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Original Article

Assessment of traffic speed-flow-density relationships for highway roads in Bangladesh

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ABSTRACT

Bangladesh, classified as a developing nation, grapples with diverse traffic conditions, presenting both opportunities and challenges for its transportation system. The integration of new technology stands as a pivotal avenue for augmenting transportation efficiency. Proficiency in implementing traffic flow concepts becomes imperative for system enhancement. This article aims to scrutinize traffic dynamics encompassing flow, density, and speed to devise a fitting model reflective of traffic behavior. Specifically, the study focuses on the Khulna–Jessore route and the Khulna–Satkhira road. Over the course of 1 h, spanning from 4:00 pm to 5:00 pm, video footage was captured at these locations using digital cameras. Through statistical analysis and examination of fundamental traffic parameters derived from the recorded video, the study unfolds insights. It reveals a normal distribution pattern for both traffic density and flow, indicating adherence to natural phenomena. Nonetheless, a comparison between the two datasets highlights disparities, indicating distinct characteristics between the roads. Notably, parameters such as speed, flow, and density consistently exhibit higher values for the Khulna–Jessore road in contrast to the Khulna–Satkhira road, signifying a greater level of activity on the former. Consequently, the findings underscore the necessity for tailored design considerations, emphasizing the need for additional development efforts on the Khulna–Jessore road to accommodate its higher traffic intensity.

Keywords: Density, flow, Khulna city, speed, traffic

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INTRODUCTION

Traffic characteristics form the basis of planning any city for a traffic engineer. There are valuable resources available to help you explore the problem and devise the best possible solutions. Traffic is similar to water flow in that it has a range of parameters associated with it. These might be macro, describing the flow of traffic as a whole, or microscopic, focusing on the interactions between individual vehicles in the stream. On the other hand, time headway, space headway, and time travel are the microscopic qualities of speed, flow or volume (q), and density or concentration (k). In traffic flow theory, three macroscopic aspects of road traffic are the primary focus.[1,17] The unit of measurement for speed is the mile per hour (mph) or kilometers per hour (km/h). The volume of traffic that passes through a certain location in a given amount of time is known as the traffic flow. It is measured in terms of the number of vehicles per hour. At a given point in time, the number of vehicles on a certain strip of highway is referred to as its traffic density. It is measured in terms of vehicles per distance, respectively.[5] The theory of traffic flow helps us to characterize the connection between flow, density, and speed for all circumstances of traffic flow on freeways. Once a certain link between two flow characteristics is established, it is possible to estimate the features of unknown variables. Numerous applications of speed-flow correlations could be widely used in the fields of transportation and traffic engineering.[7] It has been used to establish design capacity for roads, determine the level of service required for traffic flow, and compute trip rates on a specific road section, among other things. Many researchers have proposed models to characterize the connections between traffic flow characteristics on freeways, and these models have been evaluated in many research.[8] There are at least two ways to deal with the issue of traffic flow. The microscopic approach is concerned with the speed and spacing of individual vehicles, while the macroscopic approach is concerned with traffic stream flow, density, and average speed.[9]

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Apart from that, the shape of a highway facility's speed-flow-density relationship has historically had a significant influence on the highway design and planning processes, as it provides quantitative assessments of the change in speed as a function of expected or projected changes in traffic demand.[6]

