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| RESEARCH ARTICLE

Assessment of Pedestrian Flow Characteristics on Selected Urban Walkways in Khulna Metropolitan Area, Bangladesh

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| ABSTRACT

Walking is the most fundamental and proficient method of transportation for reaching a concise destination directly or after using other means at no cost. Hence, the significance of pedestrian movement is recognized worldwide and cannot be overlooked. The walking speed of pedestrians is noteworthy in an analysis of the function, layout, and provision of pedestrian facilities. Therefore, it is crucial to assess the pace of pedestrians using walkways as well as to review and authenticate the established link between their speeds, flow, densities, and area modules. Six strategically major locations in the Khulna metropolitan area, Bangladesh were selected. Data was gathered from these locations using a photographic approach and were analyzed using the statistical software IBM SPSS Statistics 32.0. The pedestrian walking statistics were examined for characteristics of flow under differing traffic circumstances and were illustrated through the development of mathematical and statistical relationships between speed-density, flow-density, speed-volume, and flow-area modules. According to the data, the typical pedestrian walking speed in Khulna City is 68.07 m/min on walkways. The walking speeds of children (69.68 m/min), adults (72.72 m/min), and elderly pedestrians (61.82 m/min) differ substantially from each other. The male pedestrian walking speed (71.23 m/min) is relatively faster than the female walking speed (61.8 m/min). Finally, when the space area per pedestrian is 1.70 m^2, the maximum flow of pedestrians on walkways is estimated to be 36 ped/min. This refers to the level of service (LOS) "C". The findings are expected to be beneficial in the design and planning of pedestrian infrastructure to ensure the continuous flow of pedestrians.

| KEYWORDS

Pedestrian flow characteristics, Walkways, Level of service, Pedestrian walking speed, Area modules

| ARTICLE INFORMATION

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1. Introduction

Rapid urbanization and increasing transportation demand have intensified pressure on urban mobility systems, particularly in developing countries where pedestrian infrastructure often receives limited attention. Understanding pedestrian behavior and flow patterns and developing appropriate models for their integration into urban design and planning have therefore become increasingly important. In many urban areas, a substantial portion of daily trips either begins or ends with walking, making pedestrian facilities an integral component of transportation systems (Zheng et al., 2016). Walking remains one of the most fundamental and sustainable modes of transportation because it is accessible, economical, environmentally friendly, and supports public health outcomes (Ahmed et al., 2021). A pedestrian footpath is a route which is designed only for pedestrians to prevent accidents with moving automobiles (Hadiyanto et al., 2017). Walkability is the spatial property of a place designed to make pedestrians intend to use the public space (Venerandi et al., 2024). The words "walkability" and "pedestrian level of service (PLOS)" are often utilized to define the quantity of service that a pedestrian can experience when walking (Paul et al., 2024). The walkability and PLOS depend on the characteristics and behavior of pedestrians.

Pedestrian flow characteristics generally describe the movement behavior of pedestrians in terms of speed, density, flow rate, and space occupancy under varying environmental and traffic conditions. Understanding these characteristics is important for the design and operation of sidewalks, walkways, transit terminals, intersections, and public spaces. The relationships among speed, density, and flow have long been considered fundamental parameters in pedestrian traffic studies because they directly influence facility capacity and Level of Service (LOS). People's walking speeds were found to vary widely based on parameters such as; age, gender, level of fitness, height, weight, terrain, company size, activity level, and trip purpose. All these aspects should be considered as extensively as possible during the development of walking facility (Rastogi et al., 2011).

