Empirical Study of Pedestrian Flow Characteristics in Navi Mumbai

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ABSTRACT: Walking is a significant mode of transport and all human beings are pedestrians for varying time periods on roads. Hence, they are vulnerable road users in traffic system. Pedestrian walking speed is a function of a pedestrian's value of time, risk and capabilities. The ultimate goal of this study understands the relationships among pedestrian speed and flow and calculate free-flow walking speed of pedestrians. For this purpose, a series of field studies were conducted to quantify the walking speed and to identify the contributing factors which affects walking speed in the Navi Mumbai.
Basic data on walking speeds and the chosen factors were collected by a photographic procedure of video recording through CCTV Servileance cameras already installed in CIDCO's jurisdictions nodal area of Navi Mumbai. The video camera was placed to record the normal walking conditions. The pedestrian flow areas (four reference points forming a rectangle) were marked off on the sidewalks with a same length of 10 m, but effective widths of sidewalks were different at each location (2.5m and 7.5 m). The surveys were conducted both in peak and off-peak periods on the selected study sites. The speed of each of the pedestrians was determined on the basis of crossing time of the taken by the pedestrians to walk through the marked boundaries. The collected data was used to develop mathematical and graphical fundamental relationships of speed-Flow for the pedestrians. The free-flow speed is found to be more than 70 m/min (1.17 m/sec). Speeds are highest at the location I, around 120 m/min (2 m/sec) with sidewalk width is 2.5 m. Free-flow speeds are found to be less at location II, around 74.3 m/min (1.24 m/sec) with sidewalk width 2.5 m. Comparison with other studies the speeds reported is nearer to observed in Delhi, Madras, Chandigarh India and higher than observed in cities like Roorkee and Mumbai, India. Mean walking speeds are less than those observed worldwide studies conducted like London, Colombia, New York, Bangkok, Dhaka etc. The present study analyzed the pedestrian flow characteristics in New Mumbai, India & found to be comparable to those observed globally.

Keywords: Pedestrian, Speed-Flow, Sidewalk, walking.

1. INTRODUCTION

Walking is the most elementary form of transportation. Unlike vehicular and railway transportation, walking happens in anywhere; from roadside to covered shopping malls; and from underground stations to foot over bridge. Whatever the progressing steps in transportation, walking is still most significant and common mean of travelling, especially for the first and the last trip leg of any journey. Pedestrians are vulnerable road users in traffic system and hence, there activities differ greatly between and within the various sections of study area. Depending upon their purposes thousands of the people walk on sidewalk and cross streets on foot at a time of day and night. Movement of pedestrians be impeded for a number of reasons including large volume of people in one area at a time, conflicts with vehicles at crosswalk, street obstructions etc. Past research on pedestrian walking speeds has provided basic guidelines on walking speed, but some of this has to be changed based on characteristics of pedestrian traffic. As per the studies passenger transport mode share refers to the percentage of passenger journeys or trips by main mode of transport and is typically reported through travel surveys. According to reports of census India, population of Navi Mumbai in the year 2011is 1119477 (1.119 Million). Talking about the forecasted population growing towards the year 2018 is 1.639 Million. Population of the city has increased by 59.2% in last 10 years and as of 2011 census there are 837 females per 1000 male in the city.