Traffic flow results from the combined movements of drivers and vehicle interactions between destinations, implying its prediction cannot rely solely on driver behavior. Designing, developing, and managing highways hinge on three key parameters. Traffic flow studies are pivotal for grasping vehicle flow characteristics, essential for crafting an efficient transportation system with minimal congestion.[13] Understanding the interactions among users (such as drivers, cyclists, and pedestrians) and infrastructure elements (such as signage, highways, and traffic control devices) is central to traffic flow analysis.[4] Such research aids in assessing traffic conditions and capacity on specific roads and informs future infrastructure designs. Through the HETEROSIM microsimulation model, Anirudhan and Thomas investigated class-wise speed-volume models for heterogeneous traffic on six-lane divided roads in Chennai.[1,18] Meanwhile, Cheng *et al*. examined the traffic speed–density relationship model on the Beijing Expressway, evaluating 10 standard models and concluding that the Newell and Logistic models exhibited the highest stability after analyzing parameter calibrations and fitting errors.[3] Barua *et al*. estimated the traffic density of the airport road in Dhaka city and compared speed–density models with moving observation data, discovering that the R^2 value for Greensberg's model is slightly higher, indicating that it can predict the variation of the speed–density relationship better than the other two models.[2,11] The density predicted by Underwood's model is underestimated, whereas the density calculated by Greenshield's and Greenberg's models is exaggerated. Furthermore, if there is frequent flow fluctuation, Greenshield's and Greenberg's models will forecast larger variance with moving observer data. Underwood's model is better in this circumstance.[12,16] Yadav *et al*. claim that the traffic flow in Sylhet city is a multiplicity of perspectives on how to improve.[10] Insufficient scientific and engineering support for most of the actions tried to ameliorate the problem. The study's major goal is to understand Sylhet's traffic flow, thereby the SCC can enhance traffic flow, reduce congestion, and plan for future traffic. The development of utility functions for key vehicles (rickshaws, auto-rickshaws, and city buses) helps users identify the best vehicle to utilize inside the city.[14,15] The entire investigation of five key Sylhet city linkages totaling 9.4 km was used to identify traffic flow. The most crowded connection is Kodomtole–Upashahar, with a traffic flow of 3.036 m/s, the lowest of all links. The K–U connection is congested and needs to be improved by adding lanes, changing traffic laws, etc.[13]

This study aimed to estimate traffic flow parameters for particular roadways and to establish the relationship and nature of fundamental diagrams connecting traffic flow parameters. In addition, the mean, standard deviation, and z-value were also calculated. In this research, traffic volume, vehicle speed, and traffic density were measured on the Khulna–Jessore (NH7) and Khulna–Satkhira (NH7) roads, and the relationship between traffic flow parameters was developed for both roads and then compared to each other.

RESEARCH METHODS

Study Area

The initial study location was selected between the Khulna–Jessore route and the Khulna–Satkhira road. The mid-block stretch of selected locations was straight and devoid of junctions, with no traffic restrictions. The national highway between Khulna and Jessore (NH7) is a two-lane divided highway. It has a 7-m roadway with a 1.5-m paved shoulder on both sides and a 4.5-m median. It is one of the city's major roadways, interconnecting Jessore and other areas. On the other hand, the roadway between Khulna and Satkhira is a two-lane divided regional highway. It has a 7-m primary carriageway with a 1.5-m paved shoulder on both sides and a 4.5-m median. It is also one of the city's major thoroughfares, linking Jessore and other districts. Samples from Khulna to Jessore road were collected at Fulbright, whereas data from Khulna to Satkhira road were collected at zero points. At first, the site was assigned to a certain length. The trap length was then set up to 30 m and the length was measured using a tape measure then a digital camera was used to capture footage from the designated location for an hour between 4.00 pm and 5.00 pm. Following the collection of the video, it was played again on the computer, and the needed data were obtained. Three types of data were collected from the video: speed, flow, and density, all of which were captured simultaneously.

Flow statistics were derived by analyzing cars passing through designated entrance and exit points within a rectangular area, ensuring a 1-min timeframe for inclusion in calculations. Data from the exit flow were particularly considered. Subsequently, density data were computed every 10 s and then averaged. Speed data were obtained by determining the time taken by vehicles to traverse the rectangular area from entry to exit, followed by dividing the segment's length by this time to calculate speed statistics.

Data Collection

A certain length was fixed for the site. The trap length was fixed at 30 m. The length was measured using tape. From the selected site, the video was taken by digital camera for a duration of 1 h for a period between 4.00 pm and 5.00 pm.

Data Extraction

Upon capturing the video, it was subsequently played back on a computer to extract the necessary data. Three types of data were gathered: Speed, flow, and density. Flow statistics were

computed at both entry and exit points, ensuring that vehicles passed through the designated rectangular area at a rate of once per minute. The study focused on exit flow. Density data were derived by monitoring the number of vehicles remaining within the rectangular area every 10 s, and these density values were then averaged. Speed data were obtained by measuring the time taken for vehicles to traverse the rectangular section, dividing the section's length by this time to calculate speed.