Due to a lack of space on the sidewalk, pedestrians are compelled to enter the roadway when traffic volumes are high, which may increase the likelihood of collisions involving other motorists (Al-Mukaram & Musa, 2020). Finnis and Walton (2008) assert that pedestrians in less crowded regions of the nation traverse at a faster pace than those in the most populous cities due to increased movement conflicts, which can adversely affect comfort, convenience, and safety. Asian countries have larger populations than developed nations in North America or Europe. The average walking pace of Asian pedestrians (73.8 m/min to 83.4 m/min) is significantly lower than that of European pedestrians (Rastogi et al., 2013). Pedestrian flow characteristics including flow, density, speed, free-flow speed, walking space, and jam density, are contingent upon the location within a city (Banerjee et al., 2018). Rastogi et al., (2013) examined the pedestrian flow characteristics (flow, density, speed, and area module) at nineteen sites across five Indian cities, categorizing pedestrian facilities as sidewalks, wide sidewalks, and precincts based on their width. The greatest free-flow speed of 94.56 m/min was observed on sidewalks, while the minimum speed of 80.40 m/min was recorded in precincts. Male pedestrians exhibited greater walking speeds than females, and younger pedestrians were generally faster at the designated places in Dhaka, with the exception of Dhaka University. Conversely, in Chattogram, middle-aged pedestrians demonstrated superior walking speeds (Nazir et al., 2026).

Level of Service is a critical criterion in assessing pedestrian infrastructure, focusing mainly on effective width and pedestrian flow (Campisi et al., 2022). In contrast to the parameters employed to assess walkability, the PLOS utilizes variables more directly related to pathway characteristics and pedestrian dynamics to evaluate the quality of services offered by pedestrian facilities (Paul et al., 2024). The determination and analysis of PLOS are crucial for the design and evaluation of current walkway. A study evaluated the influence of pedestrian speed, which varies with age, gender, group size, and travel purpose, on PLOS across six corridors in Cochin, Kerala, India (K. & Lokre, 2019).

However, research on local pedestrian features is necessary prior to developing pedestrian planning standards for any metropolis. The walking speeds of pedestrians are determined by the width of the facility as well as their age and gender(Laxman et al., 2010). John J. Fruin, (1971)stated that certain speed flow relationships have been derived for various kinds of pedestrian facilities. An extensive assessment of pedestrian facilities reaches the conclusion that any developing city must first and foremost evaluate the characteristics of pedestrians prior to devising a pedestrian model for the purpose of enhancing the road network.

Khulna Metropolitan Area, the third-largest city in Bangladesh, has experienced considerable urban expansion and increased travel demand over recent decades. Hence, a detailed understanding of pedestrian speed, density, flow relationships, and operational performance is essential for planning effective pedestrian facilities and improving urban transportation sustainability. The purpose of this research is to assess the average speed of pedestrians on walkways, make international comparisons, and identify the factors that most affect this speed. Finally, to classify pedestrian level of service design requirements for walkways and verify the established relationships between pedestrian speeds, flows, densities, and area modules. The findings of this study are expected to contribute to the development of pedestrian-friendly urban environments and provide practical recommendations for transportation planners and policymakers in Bangladesh and similar developing urban contexts.

2. Methodology

2.1 Survey Details and Data Collection

This study was conducted at six major locations in Khulna, each chosen for its proximity to a variety of walkways with diverse levels of walkability, from which insights into the factors influencing pedestrian speed could be drawn. Data on the correlations between flow, speed, and density were gathered using a photographic approach first introduced by Thompson & Heydon, (1991). To capture the scenario at the designated stations of known length, a digital video camera was deployed. Self-adhering white tape was used to designate a 10-meter-long trap on the pedestrian facility so that the speed and flow of pedestrians could be determined. On a working day, pedestrian movements were observed at both peak (8:30-9:30 AM and 4:30-5:30 PM) and off-peak (12:30-1:30 PM) hours at each research location. Appropriate time intervals were selected from the recordings to determine the walking speed, density, and flow characteristics. From the captured videos, the walking velocities of pedestrians were manually retrieved. Each pedestrian's time to cross the trap length was recorded with a precision of 0.01s to calculate their speed. From the recording, it was calculated how long it would take a pedestrian to complete the test distance. The density was calculated by counting the number of pedestrians within the perimeter of the observation site. Pedestrian volume determines the density per square meter. The area module was produced by taking the reciprocal of pedestrian density and its values were determined throughout the study period. Table 1 provides the characteristics and pedestrian numbers collected at the six study sites that have been categorized.

