MODELING FUNDAMENTAL DIAGRAM WITH EMPIRICAL TRAFFIC DATA UNDER DIFFERENT ROAD GEOMETRY AND TRAFFIC OPERATING CONDITIONS

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DEPARTMENT OF CIVIL ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY (MIST)

2017

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(BSc in Civil Engineering, RUET)

A THESIS SUBMITTED FOR

THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY (MIST)

March 2017

The Thesis titled "Modeling Fundamental Diagram with Empirical Traffic Data under Different Road Geometry and Traffic Operating Conditions" submitted by Md. Amir Hossain Khan, Student No. 1012110020 P, Session October 2012, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering (Transportation)** on 23 March 2017.

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DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

Full or any part of this thesis has not been submitted for the award of any other degree or diploma in any university previously.

March 2017

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ABSTRACT

Fundamental diagram (FD), a graphical representation of the relation among traffic flow, speed, and density, has been the foundation of traffic flow theory, hence contributes to understanding transportation engineering for many years. For example, the analysis of traffic flow dynamics relies on input from this FD to find development, propagation and dissipation of congestion. Moreover, traffic engineers can also use the FD to determine the traffic flow characteristics so that a highway and its facility can be evaluated over time and space. Underlying these importance, FD corresponding to relation between speed and density; which roughly correlates to drivers' speed choices under varying car-following distances, is used for this study. Since reported traffic stream models are mainly developed for homogeneous traffic conditions, they may not be directly suitable for the traffic condition of Bangladesh which shows weak lane discipline and heterogeneous in nature. From broad literature, hardly any studies have been found to focus this issue especially in Bangladesh. Only a very few studies have been reported from India, which is not sufficient to justifiably represent the traffic scenario in Bangladesh. In this situation, the present study investigates the characteristics of speed-density FD i.e. its shape and structure, for different roadway geometry and traffic operating conditions comprises both non-lane-based and heterogeneous traffic of Bangladesh. It also investigates the flow parameters for stated traffic condition.

For this study, 6 different cases have been considered. Traffic data is collected from 12 different locations of 3 major highways of Bangladesh. Data collection is done through video recording which is further processed by image processing technique. To investigate the structure of FD, the speed-density plots of field data for different locations are fitted with six established FD models namely: linear, 2nd degree polynomial, 3rd degree polynomial, exponential, 2nd degree exponential and logarithmic. From this investigation, it reveals that 2nd degree exponential structure is the best fitted FD model for most of the cases under prevailing traffic condition. It is also found that, free-flow speed tends to decrease dramatically if there is no footpath or shoulder and presence of market along the road-side. It is also found that if the free-flow speed decrease, the jam density is increased.

Keywords:

Fundamental Diagram Model, Heterogeneous Traffic Condition, Speed-Density Relationship.

ACKNOWLEDGEMENTS

All praise is due to the Almighty, the most merciful and the most beneficent.

I would like to express deepest gratitude and indebtedness to my supervisor, Dr. Md. Hadiuzzaman, Associate Professor, Department of Civil Engineering, BUET, Dhaka for his guidance, encouragement and continuous support throughout the progress of the work. Sincere appreciation goes to the members of my M.Sc. defense committee: Dr. Alamgir Mojibul Hoque, Dr. Md. Mizanur Rahman, Dr Mohammed Russedul Islam for their thoughtful questions, valuable comments and suggestions.

My deep appreciations and thanks are also extended to Colonel Shah Md Muniruzzaman, Head of the Department of Civil Engineering, MIST. I also convey my gratitude to all members of Military Institute of Science and Technology, Mirpur, Dhaka.

I am also thankful to Captain Imran, Lecturer, Department of Civil Engineering, MIST and Nazmul Haque, Research Assistant, Department of Civil Engineering, BUET for their extensive support and help.

Finally, I like to express my profound gratitude to my parents, wife and children for their love, continuing support, encouragement and sacrifice without which this study would have been impossible. May Almighty Allah bless us and be with us always.