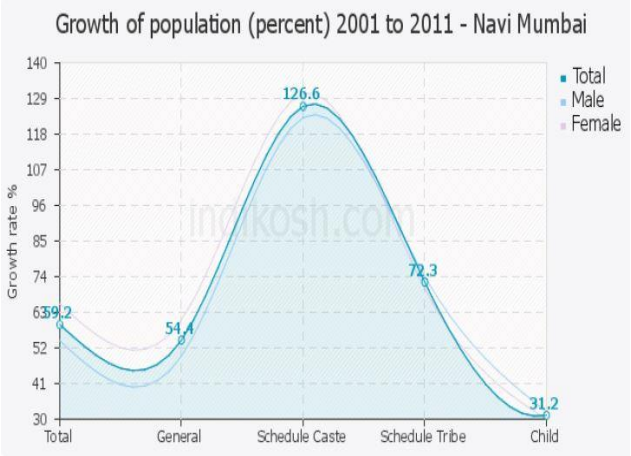


Fig:1 Population Growth(%) 2001 to 2011

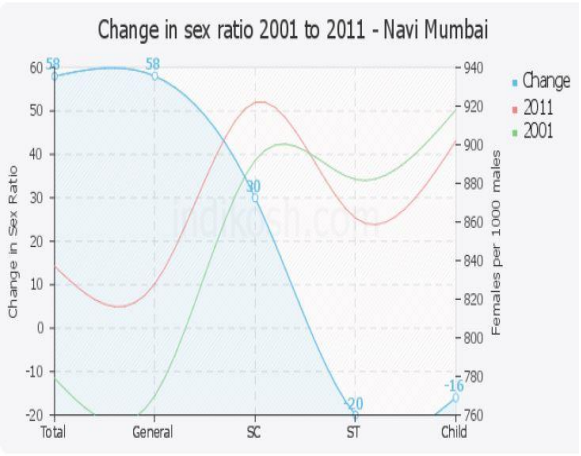


Fig:2 Change in Sex Ratio 2001 to 2010

In Indian cities, rapid development and great concentration of people in high rise office and residential buildings has put tremendous pressure on the pedestrian network. For that allowing vehicles and pedestrians to share the roadway environment safely and efficiently is not an easy task. The characteristics of both modes of travel vastly different, and yet, they complete for use of the same street and highway space. Hence there is an urgent need exists to establish guidelines for road design that would be apply where pedestrians represent the primarily mode of traffic. The traffic on Indian roads is highly heterogeneous and because of this the pedestrians experienced several types of frictions while walking like roadside development, on-street parking, encroachment of venders and vehicle movements etc. To solve of all these problems there is a requirement to study pedestrian free flow characteristics across the different types of sidewalk widths which can be more applicable in the developing countries like India. A simplified body ellipse of 0.50 m X 0.60 m, with total area of 0.30 $m^2$is used as a basic space for single pedestrian.

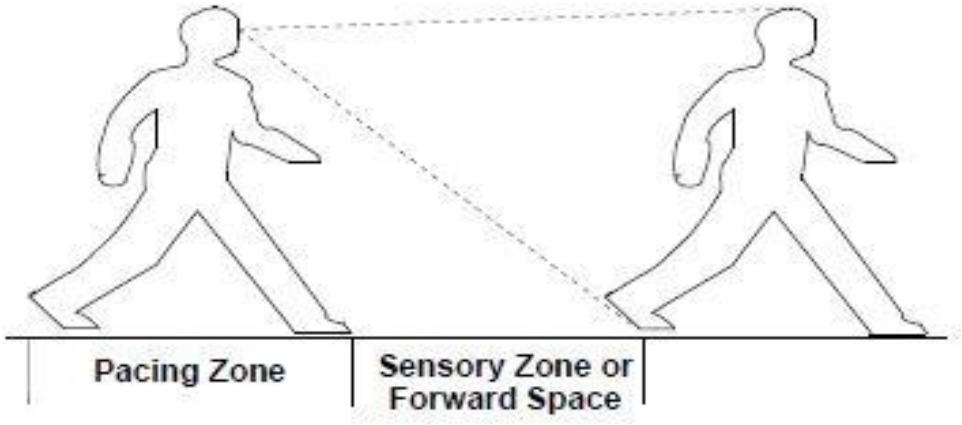


Fig: 3 Walking Characteristics of pedestrian

The primary objectives of this study are: (i) to evaluate free-flow walking speeds on different sidewalk widths. (ii) To develop the relationship between pedestrian speed and flow and compare the developed speed and flow relationship with available literatures. (iii) The study results compared with the studies conducted across the India &world.

LITERATURE REVIEW: To illustrate the robustness of pedestrian characteristics, it is important to explore the current state of researches. The past research shows that wide range of micro-level analysis on pedestrian studies.