Table 1: Characteristics of sites and number of pedestrians at peak and off-peak hour

Classification	Observations Sites	Effective Width (m)	Pedestrian Number At 8:30-9:30 AM	Pedestrian Number At 12:30-1:30 PM	Pedestrian Number At 4:30-5:30 PM	Total Number of Pedestrians
Sidewalk	Old Jashore Road	2.4	379	221	484	1084
	Majid Sharani	2.3	167	42	181	390
	M. A. Bari Road	2.4	576	481	723	1780
	Ahsan Ahmed Road	1.9	789	862	757	2408
Precinct	Khulna-Jashore Highway	6.1	277	254	519	1050
Highly Restricted Sidewalk	Clay Road	2.1	637	1079	1365	3081
Total number of pedestrians for the six locations						9793

2.2 Pedestrian Classification

This data analysis categorized pedestrians based on age and gender, as these factors appeared to affect walking speed. Pedestrians younger than 15 were classified as children (CH). Consequently, Adult (AD) pedestrians were considered to be between the ages of 15 and 50 years old. Finally, pedestrians over the age of 50 were subjectively selected to represent the elderly (old). An analysis of the significant disparity between female and male pedestrians by age was conducted. Information collected about sidewalks was loaded onto a computer using the Excel spreadsheet tool (Microsoft Office) and then analyzed with IBM SPSS Statistics 32.0, a statistical program.

2.3 Regression Analysis

Fruin's (1971) model states that there are several types of common speed-flow-density connections. They are as follows:

Pedestrian speed (u) and density (k) relationship: $\mathrm{u} = \mathrm{x} - \mathrm{yk}$

Pedestrian flow (q) and speed (u) relationship: $q = \mathrm{u}(\mathrm{x} - \mathrm{u})/\mathrm{y}$

Pedestrian flow (q) and density (k) relationship: $\mathrm{q} = \mathrm{xk} - \mathrm{yk}^2$ and

Pedestrian flow (q) and area module (M) relationship: $\mathrm{q} = \frac{\mathrm{x}}{\mathrm{M}} - \frac{\mathrm{y}}{\mathrm{M}^2}$

The parameters 'x' and 'y' in the model describing the relationship between speed and density were evaluated using regression analysis to select the best-fitting model for the data. SPSS was used for the fundamental regression analysis.

2.4 Standards for Levels of Service (LOS) on pedestrian facilities

Fruin (1971) developed six levels of service for walkways in a manner comparable to how the Highway Capacity Manual (HCM) defines levels of service for vehicular flow (TRB, 2000). The levels of service follow the same hierarchy as the Highway Capacity Manual, with A denoting unrestricted movement and F denoting breakdown flow. Levels of service B, C, and D, respectively, illustrate pedestrian flows where people are aware of the presence of others and react to it, have adequate space to move smoothly in unidirectional streams, and are constrained from freely strolling and passing other people. Finally, the state of maximum flow or capacity is referred to as Level of Service E. The number of m^2/Pedestrian required to achieve the desired level of service, also known as the pedestrian modules (M), is the measurement used to define the criteria. While the HCM uses both volume and speed to determine vehicle levels, the inverse of density is used to determine pedestrian levels. In identifying pedestrian levels of service on walkways, the HCM largely embraced Fruin's notions as the pedestrian level of service standards for walkways, where the range of values is expressed in both metric and imperial units. The purpose of the correlation between pedestrian flow and area modules is to facilitate the visualization of pedestrian densities at different service levels on walkways.