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CHAPTER 1
INTRODUCTION

1.1 Background of the Study

Bangladesh has an extensive and diversified transport system. It has 21092.57 km highways (RTHD, 2017), 2885 route km railways (Railway Forum Progress Report, 2016) and 24,000 km inland waterways (Banglapedia, 2012). Of multiple modes of transportation the road transport plays the most dominant role. It carries more than 80% passenger modal share. According to National Report on Sustainable Development in May 2012, passenger growth is reported to have increased from 11.75 billion in 1973 to 131.75 billion in 2007, growing as fast as at an annual average of 7.45%. Existing road infrastructure is insufficient against the huge traffic demand causing severe traffic congestion both in national highways and in city roads. According to a study jointly conducted by the Metropolitan Chamber of Commerce and Industry (MCCI) and Chartered Institute of Logistics and Transport Bangladesh in 2010, it was revealed that the annual cost of traffic congestion in capital Dhaka was around Tk 1 billion a day. The study found that about 3.2 million business hours were lost every day due to the traffic jams. A more recent assessment concluded that the estimated loss is now 50% more than what it was in 2010, adding up to a staggering amount of about Tk. 550 billion annually. To overcome this situation, rapid development has been started in road transport sector during last few years that includes construction of new roads & bridges and widening of existing roads & highways.

For proper planning, design, implementation and operation of such road infrastructures, it is the prime requirement to know the flow characteristic and flow parameters of the traffic stream. Planning must be done considering present and future traffic state. Otherwise, after few years of construction, the capacity of the road will be exceeded and will be needed further widening. In this regard, the prime requirement is to know the appropriate traffic flow characteristic and accurate flow parameters. Traffic stream models are used in the planning, design and operation of transportation facilities. These models provide the fundamental relationships between macroscopic traffic stream characteristics for uninterrupted flow situations. The relationships are for free-flow and congested-flow conditions away from flow interruptions such as at intersections.

The fundamental diagram (FD) is a speed-flow-density relationship that reflects the interrelation between the traffic flow parameters. A macroscopic model involving traffic flow (q), traffic density (ρ) and speed (v) forms the basis of the FD. In order to investigate the traffic flow characteristics, finding out FD is one of the most important requirements. In fact, the FD (describing flow-density, speed-density or speed-flow relationship at a given location or section of the roadway) is a basic tool in understanding the behavior of traffic stream characteristics in macroscopic flow models. It can be used to predict the capacity of a road, or its behavior when applying inflow regulation or speed limits. In the nominal work of Greenshields (1935), FD was defined and used as the relationship between q and ρ for an equilibrium traffic state. Since then, several works have been conducted to establish a static relationship between q and ρ in theory and in empirical modeling with field data fitting. It is generally recognized that FD is location dependent due to road geometry and traffic characteristics. FD may have several equivalent forms: flow-density (occupancy) which is concave, speed-density (occupancy) which is monotone decreasing and speed-flow with two foliations: upper limb and lower limb.

The beginnings for traffic flow descriptions on a highway are derived from observations by Greenshields, firstly shown to the public during 13th Annual Meeting of the Highway Research Board in Dec. 1933. He carried out tests to measure traffic flow, traffic density and speed using photographic measurement methods for the first time. Greenshields postulated a linear relationship between speed and traffic density. When using the relation Flow = density * speed; the linear speed–density relation converts into a parabolic relation between speed and traffic flow. The term ‘flow’ was not known that time and Greenshields called that term ‘density-vehicles per hour’ or density of the second kind.

Many models exist for modeling the static $v-\rho$ or $q-\rho$ relationship. Although the function expressions are different; they are more or less similar in the domain $\rho \epsilon [0, \rho_j]$. However, some of them do not satisfy the two boundary conditions $v(0) = v_f$, $\rho = 0$ simultaneously. Few well-known models for speed-density relationships are Greenberg Model (1959), Edie Model (1961), Polynomial Model (Zhang,1999) and Exponential Model by Papageorgiou (2002) and Hegyi (2002). Edie Model was a combination of Greenberg Model and Underwood Model (1961). This combination removed some shortcomings such as the violation of boundary conditions of those two models. Some other models such as BPR Model and Van Aerde Model in planning are referred to Skabardonis and Dowling (1997) and Van Aerde (1995).