RESULTS AND DISCUSSION

Analysis of the Fundamental Diagram of Traffic Flow

Flow versus density diagram and speed versus density diagram

Graphs were created with density (vehicles per meter) plotted on the X-axis and flow rate (vehicles per second) plotted on the Y-axis. Analysis of the flow versus density plot revealed that the data were best represented by a second-order polynomial curve, as anticipated for understanding the characteristics of a flow-density diagram. The peak value of the fitted curve, representing the highest flow value, indicated the capacity of the road segment.

Based on the observations from Figure 1a, it can be inferred that both the density and flow data exhibit a normal distribution, aligning with the natural patterns of density and flow. However, due to the restricted range of density covered by the gathered data, accurately predicting capacity becomes challenging.

A separate graph has been created to illustrate the relationship between density (vehicles per meter) on the X-axis and speed (meters per second) on the Y-axis. Figure 1b showcases the comparison between the speed-density diagrams of Jessore road and Satkhira road.

Both data points deviate from the existing standards. As a result, the speed data points were averaged and the speed versus density graph was generated which shown in Figure 2a and b.

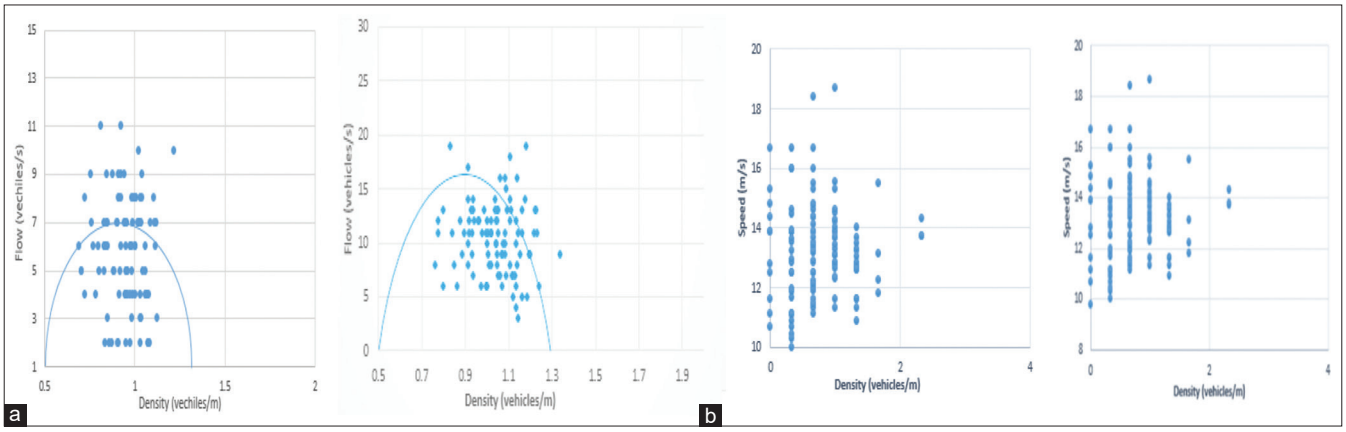

Figure 1: (a) Fitted flow versus density diagram for Jessore road and Satkhira road, respectively, (b) Speed versus density diagram for Jessore road and Satkhira road, respectively