2.5 Pedestrian Speed Study

2.5.1 Walking Speed of Pedestrian

The average walking speeds of people crossing the street were measured for the speeds provided in this section, where high pedestrian conflict rates are a result of the magnitude of traffic. At six different survey locations, it was discovered that the average walking speed of pedestrians in Khulna was 68.07 m/min. A more in-depth investigation of the gender classification revealed that male pedestrians typically walked marginally quicker than female pedestrians, with their respective walking speeds being 71.23 m/min for males and 61.8 m/min for females. The findings of the pedestrian walking speeds are summarized in Table 2 which provides an assessment of pedestrian speed in Khulna City. However, compared to the walking speeds of children and elderly travelers, pedestrian speed fluctuates far less. Where ML stands for male, FL for female, and CH for the combination of both male and female.

Table 2: Walking speeds of pedestrians on walkways

Characteristics		Children (0-15 Years)			Adult (15-50 Years)			Elderly (>50 Years)		
Mean Speed (m/min)			69.68			72.72			61.82	
Range		ML	FL	CH	ML	FL	CH	ML	FL	CH
	High	92.21	89.41	89.93	97.48	87.93	90.82	83.79	80.47	82.13
	Low	42.86	36.72	39.79	46.76	38.77	42.76	25.5	32.24	28.87
Sample Size			2042			5666			2085	

According to Table 2, the average walking speed of children was 69.68 m/min and that of adults was 72.72 m/min. However, it was discovered that the elderly walked at a slightly slower pace (61.82 m/min). Elderly pedestrians were found to move at the slowest speed of 25.5 m/min, with adult pedestrians moving at the fastest speed of 97.46 m/min.

2.5.2 Relation between Speed, Density, and Flow on Walkways

A linear relationship between speed and density was found through analysis, and it is expressed by the following equation:

$$\mathrm{u} = 73.423 - 12.942\mathrm{k}$$

Where, k represents density and u denotes speed, both represented in ped/m^2 and m/min, respectively. Thus, the subsequent relationships between flow density, speed, and flow are generated due to the linear relationship:

$$\mathrm{q} = \mathrm{u}(73.423 - \mathrm{u})/12.942; \qquad \mathrm{q} = 73.423\mathrm{k} - 12.942\mathrm{k}^2$$

The area module (M) is applied to depict density in the flow and density relationship.

$\mathrm{q} = \frac{73.423}{\mathrm{M}} - \frac{12.942}{\mathrm{M}^2}$, where M is expressed in m^2/ped.

Peak Hour **Off Peak Hour**

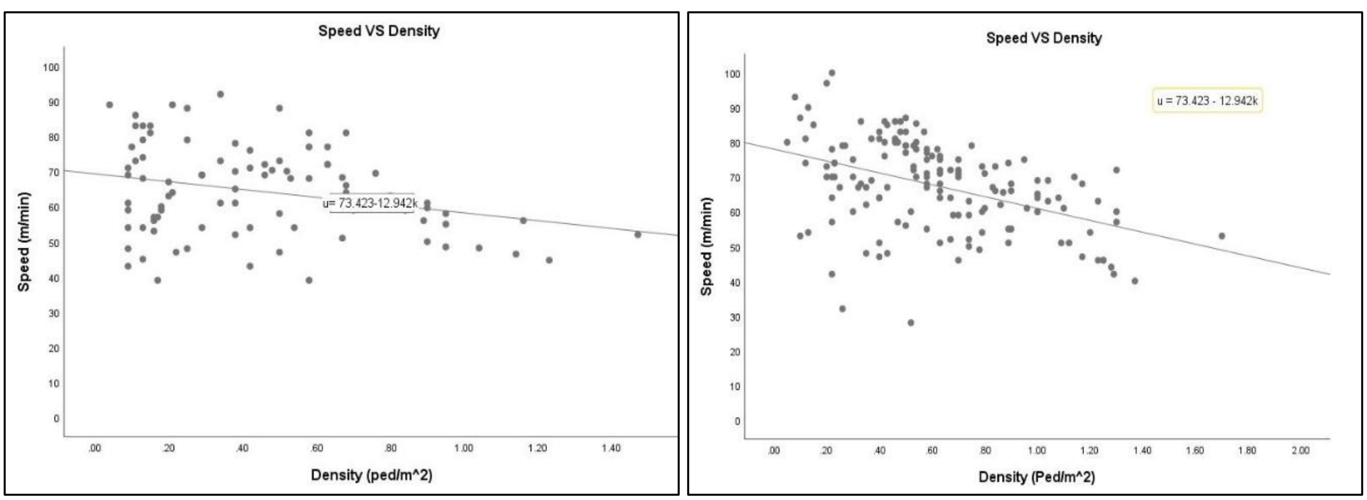


Figure 1: Speed vs Density relationship for walkways at peak (left) and off-peak hour (right)

