institute (CSIR-CRRI) and various other institutions for various locations of different Indian cities considering the peak and off-peak times during morning and evening. For data collection a trap area was selected with the 10m length and available facility width. Trap area was marked with white or yellow adhesive tape which is distinctly visible in videos. The video Camera was placed at a vantage location and height was adjusted to capture wide angle view of pedestrian facility. The video collected at study locations are automatically split into particular number of digital files by the video camera.

Pedestrian flow parameters were manually extracted from the recorded videos by playing them on big screen. Travel time of each pedestrian was observed with an accuracy of 1/100th of second and walking time was calculated by subtracting the time of entry into the trap from the time of exit. Walking speed was estimated by dividing the known length of the trap by the walking time. Randomly 5 pedestrians were selected in the system. 30 second time interval(optimized time interval) was selected based on statistical analysis done by Das et al. (2016) to extract pedestrian flow parameters.

Flow rate values were estimated in terms of pedestrians per minute per meter width (P/min/m) considering effective walkway width. Effective walkway width can be described as the width of a facility that can be effectively used by pedestrians after deducting shy distance. Number of samples used for model development at different land uses are given in Table 4.

Table 4: Details of Data Samples

Institutional	Recreational	Commercial	Terminal	Residential
1517	1390	1054	963	343

6. Macroscopic Pedestrian Flow Modelling

Pedestrian flow characteristics around different land uses were observed through development of mathematical relationships between macroscopic flow parameters and graphical representation of those relationships. Developed mathematical relationships between fundamental stream flow parameters for instance speed (u), flow (q), density (k) and area module or space (M) are provided in Table 4. It shows the established models for institutional, recreational, commercial, terminal and residential land uses. Pedestrian flow characteristics on various land uses are represented with the MFDs. MFDs represent the established relationships between speed-density, flow-density, speed-flow and flow-space. From these diagrams the secondary flow parameters for instance MFS, optimum speed (u_o), jam density (k_j), capacity (q_{max}), space at capacity (M_o) estimated and those values are provided in Table 5. MFDs for sidewalk movement at different land uses are shown in Figure 1. Also, MFDs for integrated land uses are shown in Figure 2.

Table 4: Mathematical relationships between pedestrian flow parameters

Land uses	Relationships		Equations	R^2
Institutional	Flow-Density	Parabolic	$q = 75.73\ k - 33.96\ k^2$	0.93
	Speed-Density	linear	$v = 75.73 - 33.96\ k$	
	Speed- Flow	Parabolic	$q = (75.73\ v - v^2)/33.96$	
	Flow-Space	Inverse Parabola	$q = (75.73/M) - (33.96/M^2)$	
Recreational	Flow-Density	Parabolic	$q = 60.81\ k - 10.15\ k^2$	0.93
	Speed-Density	linear	$v = 60.81 - 10.15k$	
	Speed- Flow	Parabolic	$q = (60.81\ v - v^2)/10.15$	
	Flow-Space	Inverse Parabola	$q = (60.81/M) - (10.15/ M^2)$	
Commercial	Flow-Density	Parabolic	$q = 64.62\ k - 15.19\ k^2$	0.93
	Speed-Density	linear	$v = 64.62 - 15.19\ k$	
	Speed- Flow	Parabolic	$q = (64.62\ v - v^2)/15.19$	
	Flow-Space	Inverse Parabola	$q = (64.62/M) - (15.19/ M^2)$	
Terminal	Flow-Density	Parabolic	$q = 81.49\ k - 21.16\ k^2$	0.98
	Speed-Density	linear	$v = 81.49 - 21.16\ k$	
	Speed- Flow	Parabolic	$q = (81.49v - v^2)/21.16$	
	Flow-Space	Inverse Parabola	$q = (81.49/M) - (21.16/ M^2)$	
Residential	Flow-Density	Parabolic	$q = 85.14\ k - 30.63\ k^2$	0.90
	Speed-Density	linear	$v = 85.14 - 30.63\ k$	
	Speed- Flow	Parabolic	$q = (85.14\ v - v2)/30.63$	
	Flow-Space	Inverse Parabola	$q = (85.14/M) - (30.63/ M^2)$	
Combined model	Flow-Density	Parabolic	$q = 73.28\ k - 15.69\ k^2$	0.87
	Speed-Density	linear	$v = 73.28 - 15.69\ k$	
	Speed- Flow	Parabolic	$q = (73.28\ v - v2)/15.69$	
	Flow-Space	Inverse Parabola	$q = (73.28/M) - (15.69/ M^2)$	