Fruin (1971) shows by analytically that the pedestrian speed is directly related to the density and found to be varying as per conditions. He discovered that a normal pedestrian speed varies in the range of 0.76 to 1.76 m/sec. He observed that walking speeds decline with age, particularly after age 65, but healthy older adults are capable of increasing their walking speed by 40 % for short distance. On the other hand pedestrian walking speeds are not affected with baggage carrying capacity and male pedestrians are walks faster than female pedestrians.

Koushki (1989) studied the physical and social characteristics in Riyadh, Saudi Arabia. He conducted series of OD (origin-destination) surveys and pedestrian speed studies and he found that that Riyadh's pedestrians walk significantly longer distance at lower speeds when compared to their counterparts in the cities of Western developed nations. A female pedestrian walks considerably longer distance than male pedestrians.

Polus (1983) studied the properties and characteristics of pedestrian flow on sidewalk in Haifa, Israel. He found that men pedestrian walking speeds were significantly greater than female pedestrians and speeds were inversely proportional to densities. After studying one and three regime linear speed-density regression models, he suggest that, for understanding pedestrian flow and defining level of service, the three-regime model is more realistic.

Tanaboriboon (1986) the study was conducted speed studies in concentrated areas and develop relationship between walking speed, flow and density and compared with the countries like United States, Singapore and Britain, he found that maximum flow rate in Singapore, that was 89 Ped/m/min and walking speed found to be 74 m/min which is higher than U.S. and Britain but slower than America counterparts.

Virkler and Elayadath (1994) examined seven models to establish pedestrian speed-flow-density relationship in Columbai, Massouri. Each model performance were described both by results of statistical tests and visual examination of plotted curves and Edie model observed to be the best suitable for two distinct regime conditions. The free flow speeds predicted by the models ranging from 54 to 64 m/min and optimum densities was ranged from 1.59 ped/m2 to 1.89 ped/m2. The highest recorded density was 3.149 pes/m2, but at this density flow was not zero.

Tanaboriboon&Guyano (1989) develop a set of LOS criteria for planning pedestrian walkways in Bangkok and to compare these criteria with those based on Western standards with the help of portable camera in Bangkok. They measures performance of each on the scale of A to F, with A representing the best and F the worst. The speed-flow-density relationship were analyzed found that the linear model represented the best fit between speed and density relationship. The maximum flow obtained in Thailand is about101 ped/m/min, which is higher than the maximum flow obtained in the U.S.

Lam (2000) observed pedestrian flow characteristics for different types of walking facilities in Hong Kong. They studied walking speeds of both indoor and outdoor walkways and results shows that pedestrians tend to walk faster on outdoor walkways than of

indoor walkways because of environmental situations present in the Hong Kong. The results also shows that, walking speeds on various facilities, the pedestrian flow characteristics in Mass Transit Railway (MTR) and Kowloon-Canton Railway (KCR) stations was similar. The established relationship can be further used by development of simulation models for Hong Kong of other Asian cities with similar pedestrian characteristics.

Rehman (2012) studied the pedestrian movement on sidewalks in capital city of Dhaka, Bangladesh. The data were collected from observed 1440 pedestrians by video recordings to determine the free flow walking speed and to identifying contributing factors. The analysis shows that the free flow walking speed greatly affected by pedestrian age, gender and provided walking facility for pedestrians. The observed overall free flow walking speed was 1.15 m/sec. It also found that for Dhaka the design of sidewalk value covers the walking speed of 0.70 m/sec to facilitate slower pedestrians. Female pedestrians were found to be walk slower than male pedestrians nearly by 0.17 m/sec. Pedestrian free flow mean walking speed in Bangladesh found to be 1.20 m/sec, but less than 1.50 m/sec as mentioned in Highway capacity Manual (HCM 2000).

Kotkar (2010) analyzed pedestrian flow characteristics under mixed traffic conditions at four locations in medium sized city of India. They develop mathematically and graphically the relationship between speed and volume, speed and density flow and area module. They found that pedestrian free flow speed was more than 80 m/min at all four locations. The study also shows that if level of friction under mixed traffic condition is directly proportional to pedestrians speed. Under the higher level of friction and lesser roadway width increases density of pedestrians movements. The free flow speed observed in this study is higher than those reported in Britain, Singapore and China, but slightly lesser than Germany.

