

A STUDY ON PEDESTRIAN FLOW CHARACTERISTICS FOR SELECTED WALKWAYS IN KHULNA METROPOLITAN AREA, BANGLADESH

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ABSTRACT

Walking infrastructures need to be properly assessed as walking is the most common mode of transportation and related to pedestrian flow, speed and density. This study dealt with the examination and investigation of the characteristics and services requirements of pedestrian facilities in Khulna Metropolitan city, Bangladesh. The pedestrian walking data were collected at five locations in Khulna are analyzed for pedestrians flow characteristics under mixed traffic conditions. The data are presented in the form of mathematical and graphical relationships between speed and volume, speed and density, flow and area module and flow and density. The results of the analysis are compared with those given in the literature. The analysis indicates that the pedestrian free flow speed is high on sidewalks (58.81m/min) and low on precincts (46.89m/min). The free-flow speed of pedestrians is observed to be 58.41m/min which is lower than that reported for western countries. The speed was found to be influenced by the age and gender. Male pedestrians move faster than female pedestrians. Pedestrians in the age group of 15-50 years had the highest speed, 59.72 m/min. The increase in width of the facility resulted in increased space available to a pedestrian, but reduced maximum flow rate and optimum density. Models on speed-density-flow relationships were calibrated and evaluated the maximum flow and the corresponding critical area occupancy was determined on walkways. Level of services (LOS) standards were proposed based on these analysis, which could be used as criteria in the planning of pedestrian walkways.

Keywords: Speed; Density; Sidewalk; Pedestrian; Flow characteristic.

1. INTRODUCTION

Walking is the most common mode of transportation. A study conducted in India observed that 64.7% trips were made on foot (Arasan et al. 1994). Walking speed along with other pedestrian characteristics need to be studied, where pedestrian must be able to walk safely and conveniently on walkway. It is known that insufficient crossing time at crosswalk affect traffic movement as well as creating safety problems among pedestrians (TRB, 2000). As such a study on pedestrian characteristics in Khulna Metropolitan City was carried out. The results of this study may be useful to the planners and design a more efficient, adequate and safer pedestrian facilities. This paper examines the pedestrians' movements and flow characteristics on different types of facilities and under varying prevailing conditions. Findings are compared with those reported in literature to ascertain the cultural effects. In view of the above, important research works are discussed in the next section. It is followed by the section on methodology adopted for this research, flow relationships and characteristics, flow characteristics under varying conditions and finally the conclusions. The objectives of this study is to examine the characteristics and service requirements of pedestrian and pedestrian facilities in Khulna Metropolitan City, Bangladesh. The specific objectives are to conduct the speed studies of pedestrians in Khulna Metropolitan City in different traffic conditions, to establish the relationship among speed, flow, density and area module of pedestrian on walkways, to compare the space occupied by a pedestrian and the

minimum space required for comfortable walking & to develop the level of service (LOS) design standards for walkways.

This study is an attempt to investigate the characteristics of pedestrian and its facilities in Khulna Metropolitan City under mixed traffic conditions. Due to inadequate exclusive facilities available for their movement, there exist a constant conflict between the pedestrian and the vehicle. In the city, inadequate sidewalk space spills pedestrians into the road. These sidewalks must be wide enough to accommodate prevalent pedestrian volumes (Polus et al. 1983). The results of this study may be useful to the planners and designers to design a more efficient, adequate and safer pedestrian facilities in Khulna Metropolitan City. This study was done only for pedestrians in walkways.

2. METHODOLOGY

A photographic technique was employed to collect all the data on pedestrian characteristics in Khulna Metropolitan City, Bangladesh. Khulna has a population of 1.5 million (2011 census) and density of 67,994 persons/km². Video-graphic technique was employed for collecting the pedestrian data. A trap of known length was marked on the pedestrian facility using a self-adhesive white tape for measuring the pedestrian speed and flow. The video camera was kept at an elevated point so as to cover the pedestrian movement on the entire trap. The movements of pedestrians were recorded during the morning and evening peak periods (8.30 – 9.30 A.M, and 5.00 – 6.00 P.M) on a working day at each of the study locations. The required pedestrian data were later extracted from the recorded videos. Looking at the continuous flow of pedestrians entering the trap the flow data was extracted on one minute basis though under fluctuating flows lower value of time interval would be more appropriate. The time taken by each pedestrian to cross the trap length was noted to an accuracy of 0.01s to determine pedestrian speed. Based on the pedestrian flow pedestrian density per square meter is calculated. The inverse of pedestrian density yielded the area module. These were found for the entire study duration. The sample size for the classified 5 study locations is given in Table 1.

2.1 Data Collection

Data were collected in the concentrated areas such as sidewalks along the main street at Majid Sharani, Shib Bari Mor and K. D. Ghos road, Hadis Park Mor in Khulna Metropolitan City, Bangladesh. Data of precinct were collected in front of New Market and Safe N Save. Data of Dakbangla Mor was collected as highly restricted side walk. Site descriptions and dimensions of the study areas on walkways are presented in Table-1. The surveys were conducted during both peak and off-peak periods.