Almost all these models were developed and validated for homogeneous traffic. But in Bangladesh, like other developing countries, the traffic operating condition is non-lane based and highly heterogeneous. Although non-motorized vehicle has been banned from major highways in Bangladesh recently, the fact remains that here the traffic stream comprises of private cars, buses, mini-buses, trucks, covered van, auto-rickshaws and other utility vehicles of varying shape, size, speed and other operating conditions. The traffic behavior in such heterogeneous condition is significantly different from that in homogeneous condition. This necessitates modeling fundamental diagram with empirical data of heterogeneous traffic under different road geometry and traffic operating conditions for Bangladesh.

1.2 Statement of the Problem and Opportunities

1.2.1 High-resolution data collection technique

Empirical traffic data are the basic input in building and analyzing traffic stream models. But no such data are available for the traffic of Bangladesh for this purpose. Again, no existing facilities are available to collect continuous traffic data for 24hours/7days/one year. Within the vast literature on macroscopic traffic flow modeling, surprisingly very few studies have addressed the heterogeneous traffic condition prevalent in many developing countries like Bangladesh, India etc. Such limited research is primarily attributed to the difficulty of high-resolution data collection in the stated traffic condition. For collecting data under homogeneous traffic conditions, several types of equipment are available. Among these, induction loops (Loop Detectors) are widely used for both traffic management and traffic flow modeling purposes. Loop detectors are useful in collecting microscopic as well as macroscopic traffic data. Generally, these are employed for each lane and not suitable for collecting data under non-lane based mixed traffic conditions. Again implementation and maintenance cost of loop detectors are very high. Recently, some video image processing data collection techniques are being used for data collection in case of non-lane based heterogeneous traffic condition. In this research video data collection technique is used. The technique which is based on image processing will be able to measure traffic state in the non-lane based heterogeneous operating conditions with reasonable accuracy.

1.2.2 Data processing tools

For this research, total 6 cases will be considered. For each case video footage will be taken from two different locations with duration of at least (2x2.5) 5 hours. So, total (6x2x5) 60 hours video footage will be analyzed for traffic data. It is not humanly possible to find out the vehicle count, speed and density manually by watching such a long video. Again high resolution data (20 sec data) is required for this research that is not possible to extract manually from the video footage. To overcome this problem, in the recent years, image processing tools have been applied to the field of traffic research with goals that include queue detection, vehicle classification, and vehicle counting. In this research, for extracting high resolution traffic data from the video footages, an object detection algorithm has been used which operates based on the Background Subtraction (BGS) technique of image processing. The developed algorithm can successfully detect non-lane-based heterogeneous movement of vehicles. Even, it can identify non-motorized traffic, dark car and shadow quite accurately. Video data and vehicle geometry are provided as input to the algorithm and it gives vehicle count and time mean speed at required intervals as the output.

1.3 Research Objectives and Scope of Study

The overall objective of the research work is to investigate the impact of road geometry and traffic operating conditions on traffic flow parameters. However, the specific objectives are:

(a) Finding the shape and structure of fundamental diagram for different road geometry and traffic operating conditions.

(b) Finding the trends in flow parameters for different road geometry and traffic operating conditions.

It is expected that the obtained flow parameter values for different road geometry and traffic operating conditions will provide a guideline to estimate capacity of new roads for better geometric design. It is also expected that this research will lead to development of higher order macro model suitable for non-lane-based heterogeneous traffic. In the long-run, with that model, it will be possible for designing different proactive flow control strategies.

For this study, six different geometric and traffic conditions will be considered. These are as below:

Case-1:	Roadway with and without footpath
Case-2:	Roadway with and without bus stop
Case-3:	Highway section with on-ramp and off-ramp
Case-4:	Multi-lane merged to a single lane highway
Case-5:	Roadway with and without shoulder
Case-6:	Roadway with and without road-side market

1.4 Organization of the Thesis

This thesis consisting of five chapters is structured as follows:

Chapter 1 gives an introduction of the relevant research background, statement of the problems as well as the objectives and scope of the studies.