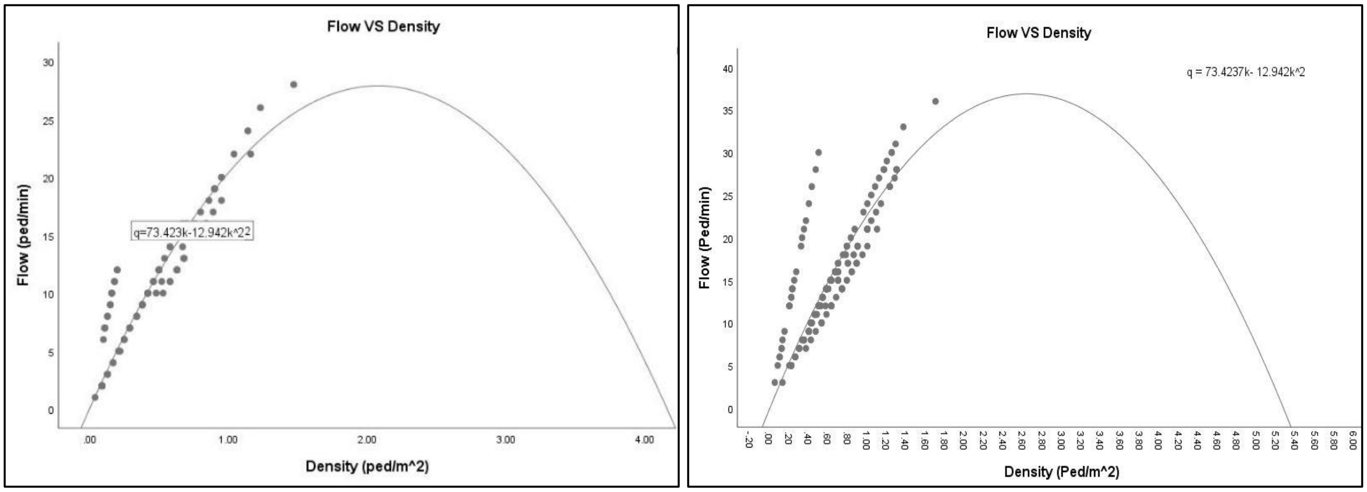


Figure 2: Flow vs Density relationship for walkways at peak (left) and off-peak hour (right)