Table 1: Description and Dimensions of Observation Sites & Dimensions on Walkways

Site No.	Observations Sites (Khulna, Bangladesh)	Length)m(Effective Width)m(Sample size, pedestrians
1.	Majid Sharani, Shib Bari Mor)Sidewalk, in front of City Inn Hotel)	10	1.1	281
2.	K. D. Ghos Road, Hadis Park Mor)Sidewalk, in front of Nagar Bhaban(10	2.1	250
3.	New Market (Precinct, in front of gate no. 1)	10	6.6	317
4.	Safe N Save, Daulatpur (Precinct, in front of gate)	10	7.1	253
5.	Clay Road, Dakbangla Mor (Highly restricted Sidewalk)	10	2.45	521

2.2 Data Processing

The processing of data was carried out by video S player and a monitor. All timing were counted in seconds using the timer installed on the screen of the monitor.

2.3 Method of Analysis

2.3.1 Speed Measurement

Speed is defined as the rate of movement of pedestrians, thus the basic data needed are distance and time. Pedestrian walking speed was calculated by dividing the length or the areas traversed by the time the pedestrian crossed the mark-off area. In this study, the time taken by a pedestrian to traverse the length was measured directly from the timer shown in the recording. Observation were conducted on walkways both in bi-directional direction

2.3.1.1 Pedestrian Classification

In this analysis of the data, pedestrians were classified on the basis of age and gender as these variables seemed to have an effect on pedestrian walking speed. Age was categorized as Adult, Young and Elderly. Young pedestrians observed were from secondary school students .Elderly pedestrians were those pedestrians who appeared to be over 50 years old and were chosen subjectively on the screen of the monitor.

Children (CH)	= Below 15 Years
Adult (AD)	= 15- 50 Years
Elderly/Older (Old)	= over 50 years

Other than age, gender was also classified as to male and female. Significant difference between male and female pedestrians among age group was analysed. The data gathered on walkways were entered in the computer by using Microsoft EXCEL software then statistical analysis was conducted by using a statistical software “SPSS”.

2.3.2 Pedestrian Speed –Density –Flow Measurement

The pedestrian data for the analysis were collected using video graphic technique. A longitudinal trap of 10 m was made on the road by self-adhesive white tape for measurement of density and speed. The camera was mounted at an elevated place so as to cover the entire test section as detailed above. The data for movements in both the directions were collected during morning and evening periods for about 2 hours on a typical weekday. The recorded film was replayed in laboratory to extract the desired information. The number of pedestrians passing through the first line of the test trap in 1 min provided the information on pedestrian flow. For the purpose of speed measurement, 4–5 pedestrians were randomly chosen out of the total count in one minute and the time taken by them to cross the trap length was noted to the accuracy of 0.1 s. The film was paused to determine the density. The pedestrians in the trap length were also counted. All these measurements were made in 1-m width of the test trap. Variation in speed with respect to pedestrian's personal characteristics like age and gender, and flow conditions like individual movement or platoon movement was also analysed. Speed of pedestrians carrying baggage was studied separately.

The data obtained from all study sites were combined to find the relationships between speed, flow and area module. This is done based on the assumption that the pedestrian characteristics at all sites are the same.

2.3.2.1 Regression Analysis

According to Fruin's (1971) model, general forms of speed-flow-density relationships are

$$\text{Speed-Density Relationship, } u = a - bk \quad (1)$$

$$\text{Flow-Speed Relationship, } q = u(a-u)/b \quad (2)$$

$$\text{Flow-Density Relationship, } q = ak - bk^2 \quad (3)$$

$$\text{Flow-Area Module Relationship, } q = a/M - b/M^2 \quad (4)$$

Regression analysis was used to determine the model that best fitted the data on speed and density relationship and parameters ‘a’ and ‘b’ were evaluated. A simple regression was analysed by using a statistical software “SPSS”

3. SPEED STUDY

3.1 Pedestrian Walking Speed

Speeds reported in this section are the mean walking speeds of pedestrians crossing the area, measured. The traffic density is high and conflicts between pedestrians are huge in amount. This is under a free flow condition in which pedestrians select their desired walking speeds. It was found that the overall average walking speed of the Bangladeshi pedestrians in Khulna at three selected study sites was 58.41 m/min.

Further analysis on the classification by gender, showed that Bangladeshi male generally walked slightly faster than the female pedestrians with their walking speed of 69.57 m/min and 53.57 m/min, respectively. Table 2 shows the summary of results of pedestrian walking speeds. On the other hand, pedestrian speed varies very little than that of old and child pedestrian walking speed. Evaluation for pedestrian speed in Khulna Metropolitan City, shown in Table 2. The values of highest speed for male pedestrian is 85.7 m/min whereas 75 m/min for female pedestrian. On the other hand, lowest speed of male and female pedestrian is 33.33 m/min and 31.58 m/min.