Chapter 2 comprehensively reviews basic relationships between traffic flow parameters and previous works on modeling FD with special focus on speed-density models. Few classical and non-classical models are reviewed in details. During this review special emphasis is given on modeling FD for heterogeneous traffic flow conditions.

Chapter 3 presents details of the study area selected and the high-resolution data collection and processing techniques adopted for the research. Some justifications regarding the choice of methods and choice of study area employed are also provided.

Chapter 4 presents developments of FD models for 6 different cases of different road geometry and traffic operating conditions for non-lane based heterogeneous traffic of Bangladesh. The shape and structure of best fitted model will be investigated for all the cases. It will also be investigated, how the flow parameters e.g. the free-flow speed and jam-density change with the change of road geometry and traffic operating conditions.

Chapter 5 summarizes the main conclusions of this research and discusses recommendations for future research works related to FD modeling for heterogeneous traffic.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The traffic flow on freeways and rural highways is described traditionally in terms of three basic parameters: the mean speed (v), the traffic flow rate (q), and the traffic density (ρ). The functional relationship between these three parameters is called Fundamental Diagram (FD). It gives the relation between speed-flow-density of traffic flow for an equilibrium state. Generally three types of FD are used to represent three basic relationships. These are speed-density relationships, speed-flow relationships and flow-density relationships. The three diagrams shown in Figure 2.1 are seem to be redundant, for it is obvious that if any one relationship is known, the other two are uniquely defined. However, all three diagrams have a particular use and purpose. Speed-density diagram is used in most theoretical work for two reasons. First, there is a single-valued speed for single-valued density, which is not true for other two relationships. Secondly, it is used to formulate car-following model where speed is a function of space. Flow-density diagram is used as the basis of freeway control system where density (percent occupancy) is used as the control parameters and flow (productivity) is objective function. Finally, the speed-flow diagram is used to determine the level of service of roadway. However, in this research more emphasis is given on the speed-density FD. So, literature review mainly focuses on speed-density models.

2.2 Relationships Between Basic Parameters of FD

The speed-density relationship is shown in the upper-left corner of figure 2.1 where a linear speed-density relationship is assumed to simplify the presentation. This relationship indicates that speed approaches free-flow speed (v_f) when density and flow approaches zero ($\rho \rightarrow 0$ and $q \rightarrow 0$). As density (and flow) increases speed is reduced until flow is maximum (q_m), and speed and density approach their optimum values ($v \rightarrow v_0$ and $\rho \rightarrow \rho_0$). Further increase in density results in lower speeds and lower flows until density reaches its maximum value (ρ_j) and correspondingly speed and flow approach zero ($v \rightarrow 0$ and $q \rightarrow 0$). Here it is to be noted that flows can be represented on the speed-density diagram as contour lines with maximum flow contour (q_{m}) just touching the speed-density line at optimum values of speed and density (v_0 and ρ_0).