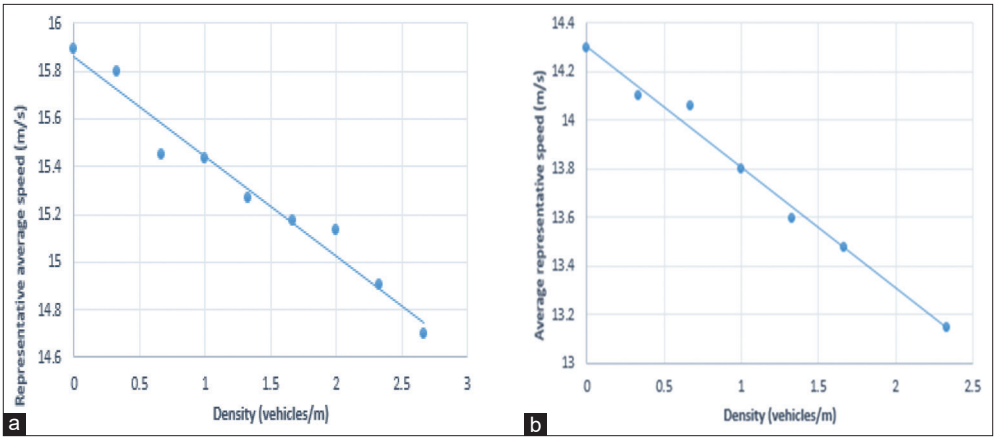

Figure 2: (a and b) Illustrate the fundamental relationship between speed and density. According to the following diagram, when speed is maximum, density is minimum, and when speed is minimum, density is maximum

Speed versus flow diagram

Figure 3a and b show the comparison between the speed and flow diagram of Jessore road and Satkhira road.

Relative Frequency Distribution of Collected Density Data and Flow Data

The average density data of Jessore and Satkhira roads were evaluated and then the frequency of those groups was calculated. The ratio of each frequency to the sum of the frequency is called relative frequency. Figure 4a shows the relative frequency distribution based on the density range for Jessore road and Satkhira road.

The average flow data of Jessore and Satkhira roads were evaluated and the frequency of those groups was determined then the relative flow range was estimated by dividing each frequency by the sum. Figure 4b displays the relative frequency distribution based on the flow range for Jessore road and Satkhira road.

Relative Frequency Distribution of Collected Speed Data

The average speed data of Jessore and Satkhira roads were selected and then the frequency of those groups was calculated. The relative frequency of the speed range was

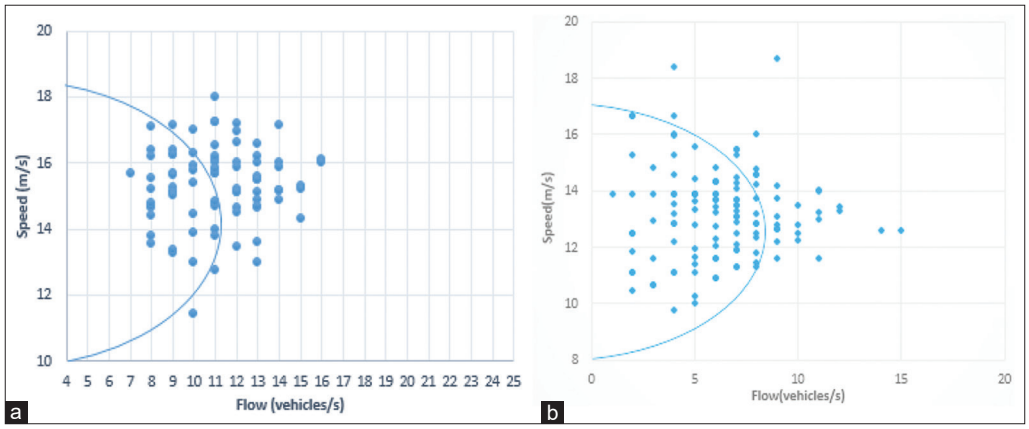

Figure 3: (a) Speed versus flow diagram for Jessore road, (b) Speed versus flow diagram for Satkhira road