Table 2: Walking Speeds of Pedestrians on Walkways, Khulna, Bangladesh

M=Male; F=Female; C=Combined

Characteristics	Child (0-15 Years)			Adult (15-50 Years)			Elderly >50 Years		
	M	F	C	M	F	C	M	F	C
Mean speed (m/min)	53.73	44.44	50	62.01	51.4	59.72	48.91	43.9	46.15
Range	High	82.76	70.59	82.76	85.71	77.42	85.71	72.73	68.57
	Low	36.36	32.43	32.43	41.38	33.33	33.33	34.29	30.77
Sample Size (pedestrians)	150			1375			90		

Referring to Table 2, the mean walking speeds of young and adult pedestrians were 50 m/min and 59.72 m/min, respectively. The value of combined speed for Child, adult and elderly pedestrian were not vary more than 5 % compared to male and female, respectively.

3.2 Levels of Service Standards on Walkways

Fruin (1971) defined six levels of service for walkways in a somewhat similar manner to the levels of service for vehicular flow in the Highway Capacity Manual (TRB, 2000). As in the Capacity Manual, levels of service range from A, representing free movement, to F, representing breakdown flow. Level of Service E refers to the capacity or maximum flow

condition. Criterion are given in terms of pedestrian modules (M), or the number of m²/ped necessary to give the desired level of service. Unlike the HCM, where vehicle levels are defined by speed and volume, pedestrian levels are defined in terms of the inverse of density (number of pedestrians per square m). To a great extent, the Highway Capacity Manual (TRB, 2000) adopted Fruin's concepts in the identification of pedestrians levels of service on walkways as shown in the Table 3 at which range of values are expressed both in imperial and metric units.

Table 3: Pedestrian Level of Service Standards for Walkways

Level of Service	Space (M) Area per Person		Flow Rate Person/Minute		Normal Walking Speed	Reverse Flow	Cross Flow	Volume Capacity Ratio (v/c)
	SQ FT	SQ M	PER FT	PER M				
A	≥40	≥3.72	<7	<23	F	F	F	<0.08
B	25-40	2.3-3.7	7-10	23-33	F	F	R	<0.28
C	15-25	1.4-2.3	10-15	33-50	F	R	R	<0.40
D	10-15	0.9-1.4	15-20	50-66	F	R	S	<0.60
E	5-10	0.46-0.9	20-25	66-82	R	S	S	<1.00
F	<5	<0.46	25	82	S	S	S	

Note: F = relatively free, minimum of restrictions or inconvenience

R = restricted, higher probabilities of conflict and inconvenience

S = severely restricted

Source: Highway Capacity Manual (HCM), (TRB, 2000)

Level of service standards for walkways are described below and summarized in Table 4. Pedestrian flow and area module relationship is to aid in visualizing the pedestrian concentrations at the various levels of service of walkways.

Table 4: Proposed Pedestrian Levels of Service Standards Walkways in Khulna Metropolitan City, Bangladesh

Levels of Service	Space (M) Area per Pedestrian(Square Meter)	Flow Rate, Ped/m/min
A	3.7 or greater	23 or less
B	2.3-3.7	23-33
C	1.4-2.3	33-50
D	0.9-1.4	50-66
E	0.46-0.9	66-82
F	0.46 or less	85 or variable

Level of service A

At level of service a pedestrians can freely select their walking speed and basically move in desired paths without altering their movements in response to other pedestrians. Conflicts between pedestrians are unlikely.

Level of service B

At this level, pedestrian begin to be more aware of other pedestrians and respond to their presence in the selection of walking path.

Level of service C

At this level sufficient space is available to select normal walking speeds and to bypass other pedestrians in primarily unidirectional streams. Where pedestrian cross movements and reverse flows exist, minor conflicts will occur, slightly lowering mean pedestrian speeds and potential volumes.

Level of service D

Freedom to select individual walking speed and to freely pass other pedestrians is restricted. Where pedestrian crossing or reverse-flow movement exist, there is a high probability of conflict and to avoid contact with other pedestrians require frequent adjustment of speed and direction. However considerable friction and interaction between pedestrians is likely to occur.

Level of service E

Virtually all pedestrians have their normal walking speed restricted, requiring frequent adjustment at gait. At the lower range of this LOS, forward progress is only possible by "shuffling". Area is insufficient for passing slow moving pedestrian. Design volumes approach the limit of walkway capacity, resulting stoppages interruptions to flow.

Level of service F

All pedestrian walking speeds are severely restricted and forward progress is made only by "shuffling". Unavoidable contacts with other pedestrian are frequent. Cross and reverse flow movement are virtually impossible. Flow is sporadic and unstable where movement is based on those in front. Space is more characteristic of queued pedestrians than of moving pedestrian streams.

3.3 Speed-Density-Flow Relationships on Walkways

It was found in the analysis, that the relationship between speed and density can be assumed linear. The relationship is given by the following equation:

$$u = 73.629 - 67.319k \quad (5)$$

Where u is speed expressed in m/min and k as density expressed in ped/m².

Consequently, from the linear relationship, speed and flow as well as flow density relationships are formulated, respectively as follows:

$$q = u(73.629 - u) / 67.319 \quad (6)$$

$$q = 73.629k - 67.319k^2 \quad (7)$$

In flow and density relationship, density is expressed in terms of area module M ; then

$$q = 73.629/M - 67.319/M^2 \quad (8)$$

Where, M is expressed in m²/ped.