Table 5: Estimated Flow parameters for different land uses

Land use	MFS (m/min)	kj (P/m^2)	qmax (P/min/m)	uo (m/min)	Mo (m^2/P)
Terminal	81.49	3.85	78.46	40.74	0.52
Institutional	75.73	2.2	42.22	37.86	0.89
Recreational	60.81	5.9	91.0	30.40	0.33
Commercial	64.62	4.25	68.73	32.31	0.47
Residential	85.14	2.7	59.14	42.47	0.71
Combined (or mixed)	73.28	4.6	85.6	36.64	0.42

The capacity was found maximum at recreational land use (91 P/min/m). The friction caused by the other pedestrian coming from opposite direction on sidewalk and increase jam density. Due to high jam density, the space occupied by per person reduces which obstruct the free movement of pedestrian. Table 5 shows the area module at capacity is minimum for recreational land use (0.33 P/m^2) as compared to other land use due to presence of more number of pedestrian in unit area. The estimated value is quite lower as compared to the space value specified corresponding to same LOS in IRC:103-2012. Pedestrian try to reduce their area module while walking in recreational land use to ensure movement with their family members. The proportional of more child pedestrian in platoon reduced the area requirement for individual pedestrian. MFS of pedestrians is found maximum for residential land use (85.14 m/min). Activities in morning peak hours i.e. school and office going activities are the only reason for higher speed. The MFS value is similar to the speed reported by Parida (2006) in India (86.0m/min).

Comparison between pedestrian flow characteristics can be observed clearly from the Figure 2. This figure shows the maximum capacity and minimum required space around recreational area, maximum MFS around residential area. Combined model (Figure 1) shows the capacity value is 85.6 P/min/m at 2.3 P/m^2 density level. Comparison between mean walking speeds of pedestrians on sidewalks with the past studies are presented in Table 6.