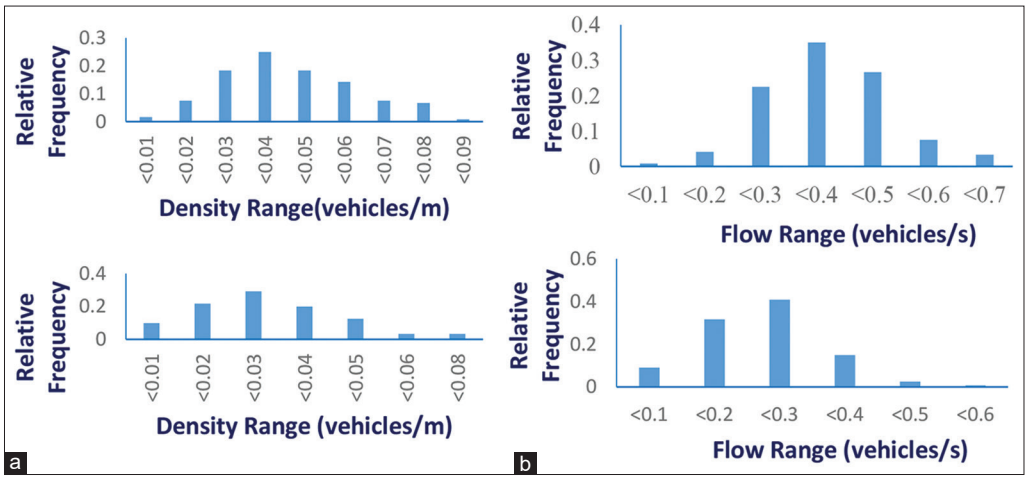

Figure 4: (a) Relative frequency distribution for Jessore road and Satkhira road, respectively, (b) Relative frequency distribution of flow data for Jessore road and Satkhira road, respectively

Table 1: Mean, standard deviation, and number of data points of collected data

Data collected	Mean of flow (vehicles/sec)	Mean of density (vehicles/m)	Mean of speed (m/s)	Standard deviation of flow	Standard deviation of density	Number of points of flow	Number of points of density
Khulna to Jessore road	0.351	0.0402	15.351	0.113	0.019	120	120
Khulna to Satkhira road	0.21	0.025	13.216	0.090	0.017	120	120

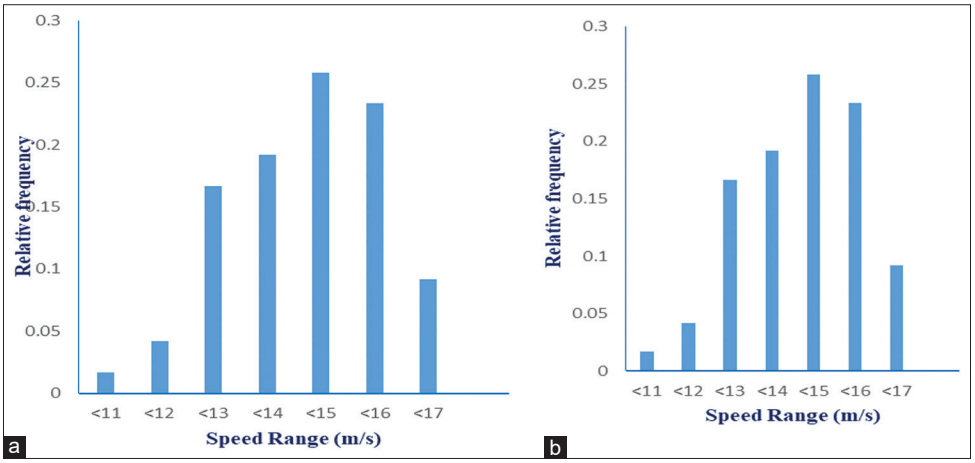

Figure 5: (a) Relative frequency distribution of speed data for Jessore road, (b) Relative frequency distribution of speed data for Satkhira road

Table 2: Z-values of flow and density

Factor	Flow	Density
Z-value	22.912	80.733

obtained by dividing each frequency by the total frequency. Figures 5a and b display the relative frequency distribution based on the speed data for Jessore road and Satkhira road.

Data Comparison

The comparison involves analyzing both datasets and calculating the Z-score values for each, followed by a comparison with the critical Z-value. Table 1 provides details including the mean, standard deviation, and the quantity of collected data. In addition, Table 2 displays the Z-values computed within this study.

The table indicates that the calculated Z-value surpasses the critical Z-value, indicating a clear distinction between the datasets.

CONCLUSION

The study's key findings are as follows:

- Density and flow data conform to a normal distribution, reflecting natural density and flow phenomena
- Comparison of the datasets reveals their distinctiveness
- The collected data are from a limited domain of density, so unable to predict capacity properly
- From the scope of the study, a possibility of predicting the relation in between traffic parameters as shown in fundamental diagrams
- Analysis of traffic flow parameters such as speed, flow, and density indicates consistently higher values for the Khulna–Jessore road compared to the Khulna–Satkhira road, indicating greater congestion on the former. Consequently, future development plans for the selected roads should prioritize additional design considerations for the Khulna–Jessore road.

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