These relationships among speed, density, flow and area module also presented in Figure 1 to 4.

The linear model represented the best fit between speed and density relationship and was calibrated in terms of correlation coefficient and other statistical parameters. Parameter "a" From model equation (Equation 5) which is the free flow speed was found to be 73.629 m/min. From Figure 1 it can be seen that as pedestrian speed declined, density increased to a maximum of 1 ped/m² where no movement occurred at a level often called as jam density.

Figure 2 and Figure 3 shows the curves derived from model equation (Equation 7 and 8) indicating the rise to a maximum and subsequent fall in the flow levels. The maximum flow was approximately 74 ped/m/min and occurred when the space was about 0.45 m²/ped. Similarly the reciprocal of pedestrian density, M (m²/ped) was used for convenience in visualizing relative levels of pedestrian freedom as shown in Figure 4. The curve confirms the normal human walking speed requires significant amount of pedestrian area, and that crowding causes restricted human locomotion.

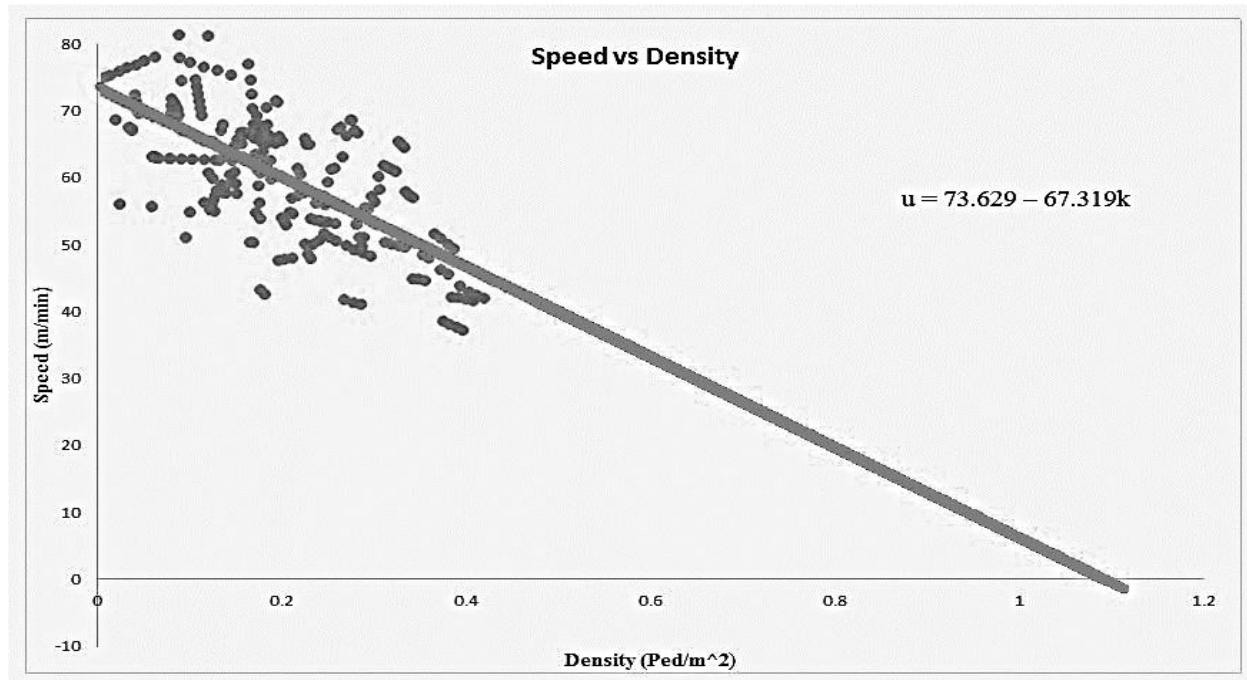


Figure 1 : Speed and Density Relationship for Walkways in Khulna, Bangladesh

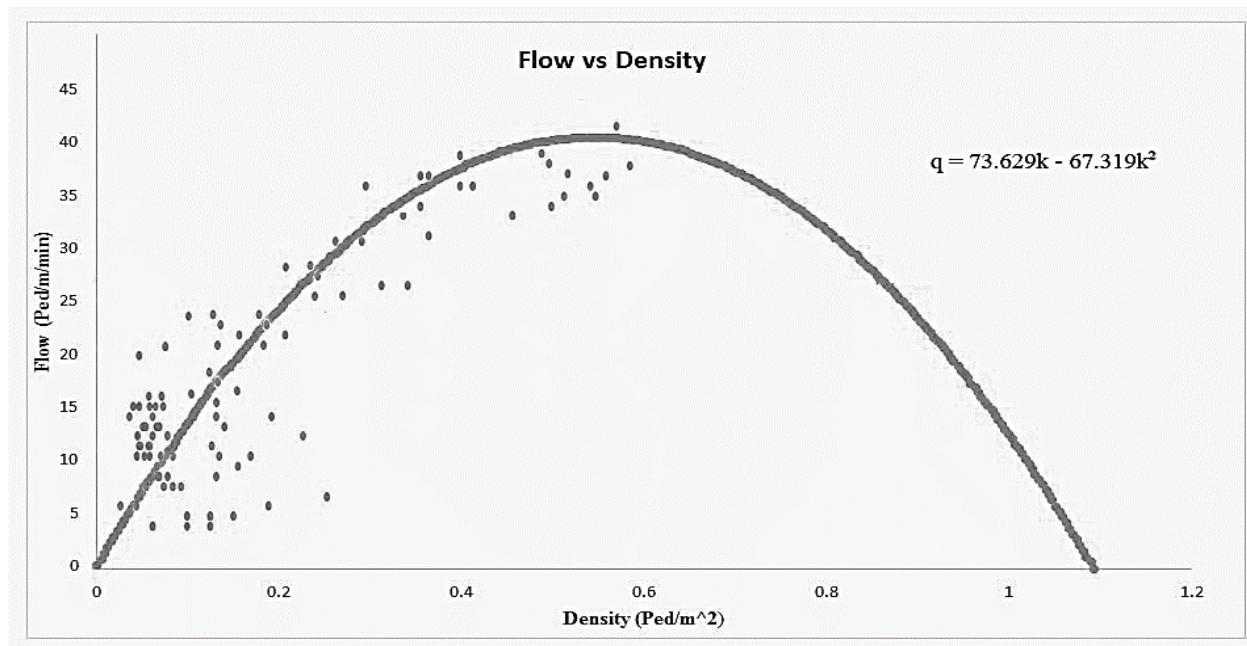


Figure 2 : Flow and Density Relationship for Walkways in Khulna, Bangladesh

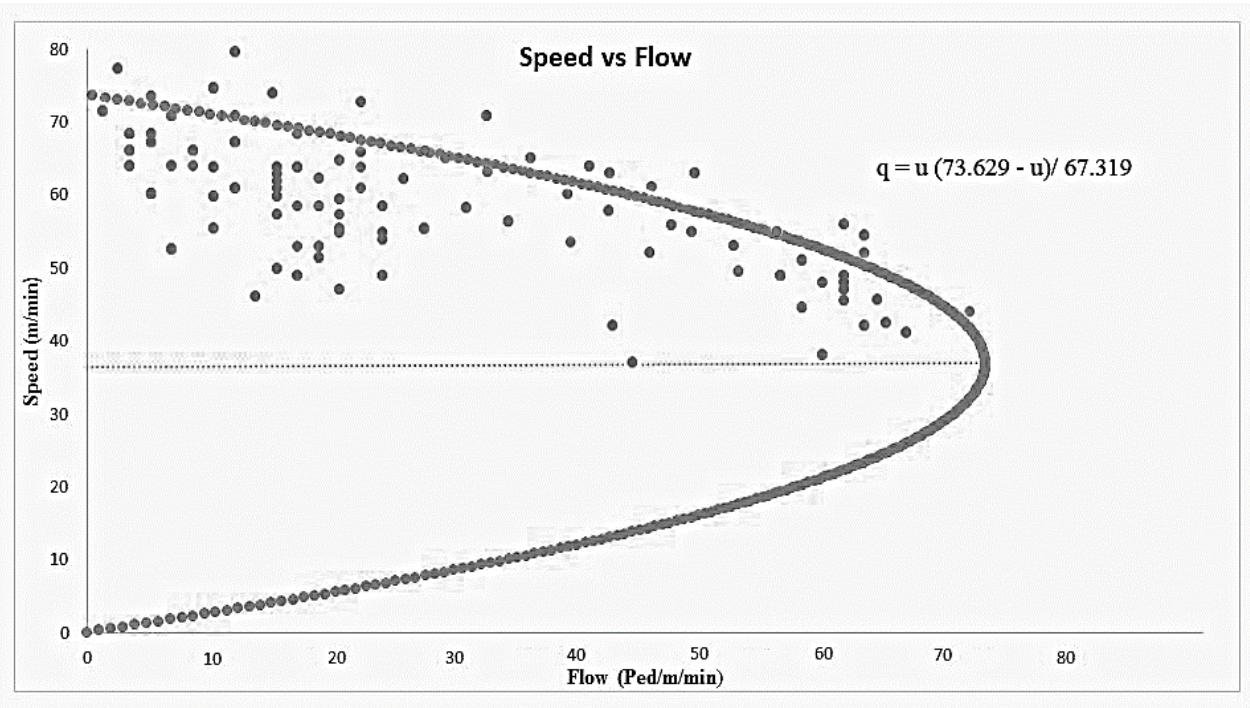