Rastogi (2011) studied pedestrian walking speeds on three different walking facilities in eighteen locations in Indian. They describe these facilities as sidewalks, wide-sidewalks and precincts. The pedestrian walking speeds were decreases with increases in age, group size and any additional activity. A young adult walks faster than older pedestrians while considering all three facilities. According to type of facility higher group sizes causes high reduction of walking speeds.

Parida (2008) developed a methodology assessing the quality of service offered by any sidewalk with the five point rating scale. This rating scale was based on attributes like surface, obstruction, encroachment, vehicle conflict and continuity. This method used for grading a pedestrian facility in terms of safety index.

DATA COLLECTION LOCATIONS AND METHODOLOGY:

Study location:

The study sites were selected in Navi Mumbai, India. The total population of the city is 1.119 million. Surveys were carried out in month of August, 2018 after sufficient favorableweather condition. For the purpose of this study basic data were collected on pedestrians travel time, pedestrian flow and physical dimensions of surveyed sections/areas by a photographic procedure of video recording with prior carried out pilot study. All two locations in Navi Mumbai, India were selected for the same. This all locations were selected in such a way that there should not be any obstructions due to bus stops or shops, study site should be clearly visible and straight, the pedestrian flow should be maximum, sidewalk is uniform width with good paved surface. The locations of sidewalk with its physical characteristics are given in table 1.

Table 1.Locations of Sidewalk

Location Number	Location Description	Length (m)	Width (m)
1	Khandeshwar Railway Station Premises, Kamothe	10	2.5
2	Hiranandani Near 3-Star, Kharghar	10	7.5

DATA COLLECTION:

Data were collected by a photographic procedure of video recordingthrough CCTV Servileance cameras already installed in CIDCO's jurisdictions nodal area of Navi Mumbai. The video recorded in a way to capture the normal walking conditions of each pedestrian along the selected stretch. A longitudinal trap of 10 m length was made on the road for measurement of walking speed. The data for movements in both the directions were collected during morning and evening pick periods of day. The walking speeds of pedestrians are manually extracted from the recorded videos in the following steps:

1. A random pedestrian about to enter the trap is selected, and the time taken by the pedestrian to cross the length of the section was noted to the accuracy of 0.01 s.
2. The walking speeds of pedestrians are estimated as a ratio of the known length of the trap and the time taken by the pedestrian to cross the trap length.

The pedestrian flow was obtained by counting the number of pedestrians passing through the marked line of the observed location within the time interval.

From the recorded video all necessary information is extracted like Personal characteristics of pedestrians, such as age and gender, and associative activities such as carrying of baggage, talking on cell phone while walking, and movements in groups of different sizes were noted down by manually. The age was judged from the face value of the pedestrian. It is obvious that it was impossible to calculate the exact age of the pedestrian on the ground we split it into four age groups: 0-14 years, 15-30 years, 31-55 years and > 55 years. Despite this distinction but while extraction of data it depends upon an individual how he perceive the age group. The advantages of the present technique are that the data can be analyzed for longer time periods covering a wider range of

pedestrians; because the camera is hidden, the normal walking behavior of the pedestrians can be observed and the record of pedestrian movement and behavior is permanent.

Table 2. Mean walking speed

Location	**I**	**II**
Time of Survey	Morning (8:40 to 10:00)	Morning (9:30 to 10:00) Evening (5:00 to 6:15)
No. of samples	500	510
Direction	Two	Two
Crossing type	Walk	Walk
Pedestrian Behavior	Mostly single/ two	Mostly single/ two

(a) Location I **(b) Location II**

Fig: 4 Survey Locations in Navi Mumbai

DATA ANALYSIS AND RESULTS:

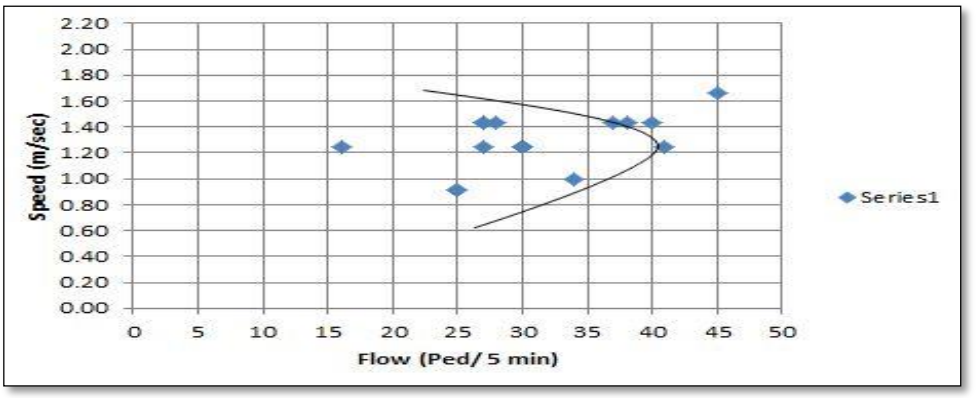
Pedestrian speed studies:

Empirical observations, similar to that illustrate in literature were taken of pedestrian movements on different widths of sidewalks. Observations were made for all four selected locations. Analyses of these observations were done and mean walking speeds of pedestrians according to gender were calculated for all listed locations. The walking speeds of male pedestrians is found to be 120 m/min in all locations, but the mean walking speeds of female pedestrian is found to be 100 m/min. It was found that the Navi Mumbai male pedestrians generally walk faster than females. These speeds are given in table 3.

Table 3. Mean walking speed of Pedestrian

Gender	**Mean Walking Speed (m/min)**	
	Location I	**Location II**
Male	79.6 m/min	74.3 m/min
Female	73.6 m/min	72.7 m/min

Walking speeds of pedestrians with respect to different characteristics such as age groups, with baggage and without baggage and grou determined from the face value of pedestrian from the recorded video. In this study only three different age groups were considered for this as young age (15-30 years), middle age (31-55 years), and elderly (above 55 years). The children category was not considered in this analy variation is observed in walking speeds. The variation of speeds with age can help in the design of specific facilities, e.g., near schools and and recreational facilities. As expected, the speed of the elderly pedestrians speed found to be lowest in the study.



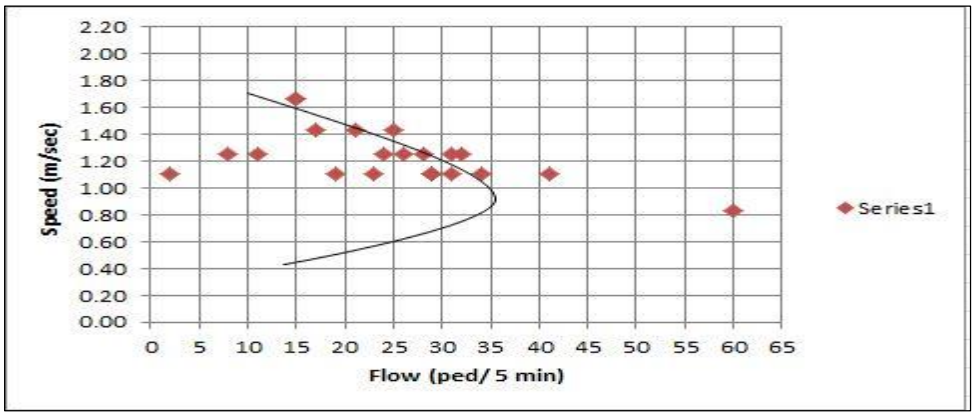


Figure 5. Pedestrian Speed-Flow relationship at Location I &II

These pedestrians are less affecting to the mean walking speed of pedestrians and because of this reason these categories are not considered for any analysis in this study. After analyzing the total categories in the walking speeds on the sidewalk, the speed of total flow distribution of pedestrian walking on sidewalk is calculated and it found that it follows the normal distribution curve. The values are tabulated in table 4