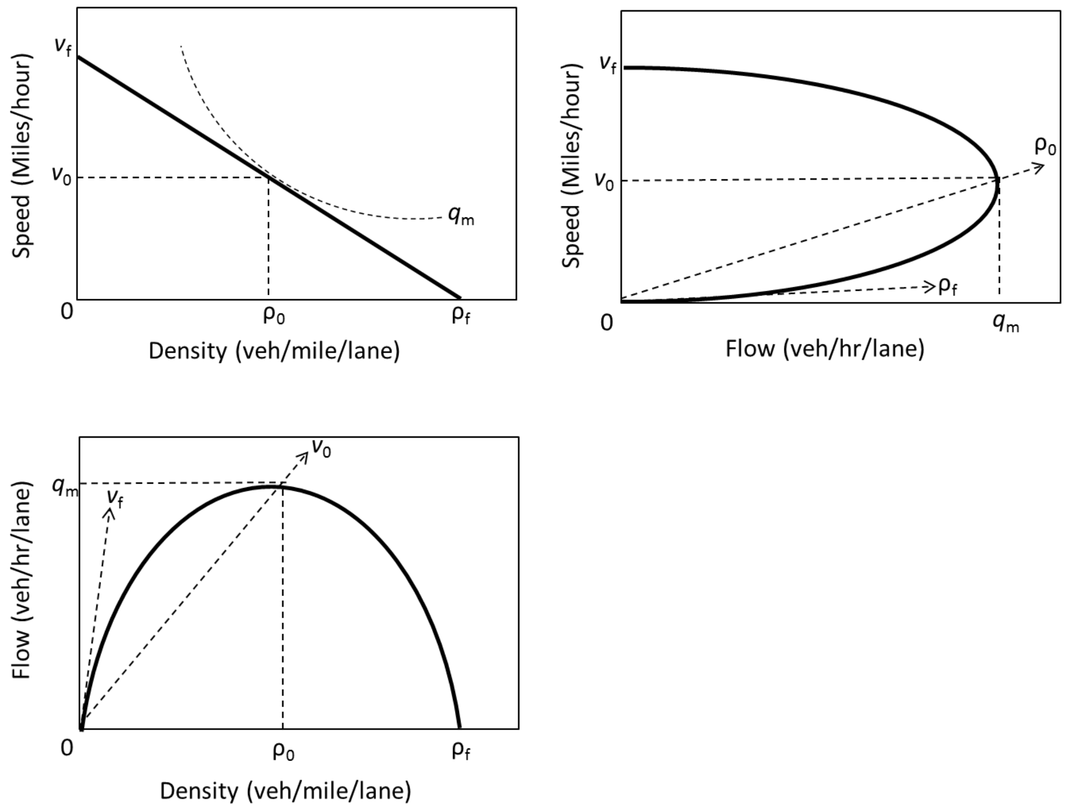


Figure 2.1 Fundamental Diagrams

The flow-density relationship is shown directly below the speed-density relationship in figure 2.1 because of their common horizontal scales. Under very low density conditions ($\rho \rightarrow 0$), flow approaches zero ($q \rightarrow 0$), and speed approaches free-flow speed ($v \rightarrow v_f$). As flow increases, density increases while speed is decreasing. When optimum density is reached, flow becomes maximum. Further increase in density results in decreased flow until finally, as jam density is reached and flow approaches zero. Here, speeds can be represented on the flow-density diagram as radial lines extending up to the right from the origin. Steeper-sloped lines represent higher speeds; that is, a vertical line represents a speed of infinity while horizontal line represents a speed of zero. The slope of flow-density curve is when maximum flow occurs.

The speed-flow relationship is shown directly to the right of speed-density relationship in figure 2.1 because of their common vertical scales. The upper limb of the speed-flow curve is described as the free-flow regime and lower limb is referred as congested flow regime. Under free-flow conditions, the speed decreases as the flow level increases up to the maximum flow. Further speed restrictions coupled with flow reductions are encountered when density exceeds optimum density.

2.3 FD Model

Modeling of the speed–density relationship began with the Greenshields' linear model in the seminal paper: A Study in Highway Capacity (Greenshields, 1935). There has been a fairly large amount of effort afterwards to revise or improve such an over-simplified relationship. These efforts include Greenberg's Model (Greenberg, 1959), the Underwood Model (Underwood, 1961), Northwestern (Drake and May, 1967; Drew, 1968), Pipes–Munjal Generalized Model (Pipes, 1967), Newell's Model (Newell, 1961), Del Castillo and Benitez Model (Del Castillo, 1995a,b), Modified Greenshields Model (Jayakrishnan and Tsai, 1995), Kerner and Konhäuser Model (Kerner and Konhäuser, 1994), Van Aerde Model (Van Aerde, 1995) and MacNicolas Model (MacNicholas, 2008). From the vast literature, it is found that many models exist for modeling the static $v-\rho$ or $q-\rho$ relationship. Although the function expressions are different; they are more or less similar in the domain $\rho \in [0, \rho j]$. However, some of them do not satisfy the two boundary conditions $v(0) = vf$, $\rho = 0$ simultaneously. Few classical and non-classical models are discussed as below.