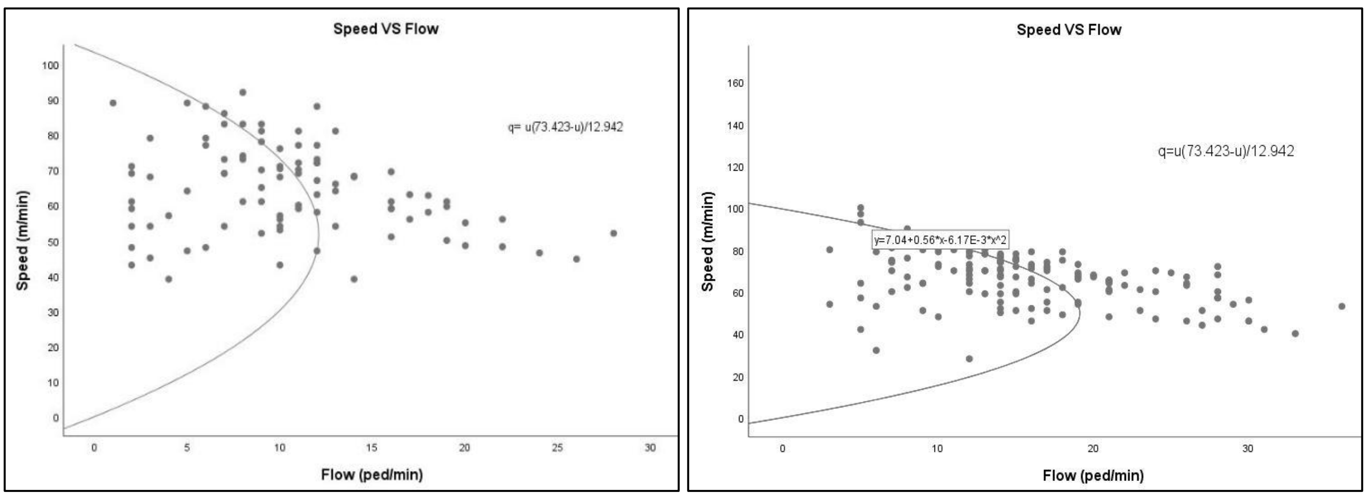


Figure 3: Speed vs Flow relationship for walkways at peak (left) and off-peak hour (right)

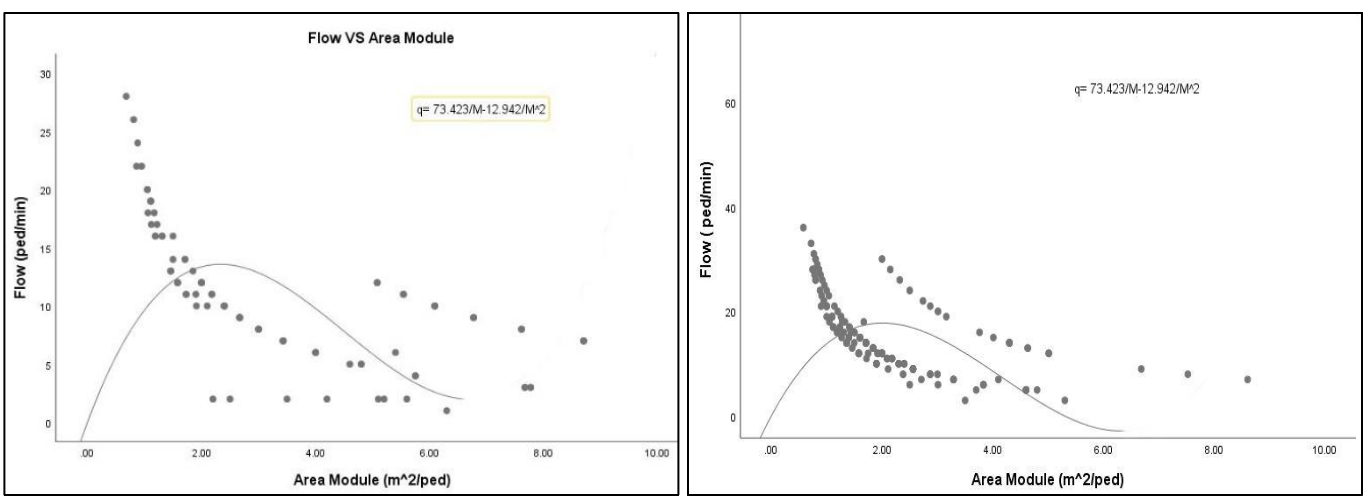


Figure 4: Flow vs Area relationship for walkways at peak (left) and off-peak hour (right)

The following Figures 1-4 illustrate the correlation between speed, density, flow, and area module. The linear regression model, which has been assessed regarding correlation coefficient as well as other statistical characteristics, provided the best fit between the speed and density connection. The free flow speed, denoted by parameter "x" from the model equation, was determined to be 73.423 m/min. Figure 4 illustrates how density increased to a maximum of one pedestrian per square meter when pedestrian speed decreased. The graphs in Figures 2 and 3 represent the rise to a peak and subsequent reduction in flow levels as determined by the model equation. When the area was around 1.70 m^2/ped, the flow reached its maximum of 36 ped/m/min. To conveniently visualize the various levels of pedestrian freedom, Figure 4 uses the reciprocal of pedestrian density, M (m^2/ped). The above curve demonstrates that adequate pedestrian space is necessary for humans to walk at a regular pace and that crowded conditions hinder human movement.