Table 4. Pedestrian values at each location

Location Number	Location Description	Maximum speed (m/min)	Minimum Speed (m/min)	Average Speed (m/min)
1	Khandeshwar Railway Station Premises, Kamothe	120	50	79.6
2	Hiranandani Near 3-Star, Kharghar	120	50	74.3

The speed and flow data collected in all location was used to model the relationship among them and to plot the graphs. The average speed is found to be more than 70 m/ min. The study was conducted in areas where flow was bidirectional. The cross flows at selected site is not considered for analysis. Curves were plotted between speed and flow. These are presented in Figure 5.The scattered plot of data points are plotted on graph which suggested that the points are follow a same kind of trend line between speed and flow. It is also observed that the scattered plot follow same plot pattern up to specific volume that was mentioned by Lam (2000).

DISCUSSION ON RESULTS:

The present study represent similar characteristic those reported in literature reviews. The free-flow pedestrian speeds are found to be more than 70 m/min at all the two locations. Surprisingly these speeds are highest at the location I, around 79.6 m/min. The width of sidewalk for this location I is 2.5 m. At this location the side friction is not present due to any of the unfavorable conditions and also another reason is flow on the sidewalk is less, so friction among the pedestrians is very less. Due to high traffic on road the pedestrians are forced to walk on the sidewalk.At the location II it is also observed that the width of sidewalk is 7.5 m because of this reason pedestrians are free to walk on the sidewalk&thousagarage speed is reduced to 74.3 m/min. Comparison with other studies the speeds reported is nearer to observed in Delhi, Madras, Chandigarh India and higher than observed in cities like Roorkee and Mumbai, India.

Table 5. Walking Speed observed in various studies.

Locality, Country	Author	Mean speed (m/min)
Pittsburgh United States	Hole (1968)	88.00
London, England	Older (1968)	79.00
Colombia, United States	Navin And Wheeler (1969)	79.00
New York, United States	Fruin (1971)	81.00
Haifa, Israel	Polus (1983)	79.00
India, Delhi	Gupta (1986)	72.00
India, Madras	Victor (1989)	72.00
India, Roorkee	Laxman (2010)	88.00
India, Chandigarh	Rastori (2011)	71.22
India, Mumbai	Vedagiri (2011)	82.47

Table 6. Walking speeds for different pedestrians

Locality, Country	Mean walking speed (m/min)			
	Men	Women	Young	Elder
Colombo	81.00	78.00	-	72.00
Calgary	86.00	81.00	-	-
Singapore	79.00	69.00	76.00	54.00
Riyadh	70.00	53.00	-	-
Bangkok	76.00	70.00	74.00	50.00
Roorkee	78.00	70.10	80.90	68.40
Chandigarh	70.36	69.07	82.38	56.19
Dhaka	74.40	64.20	75.60	62.40

CONCLUSION:

The free-flow speed is found to be more than 70 m/min (1.17 m/sec). Speeds are highest at the location I, around 120 m/min (2 m/sec) with sidewalk width is 2.5 m. Free-flow speeds are found to be less at location I, around 79.6 m/min(1.33 m/sec) with sidewalk width 2.5 m. Comparison with other studies the speeds reported is nearer to observed in Delhi, Madras, Chandigarh India and higher than observed in cities like Roorkee and Mumbai, India.

Mean walking speeds are less than those observed worldwide studies conducted like London, Colombia, New York, Bangkok, Dhaka etc.The present study analyzed the pedestrian flow characteristics in New Mumbai, India & found to be comparable to those observed globally.

The maximum walking free-flow speed observed in this study is 120 m/min & this speed is comparable with past studies conducted in India. The present study also finds that male pedestrians walk faster than females. Significant variation was observed in pedestrian mean speed with age, gender, groups. Pedestrian speed-flow relationship is formulated & it observed to satisfactory. The results are same as mentioned by Lam (2000). There is a need to enhance this relationship based on model proposed by researchers like Greenshild, Edie & Greenburg etc.

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