2.3.1 Classical FD models

The Greensheilds Model: The model was proposed by Greenshields (1935) as a linear model to analyze the relationship between speed, flow and density. The model is simple and satisfies all boundary conditions, (v = 0 at $\rho = \rho_j$ and $v = v_f$ at ρ = 0), but the goodness of fit is generally not high, particularly for freeway data. The Greenshields formulation is as follows:

$$v = v_f \left(1 - \frac{\rho}{\rho_j} \right) \tag{2.1}$$

Where: v – speed, ρ – density, v_f – free-flow speed, ρ_j – jam density.

The Greenberg Model: Proposed by Greenberg in 1959, the model uses a fluid flow analogy and data from the Lincoln Tunnel in New York to establish a logarithmic relation between speed and density, namely

$$v = v_c \ln \frac{\rho_j}{\rho} \tag{2.2}$$

Where v_c is the speed at capacity.

This model does not satisfy the boundary condition at the low concentration regime ($v \to \infty$ at $\rho=0$) but behaves well under congested conditions ($v = 0$ at $\rho = \rho_j$).

The Underwood Model: Developed by Underwood in 1961, the model hypothesizes an exponential relationship between density and speed. The model is observed to generally have a better fit than the Greenshields and Greenberg models for the uncongested traffic conditions, but does not present a good fit to the data for congested conditions. The Underwood model is as follows:

$$v = v_f e^{-\rho/\rho_o} \tag{2.3}$$

Where, ρ_o is optimum density.

The Drake Model: This model was developed by Drake in 1967. He studied the various macroscopic traffic models postulated at that time and did not find any of them statistically significant. In developing his model, he estimated the density from speed and flow data, fitted the speed vs. density function and transformed the speed vs. density function to a speed vs. flow function. His model generally yields a better fit than the above three models for uncongested conditions. However, as in the Underwood case, it is not a good fit for congested conditions. The formulation of the Drake model is as follows:

$$v = v_f \ e^{\left[-\frac{1}{2}\left(\frac{\rho}{\rho_o}\right)^2\right]} \tag{2.4}$$

2.3.2 Non-classical FD model

There are many combinations and modifications of the classical models which are known as non-classical model. Few non-classical models are discussed below:

Edie Model: It is a combination of the Greenberg model and Underwood Model. This combination removed some shortcomings such as the boundary conditions of those two models. Edie model is expressed as:

$$v(\rho)=\begin{cases} \mathrm{e}^{\left(-w_1\frac{\rho}{\rho_j}+w_2\right)}, \rho \le \rho_j \\ g_1+g_2\ln\left(\dfrac{\rho}{\rho_j}\right)^n, \rho \rangle \rho_j \end{cases} \tag{2.5}$$

The Modified Greenberg Model: Considering that even under very light traffic conditions there are always some vehicles on the freeway, the modified Greenberg model introduces a non-zero average minimum density, ρ_0 , in the Greenberg model (Ardekani & Ghandehari, 2008). The modified Greenberg model formulation is as follows:

$$q=v_c\rho\ln\frac{\rho_j+\rho_0}{\rho+\rho_0} \tag{2.6}$$

Where, ρ_0 is the average minimum density, v_c is the speed at capacity.

Unlike the classic Greenberg model, the modified version yields a finite free flow speed of $v_f = v_c \ln(1+\rho_j / \rho_0)$ when density approaches zero.

The Underwood Model with Taylor Series Expansion: The Underwood model does not yield a solution for the jam density when speed approaches zero. But the exponential function can be expanded in a Taylor series obtaining a numerical approximation for the jam density

$$v=v_f e^{-\rho/\rho_c}=v_f\left(1-\frac{\rho}{\rho_c}+\frac{\rho^2}{2\rho_c^2}-\frac{\rho^3}{6\rho_c^3}+\frac{\rho^4}{24\rho_c^4}-\frac{\rho^5}{120\rho_c^5}+\text{........}\right) \tag{2.7}$$

Taking up the term containing ρ^3 yields

$$v=v_f e^{-\rho/\rho_c}=v_f\left(1-\frac{\rho}{\rho_c}+\frac{\rho^2}{2\rho_c^2}-\frac{\rho^3}{6\rho_c^3}\right) \tag{2.8}$$

For v=0, the solution of equation (2.7) gives an estimate for the jam density.