Figure 3: Flow and Speed Relationship for Walkways in Khulna, Bangladesh

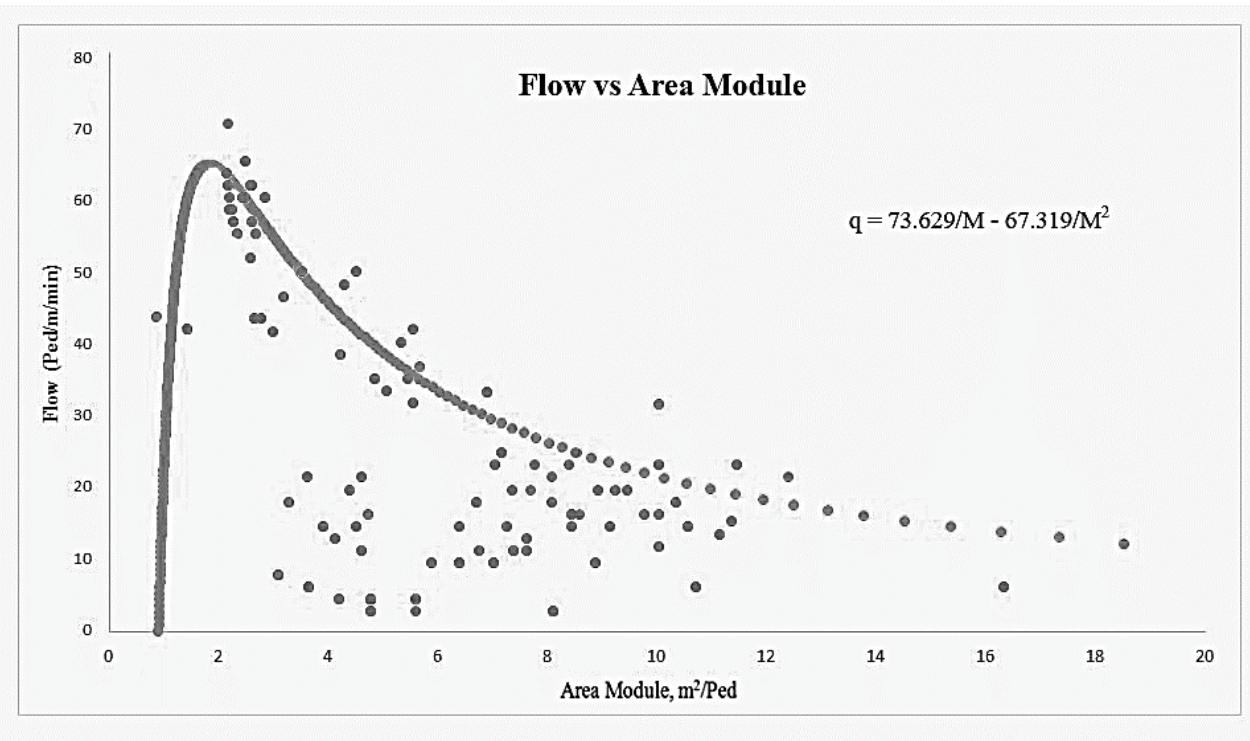


Figure 4: Flow and Area Module Relationship for Walkways in Khulna, Bangladesh

4. RESULT AND DISCUSSION

4.1 Pedestrian Flow Relation for Classified Conditions

Before estimating various flow characteristics for pedestrians at different selected locations, the locations which are found similar (based on pedestrian flow conditions and width of the facility) have been clubbed together. Data the locations are combined under the heads sidewalk, restricted sidewalk and precinct and the flow characteristics like pedestrian flow, speed, density and area module are estimated.

Table 5: Sample size for classified conditions

Classification	locations	Effective Width (m)	Pedestrian number	Total number of Pedestrians
Sidewalk	Majid Sharani, Shib Bari Mor	1.1	281	531
	K. D. Ghos Road, Hadis Park Mor	2.1	250	
Precinct	New Market (In front of gate no. 1)	6.6	317	570
	Safe N Save, Daulatpur (In front of gate)	7.1	253	
Highly restricted sidewalk	Clay Road, Dakbangla Mor	2.45	521	521
				1615

A single-regime approach is used to ascertain the relationship between speed and density due to constraints of the data points. Various distributions like linear, logarithmic, power, polynomial, exponential, etc. are considered to arrive at the best fit distribution. Once