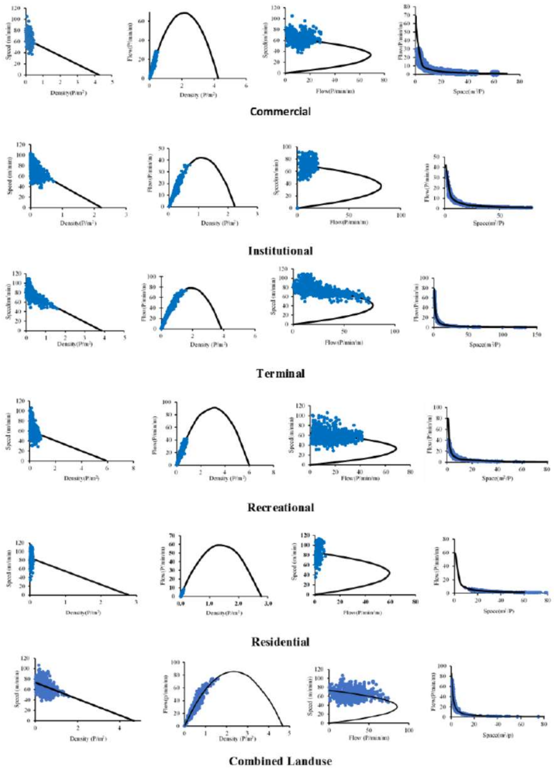

Figure 1: Land use based MFDs for sidewalks

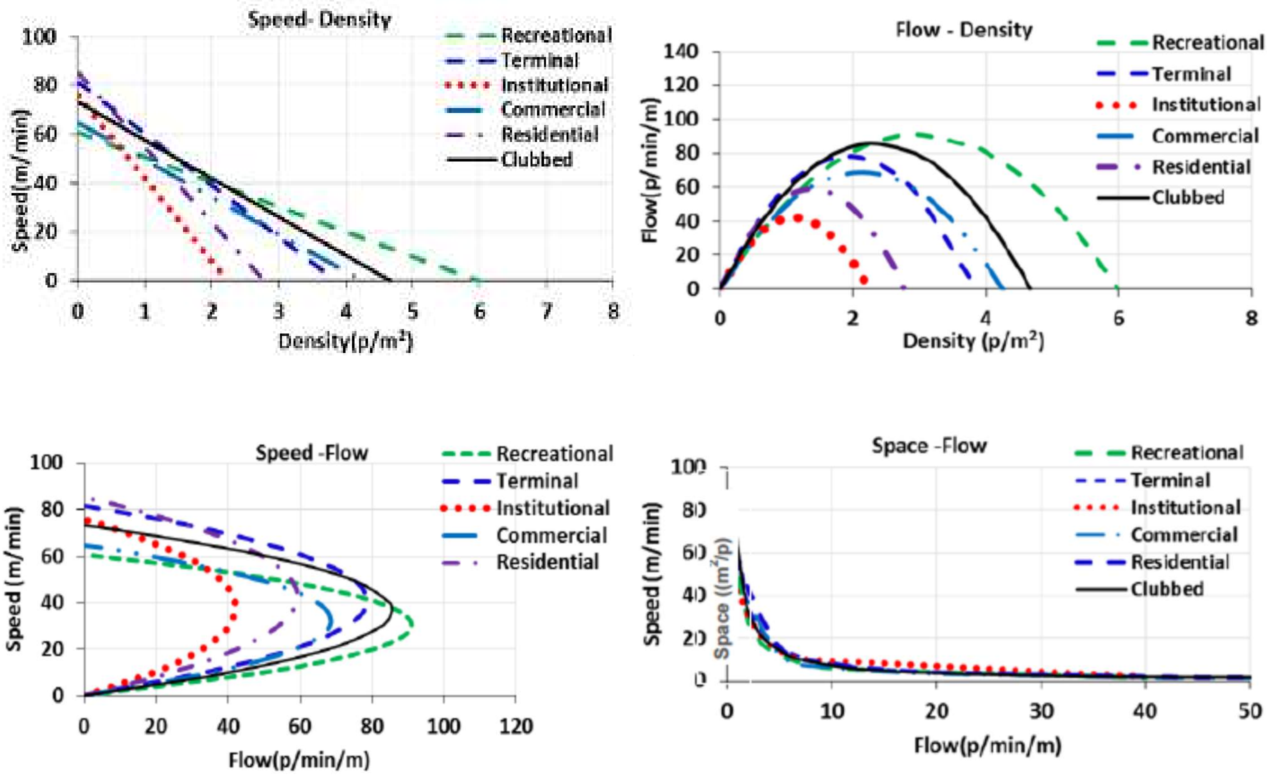

Figure 2: Comparison between MFDs for pedestrian movement on different land uses

Table 6: Comparison of mean walking speed with past studies

Land use	**Author**	**Country**	**Mean walking Speed (m/min)**	**Present Study**
Commercial	Older (1968)	London	79.0	64.0
	Koushki and Ali (1988)	Kuwait	71.0	
	Lam and Cheung(2000)	Hong kong	74.0	
	Parida et.al.(2006)	India	68.64	
Residential	Parida et.al.(2006)	India	86.0	85.14
	Ilango et. al.	India	88.77	
Institutional	Navin and Wheeler (1969)	USA	79.0	75.73
	Parida et.al.(2006)	India	76.0	
Terminal	Fruin (1971)	USA	81.0	81.49
	Sarkar et al (2001)	India	87.6	
	Parida et.al. (2006)	India	76.0	