The Drake Model with Taylor Series Expansion: As in the case of the Underwood, the Drake model also does not yield a solution for the jam density when speed approaches zero. Hence, we can use the Taylor series expansion to obtain a numerical approximation for the jam density, as follows:

$$v = v_f \left(1 - \frac{\rho^2}{2\rho_c^2} + \frac{\rho^4}{8\rho_c^4} - \frac{\rho^6}{48\rho_c^6} \right) \tag{2.9}$$

Again, at v=0 the solution of equation (2.8) would yield an estimate for the jam density, $\rho_{j.}$

The Polynomial and Quadratic Models: We can also express the relationship between density and speed in terms of a second degree polynomial equation namely

$$v = v_f + b\rho + c\rho^2 \tag{2.10}$$

,

Where, b and c are additional model parameters

Alternatively, the speed vs. density relationship may be expressed as a quadratic equation of the form

$$v = v_f \left(1 - \frac{\rho^2}{\rho_j^2} \right) \tag{2.11}$$

The following polynomial model is cited in (Zhang, 1999) as the one-parameter polynomial model:

$$v = v_f \left(1 - \left(\frac{\rho}{\rho_c} \right)^n \right) \tag{2.12}$$

Where, v_f = the free-flow speed, ρj = the Jam density, n=1 is the Greensheild model.

Exponential Model: An exponential model used by papageorgiou (2002) and Hegyi et al (2002) as follows:

$$v(\rho) = v_f \exp\left(-\frac{1}{a} \left(\frac{\rho}{\rho_c} \right)^a \right) \tag{2.13}$$

Where, v_f = free-flow speed, a=model parameter, ρ_c= Critical density. It generalizes somehow the Underwood model.

Generalized Polynomial Model for v (ρ)

It can be shown that most previous models can be approximated by or generalized to the following polynomial with non-negative coefficients and possibly non-integer power:

$$v(\rho) = v_m \left[1 - \sum_{i=0}^{N} a_i \left(\frac{\rho}{\rho_j} \right)^{b_i} \right], \quad b_i > 0,\ a_i \geq 0,\ i = 0, 1, \ldots\ldots, N \tag{2.14}$$

to avoid any ambiguity, $b_i \neq b_j$ for $i \neq j$. Equation (2.12) is called Generalized Polynomial FD Model. The nonnegative coefficients (a_0, a_1, a_2,….., a_N) are to be determined by fitting from practical data. The concavity is an important property for FD for the following reasons: (a) modeling of the static relationship; (b) understanding average driver behavior; and (c) its potential application in traffic control. The concavity holding for previous models is also true for the Generalized Polynomial FD model (2.12) in $q - \rho$ relationship for $\rho \in [0, \rho_j]$. In fact, it is easy to calculate that

$$\frac{d^2 q(\rho)}{d\rho^2} \langle 0, \qquad \text{for } \rho > 0 \tag{2.15}$$

which means that $q(\rho) = \rho.V(\rho)$ is strictly concave for $\rho>0$ since the coefficients (a_0, a_1, …, a_N) are all nonnegative. It is clear that $v(0)=v_f$ the free flow speed. $v(\rho_j)=0$ leads to the constraint that $\sum_{i=0}^{N} a_i = 1$. It is thus called generalized Polynomial Model with Unit Sum Coefficients (GPMUSC). This model is a generalization of previous models if one considers Taylors series approximation to order N.

Reversed λ Shaped FD: The simplest reversed λ shape FD is to adopt straight line segment for the two limbs as shown in Figure 2.2

With this shape, the slope of the left limb is the homogenous-flow speed v_h. Several possible models for the left and right limbs are listed below.