this is ascertained, the mutual relationships between flow, density and speed are derived theoretically and their goodness of fit is examined based on data plot and statistical parameters like R². The goodness-of-fit statistics are calculated for the observed range of the data.

Table 6: Relationships between pedestrian flow characteristics

Relation	Value of parameters		Model equation	R ² value
	a	b		
Sidewalks	Speed-Density (u-k)		$u = 74.281 - 86.937k$	
	Flow-speed (q-u)		$q = u (74.281 - u)/86.937$	
	74.281	86.937	$q = 74.281k - 86.937k^2$	0.7424
	Flow-density (q-k)		$q = 74.281/M - 86.937/M^2$	
Precincts	Speed-Density (u-k)		$u = 64.464 - 129.99k$	
	Flow-speed (q-u)		$q = u (64.464 - u)/129.99$	
	64.464	129.99	$q = 64.464k - 129.99k^2$	0.0304
	Flow-density (q-k)		$q = 64.464/M - 129.99/M^2$	
Highly Restricted Sidewalks	Speed-Density (u-k)	75.607	92.877	$u = 75.607 - 92.877k$ 0.6017

	Flow-speed (q-u)	$q = u (75.607 - u) / 92.877$
	Flow-density (q-k)	$q = 75.607k - 92.877k^2$
	Flow-area (q-M)	$q = 75.607/M - 92.877/M^2$
	Speed-Density (u-q)	$u = 73.629 - 67.319k$ 0.4279
Combination of all kind of facilities	Flow-speed (q-u)	$q = u (73.629 - u) / 67.319$ 0.5195
	Flow-density (q-k)	$q = 73.629k - 67.319k^2$ 0.7058
	Flow-area (q-M)	$q = 73.629/M - 67.319/M^2$ 0.8570

The flow relationships developed for different types of pedestrian facilities are shown in Figure 5.