3. Results and Discussion

3.1 Pedestrian Flow Relation for Classified Conditions

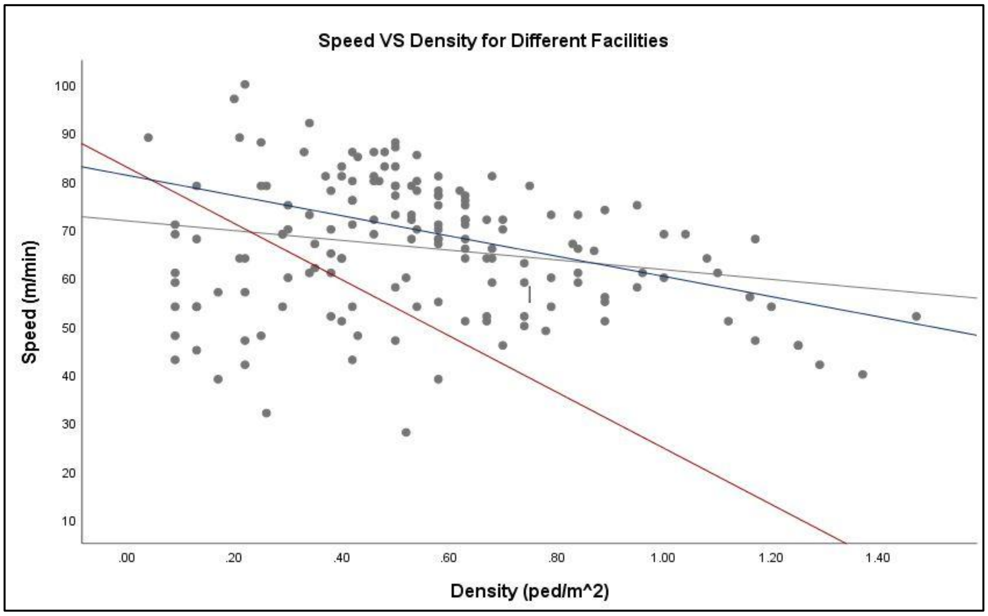
The single-regime approach to determining the relationship between speed and density is necessitated by the sparsity of the data points. To choose the distribution that fits a given data set best, a variety of distributions, including logarithmic, polynomial, linear, exponential, power, and so on are considered. Once this is established, the theoretically calculated correlations between flow, density, and speed are tested for quality of fit using data plots, and statistical measures like R^2 and the statistical significance measures are computed using the observed range of data.

Table 3: Relationship between characteristics of pedestrian flow

Classification	Relationship	Value of Parameters		Model Equation	R^2
		x	y		
Sidewalks	Speed-Density (u-k)	71.776	10.098	$u = 71.776 - 10.098k$	0.67
	Flow-Speed (q-u)			$q = u(71.776 - u)/10.098$	
	Flow-Density (q-k)			$q = 71.776k - 10.098k^2$	
	Flow-Area (q-M)			$q = \frac{71.776}{M} - \frac{10.098}{M^2}$	
Precincts	Speed-Density (u-k)	82.866	58.148	$u = 82.866 - 58.148k$	0.29
	Flow-Speed (q-u)			$q = u(82.866 - u)/58.148$	
	Flow-Density (q-k)			$q = 82.866k - 58.148k^2$	
	Flow-Area (q-M)			$q = \frac{82.866}{M} - \frac{58.148}{M^2}$	
Highly Restricted Sidewalk	Speed-Density (u-k)	81.197	20.916	$u = 81.197 - 20.916k$	0.32
	Flow-Speed (q-u)			$q = u(81.197 - u)/20.916$	
	Flow-Density (q-k)			$q = 81.197k - 20.916k^2$	
	Flow-Area (q-M)			$q = \frac{81.197}{M} - \frac{20.916}{M^2}$	
All-inclusive facilities	Speed-Density (u-k)	73.423	12.942	$u = 73.423 - 12.942k$	0.51
	Flow-Speed (q-u)			$q = u(73.423 - u)/12.942$	0.45
	Flow-Density (q-k)			$q = 73.423k - 12.942k^2$	0.76
	Flow-Area (q-M)			$q = \frac{73.423}{M} - \frac{12.942}{M^2}$	0.27