7. Development of Level of Service for Pedestrian Facilities (PLOS)

Level of service is a measure for assessing the operating condition of facilities quantitatively. It denotes the level of comfort ability provided by facility to pedestrians while using the facility. Recommended PLOS as per Tanaboriboon and Guyano (1989) study, HCM 2010 and IRC:103-2012 are provided in Table 7. It can be observed that IRC values are on lower side as compared to US HCM 2010. Estimated PLOS values from this study are provided in Table 8 and 9.

Table 7: Recommended PLOS for sidewalks from Past Studies

LOS	Tanaboriboon and Guyano (1989)		HCM 2010			IRC:103-2012	
	Space (m^2/P)	Flow Rate (P/min/m)	Space (m^2/P)	Flow Rate (P/min/m)	Speed (m/min)	Space (m^2/P)	Flow Rate (P/min/m)
A	≥2.38	≤28	>5.58	≤16.39	>77.78	>4.9	≤12
B	>1.60-2.38	>28-40	>3.72-5.58	>16.39-22.95	>76.31-77.78	>3.3-4.9	>12-15
C	>0.98-1.60	>40-61	>2.23-3.72	>22.95-32.79	>73.20-76.31	>1.9-3.3	>15-21
D	>0.65-0.98	>61-81	>1.40-2.23	>32.79-49.18	>68.63-73.20	>1.3-1.9	>21-27
E	>0.37-0.65	>81-101	>.74-1.40	>49.18-75.41	>45.75-68.63	>0.6-1.3	>27-45
F	≤0.37	>101	≤0.74	variable	≤45.75	≤0.6	Variable

Table 8: Proposed PLOS for commercial, Institutional and Terminal land uses

LOS	Commercial			Institutional			Terminal		
	Space (m^2/p)	Flow (p/min/m)	Speed (m/min)	Space (m^2/p)	Flow (p/min/m)	Speed (m/min)	Space (m^2/p)	Flow (p/min/m)	Speed (m/min)
A	>4.87	≤12.63	>61.5	>5.29	≤13.1	>69.31	>5.22	≤14.83	>77.44
B	>3.07-4.87	>12.63-19.44	>59.67-61.5	>3.49-5.29	>13.1-18.91	>66.0-69.31	>2.82-5.22	>14.83-26.24	>73.99-77.44
C	>1.87-3.07	>19.44-30.21	>56.5-59.67	>2.29-3.49	>18.91-26.59	>60.9-66.0	>2.22-2.82	>26.24-32.41	>71.96-73.99
D	>1.07-1.87	>30.21-47.12	>45.14-50.84	>1.49-2.29	>26.59-35.53	>52.94-60.9	>0.82-2.22	>32.41-67.91	>55.69-71.96
E	>0.47-1.07	>40.67-68.73	>29.11-45.14	>0.89-1.49	>35.53-42.22	>37.57-52.94	>0.52-0.82	>67.91-78.46	>40.80-55.69
F	≤0.47	variable	≤29.11	≤0.89	variable	≤37.57	≤0.52	variable	≤40.80

Table 9: Proposed PLOS for Recreational and Residential land uses

LOS	Recreational			Residential		
	Space (m^2/p)	Flow (p/min/m)	Speed (m/min)	Space (m^2/p)	Flow (p/min/m)	Speed (m/min)
A	>4.73	≤12.42	>60.29	>5.11	≤15.49	>79.14
B	>2.93-4.73	>12.42-19.6	>58.66-60.29	>3.31-5.11	>15.49-22.93	>75.88-79.14
C	>1.73-2.93	>19.6-31.8	>54.94-58.66	>2.11-3.31	>22.97-33.47	>70.61-75.88

D	>0.93-1.73	>31.8-53.73	>49.9-54.94	>1.31-2.11	>33.47-47.14	>61.75-70.61
E	>0.33-0.93	>53.73 -91.2	>30.05-49.9	>0.71-1.31	>47.14-59.14	>41.98-61.75
F	≤0.33	variable	≤30.05	≤0.71	variable	≤41.98

For different land use the level of service criterion are developed using the space parameter which denotes the comfort and convenience factors for pedestrian movement. The level of service experienced at maximum flow for facilities in different land use are given below in Table 8 and 9 on the basis of space available at capacity. Table 10 shows the PLOS ranges of sidewalks for integrated land use in India.