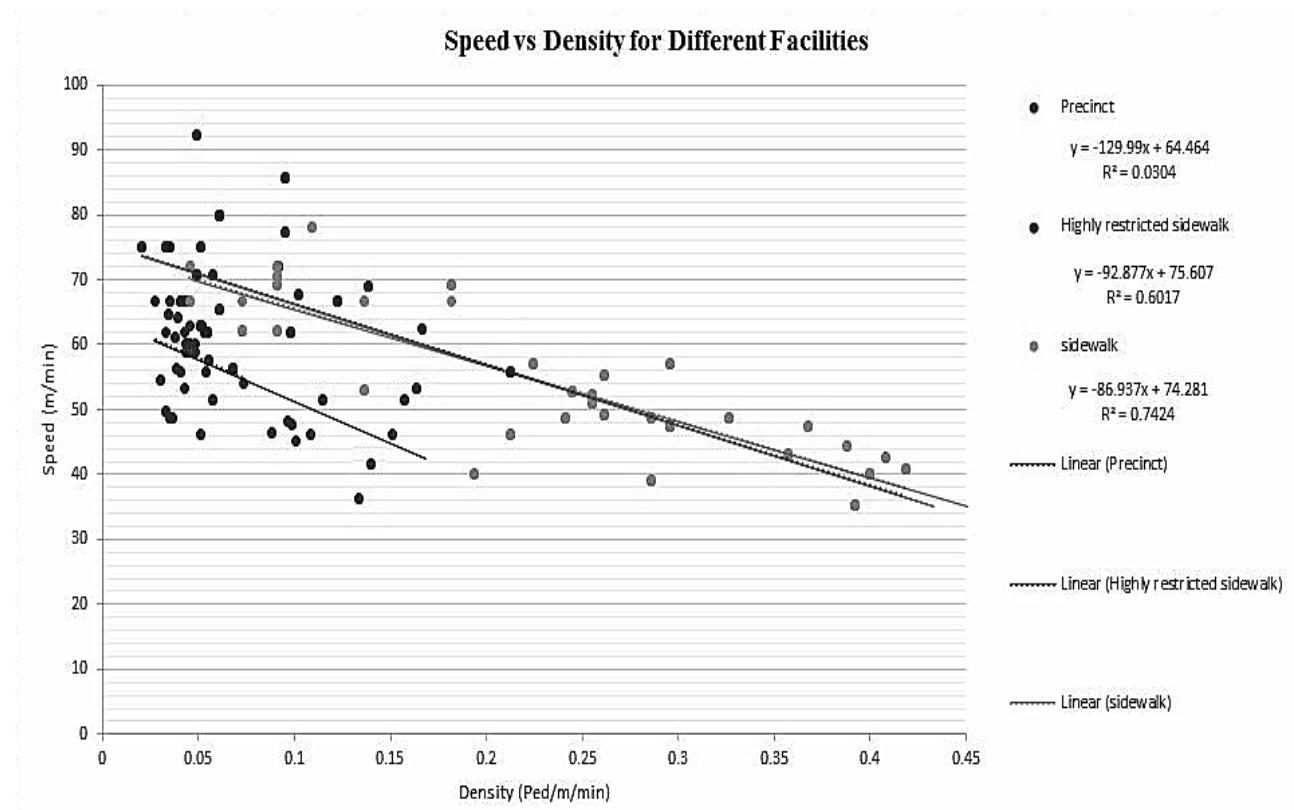


Figure 5: Pedestrian flow characteristics on different facilities

It shows the trend line of restricted sidewalk is steeper than regular sidewalk and less steep than precinct. These relationships clearly indicate the difference in the three types of sidewalk facilities as classified in the present work.

The mean speeds in literature vary from 1.23 m/s to 1.50 m/s on sidewalks/walkways; the variation being from 1.23 m/s to 1.39 m/s in Asian countries (Tanaboriboon et al. 1986, Lam and Cheung 2000, Honggei et al. 2009, Kotkar et al. 2010); from 1.31 to 1.50 in European countries (Oeding 1963, Older 1968); and from 1.31 to 1.37 m/s in the US (Navin and Wheeler 1969, Fruin 1971). Pedestrian walking speeds under mixed traffic are studied by Yu (1993, China), Gerilla (1995, Phillipines) and Kotkar et al. (2010, India). The speed is found lower in China (1.26 m/s) and comparable in Philippines and India (1.38-1.39 m/s). From Equation 1, speed of 73.629 m/min (1.228m/s) obtained locally smaller as compared to

various research in USA, Britain and Israel which speed ranges from 78 to 82 m/min. Speed obtain in Singapore and India is comparatively lower than obtained in Bangladesh.