Error! Reference source not found. displays the flow correlations created for various types of pedestrian facilities. The graphs depict that the trend line for restricted sidewalks is steeper than that for precincts and conventional sidewalks. These associations clearly show how the three categories-flow, density, and speed of sidewalk facilities, as identified in the current analysis, differ from one another.

The model equation predicts a speed of 73.423 m/min (1.2 m/s) for this area, which is slower than the velocities recorded in investigations carried out in the United States, Great Britain, and Israel, which range from 78 to 82 m/min. The model equation predicted a maximum theoretical flow of 71 ped/min, which is higher due to greater pedestrian density in Bangladesh.



Pedestrian density in Bangladesh is higher and closer to Singaporean levels than in other nations because Bangladeshi pedestrians, who tend to be physically smaller than those in the United States, Britain, and Israel, therefore require less personal space (Shams-E-Rabbi & Hossain, 2018). Table 4 compares pedestrian flow characteristics in the city of Khulna before and after the installation of new sidewalks in 2025.

Table 4: Comparison of pedestrian flow characteristics in varying circumstances in Khulna city

Condition	Maximum Free Flow Speed (m/min)	
	Current Research (2026)	Shams-E-Rabbi & Hossain, 2018
Sidewalks	71.776	74.28
Precincts	82.866	64.46
Highly Restricted Sidewalks	81.197	75.61

The behavior of pedestrians on precincts and severely constrained sidewalks seems to be more identical compared to that on sidewalks due to the correlation between flow characteristics.

4. Conclusion

The study evaluated the pedestrian flow characteristics of selected urban sidewalks in Khulna Metropolitan Area, Bangladesh by field observations and statistical analysis of pedestrian movement under different traffic circumstances. The results show that the average walking speed of pedestrians in Khulna City is 68.07 m/min (1.14 m/sec) and there are significant differences between age and gender groups. The walking speed of adult pedestrians was the highest, while the elderly pedestrians showed comparatively slower movement characteristics. It was shown that male pedestrians walk faster than female pedestrians, which indicates that demographic considerations play an important role in behavior of pedestrians. The investigation showed statistically significant correlations between pedestrian speed, density, flow and area module and confirmed that the higher the pedestrian density the poorer the walking speed and overall movement efficiency. The results also showed that the maximum pedestrian flow on sidewalks occurs at around 36 ped/min when the available space per pedestrian is around 1.70 m^2/ped, which corresponds to LOS "C". This means that under moderate crowding situations, an operational trade-off between pedestrian mobility and facility use exists. Comparative analysis with prior studies suggests that the walking speeds of pedestrians in Khulna are generally lower than those in most Asian and Western cities. This is due to differences in the pedestrian behavior, urban fabric and geographical restrictions. In addition, differences in pedestrian patterns across sidewalks, precincts and strongly restricted paths indicate that the physical characteristics and operational circumstances of facilities have a strong effect on pedestrian movement. The findings of this study are useful for transportation planners, urban designers and policymakers for the development of pedestrian oriented infrastructure in Khulna City and similar metropolitan settings. Future research should include more behavioral aspects such as trip purpose, environmental factors, pedestrian interactions, and land-use features to construct more comprehensive pedestrian flow models and improve urban mobility planning.

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