The space at capacity (LOS F) is found maximum for institutional land use (0.89 m^2/P) which is quite higher as compared to the value specified in IRC:103 (0.6 P/m^2). In Institutional land use, sufficient area is available in level of service F condition due to low flow rate (42.22 P/min/m).

The area module for terminal land use is found as 0.52 P/m^2.It can be inferred that pedestrian with baggage and children cause the maximum reduction in area module but the high speed characteristics of pedestrians in terminal (81.49 m/min) do not allow the pedestrian to cause much reduction in area module.

The space at capacity in commercial land use is found as 0.47 P/m^2. Due to obstructions by hawkers on sidewalks, pedestrian try to avoid interaction with them and try to move on the middle portion of facility. Further involvement of pedestrians in window shopping reduce the speed. This is the major reason behind the reduction of area module and speed in commercial land use. The observed space requirement at capacity in commercial, recreational and terminal land use is found lower as compared to the value reported by both HCM 2010 and IRC:103-2012 guidelines. These values indicate that pedestrians' in India are more tolerant about sharing their available space while moving as compared to the pedestrian in other countries.

Developed PLOS for integrated land uses is not able to provide optimized quantification of service quality for different land uses. It is better to observe service quality for different land use activates separately which will give more accuracy to observe the present condition.

Table 10: PLOS for Integrated Sidewalks (India)

LOS	Space (m^2/P)	Flow (P/min/m)	Speed (m/min)
A	>4.82	≤14.53	>70.02
B	>3.02-4.82	>14.53-22.54	>68.08-70.02
C	>1.82-3.02	>22.54-35.53	>64.66- 68.08
D	>1.02-1.82	>35.53-56.76	>58.72-64.97
E	>0.42-1.02	>56.76-85.53	>35.79-58.72
F	<0.42	variable	≤35.79

8. Conclusions and Recommendations

This study provides comparison of pedestrian characteristics for sidewalk movement based on land use. Pedestrians flow models were developed for each land uses and integrated land uses also. Developed PLOS criterion for sidewalks are provided in this study for urban areas. The variations in estimated flow parameters provides the need of this study because a single model fails to provide optimized values. From the results, it can be observed that higher value of MFS at residential land use and lower value for recreational land use. Estimated capacity for sidewalks varies in between 42.22 to 91.00 P/min/m for different land uses and for combined model value is 85.6 P/min/m. The value of optimum

density ranges from 1.1 P/m^2 to 2.9 P/m^2 and optimum speed varies from30.4 m/min to 42.47 m/min as per this study depending on type of land use. Space at capacity varies from 0.33 m^2/P to 0.89 m^2/P ranges. For integrated sidewalk space at capacity is 0.42 m^2/P. On the basis of comparison with IRC: 103-2012 the level of service conditions have been found at maximum flow condition. It indicates that sidewalk in different land use at capacity will be service in range of LOS E to LOS F. Therefore, pedestrian movement will be possible by shuffling only in that case. The LOS criterion in present study for the integrated land use found to be similar as the criterion given by Tanaboriboon and Guyano (1989). To design walking facility, structure should be economical and efficient. So, land use-based models concept should be considered for design as well as planning purpose. In places where mixed land use is prevailing integrated land use concept should be implemented.
In future study can be extended for grade separated pedestrian facilities. Also effect of geographical parameters, demographic and ethnic characteristics on pedestrian behaviour can be included in further study.

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