The maximum theoretically flow obtained locally as a derived from equation 8 is 74 ped/m/min which is higher and can be explained by higher concentration occupied by Bangladeshi pedestrians. Bangladeshi pedestrians typically of small physical sizes tend to require less personal space thus, the density is higher compared to that obtained in USA, Britain and Israel is closer to that obtained in Singapore.

Table 7: Pedestrian flow characteristics under different conditions.

Facility /Condition	Maximum free flow speed (m/min)	Jamming flow (Ped/m/min)
Sidewalks	74.28	0.8544
Precincts	64.46	0.4959
Highly Restricted Sidewalks	75.61	0.8141

Based on the relationship between flow characteristics and characteristics parameter values, the behaviour of the pedestrians on sidewalks and highly restricted sidewalks is found to be more similar than that on precinct.

5. CONCLUSIONS

The following conclusions can be drawn from this study:

- The mean walking speed is 58.41 m/min or 0.97 m/s on walkways was significantly lower as compared to the Asian counterpart as well as European countries and US.
- Male pedestrian walking speed of 69.57 m/min is relatively faster than female pedestrian walking of 53.57 m/min.
- It was found that walking speeds among child (50 m/min), adult (59.72 m/min) and elderly pedestrian (46.15 m/min) vary significantly with each other.
- The relationship between pedestrian walking speed (u), density (k), flow (q) and area module (M) for walkway in bi-directional flows can be represented by following equations:

$$\begin{aligned} u &= 73.629 - 67.319k; \\ q &= u(73.629 - u)/67.319; \\ q &= 73.629k - 67.319k^2; \\ q &= 73.629/M - 67.319/M^2. \end{aligned}$$

Where,

u is in m/min, q in ped/m/min, k in ped/m², M in m²/ped.

The maximum flow of pedestrian at walkways was found to be 74 ped/m/min when space area is 0.45m². Which refers Level of Service 'E'.

REFERENCES

- Arasan, V. T., Rengaraju, V. R., and Rao, K. V. K. (1994). "Characteristics of trips by foot and bicycle modes in Indian city." J. Transp. Eng., 120(2), 283-294.
- Furin, J.J. (1971). Designing of pedestrians: A level of Science Concept, Highway Research record, No.355, pp. 1-14.
- Gerilla, G. P. (1995) "Proposed Level of Service Standards for Walkways in Metro Manila," Journal of the Eastern Asia Society for Transportation Studies, 1(3), Autumn 1995.

- Honggei, JIA, Yang, L, and Ming, T. (2009) "Pedestrian Flow Characteristics Analysis and Model Parameter Calibration in Comprehensive Transport Terminal," *Journal of Transportation Systems Engineering and Information Technology*, 9 (5), 117-123.
- Kotkar, K. L., Rastogi, R. and Chandra, S. (2010) "Pedestrian Flow Characteristics in Mixed Flow conditions," *Journal of Urban Planning and Development*, ASCE, 136 (3), 23-33.
- Lam, W., and Chueng, C. (2000). "Pedestrian Speed/Flow Relationships for Walking Facilities in Hong Kong." *J. Transp. Eng.*, 126(4), 343-349.
- Lam, W. H. K., Lee, J. Y. S., Lee, K. S., and Goh, P. K. (2003) "A Generalised Function for Modelling Bi-directional Flow Effects on Indoor Walkways in Hong Kong." *Transportation Research Part A: Policy Practice*, 37(9), 789–810.
- Navin, F.P.D., and Wheeler, R.J. (1969). Pedestrian Flow Characteristics, *Traffic Engineering*, June, Vol.39, No.9, pp.30-36.
- Oeding, D. (1963) "Verkehrsbelastung und Dimensionierung von Gehwegen und anderen Anlagen des Fussgangerverkehrs", *Strassenbau und Stasserverkehrstechnik*, Heft 22, Bonn.
- Older, S. J. (1968) "Movement of pedestrians on footways in shopping streets," *Traffic Engineering and Control*, 10(4), 160-163.
- O'Flaherty, C.A. & M.H. Parkinson (1972) "Movement on a city centre footway," *Traffic Engineering and Control* 13, 434–438.
- Polus, A., Schofer, J.L., and Ushpiz, A. (1983). Pedestrian Flow and Level of Service, *Journal of Transportation Engineering*, ASCE, Vol.109, No.1, pp.46-56.
- Sarkar, A.K. and K.S.V.S. Janardhan (1997) "A study on pedestrian flow characteristics," In CD-ROM with Proceedings, *Transportation Research Board*, Washington.
- Tanaboriboon, Y., Sim, S.H., and Chin, H.C. (1986). Pedestrian Characteristics study in Singapore, *Journal of Transportation Engineering*, ASCE, Vol.112, No.3, pp.229-235.
- TRB (2000). *Highway Capacity Manual*, National Research Council, Washington DC, USA.
- Virkler, M.R. and Elayadath, S. (1994) "Pedestrian Speed-Flow-Density Relationships" *Transportation Research Record* 1438, 51-58.
- Yu, Min Fang (1993) "Level of Service Design Standards for Non-motorized Transport in Shanghai," China, AIT Thesis no GT 93-35, Asian Institute of Technology, Bangkok.