Left Limb Models:

(1) **Linear Model:** q+a_1+$b_1\rho$, $\rho \leq \rho_c^h$

(2) **Parabolic Model:** $q = \alpha + \beta\rho + \gamma\rho$, $\rho \leq \rho_c^h$

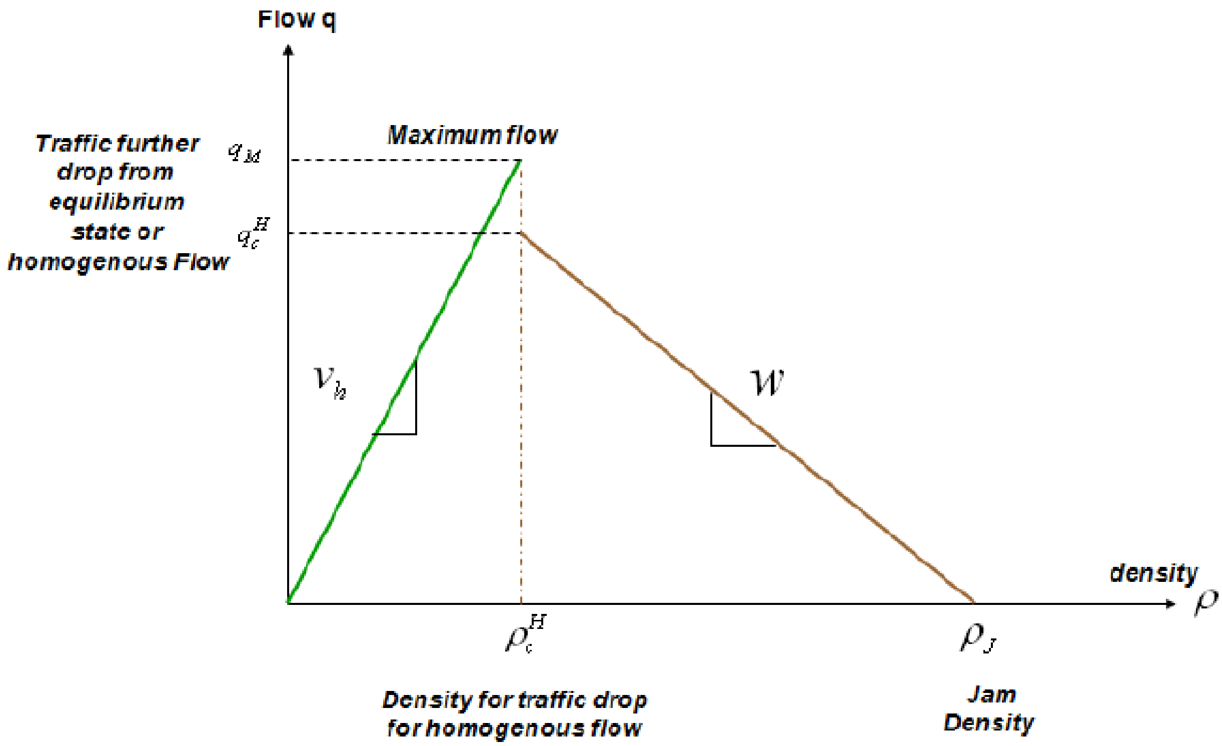


Figure 2.2 Reversed λ Shape FD with both limbs as straight line

Right Limb Models:

(1) Linear model: $q = a_1 + b_1\rho$, $\rho_c^h < \rho \leq \rho$

(2) GPMUSC Model for $\rho_c^h < \rho \leq \rho_j$

(3) Edie model for ρ_c^h $\rho < \rho \leq \rho_j$

2.3.3 Few study on FD model for heterogeneous traffic

Traffic comprising of motorized and non-motorized two-wheelers and three-wheelers along with several other vehicles with no-lane discipline is termed as heterogeneous. From the literature it can be seen that most of the models were validated using the data collected from western countries with homogeneous and lane disciplined traffic conditions. Only limited amount of research has been reported from non-homogeneous traffic conditions in recent years. Kadiyali *et.al* studied the speed flow relationships on different categories of rural highways in India in 1982. They developed linear speed-flow relationships by regression analysis.

In a study Thankappan et al. (2010) investigate the speed-density FD model for heterogeneous traffic. They utilized 1hour video data of 3 week days for peak traffic flow conditions at afternoon from Rajib Gandhi road, Chennai,India. The exponential model was found to be the best for speed-density relationships. The shape of FD was as:

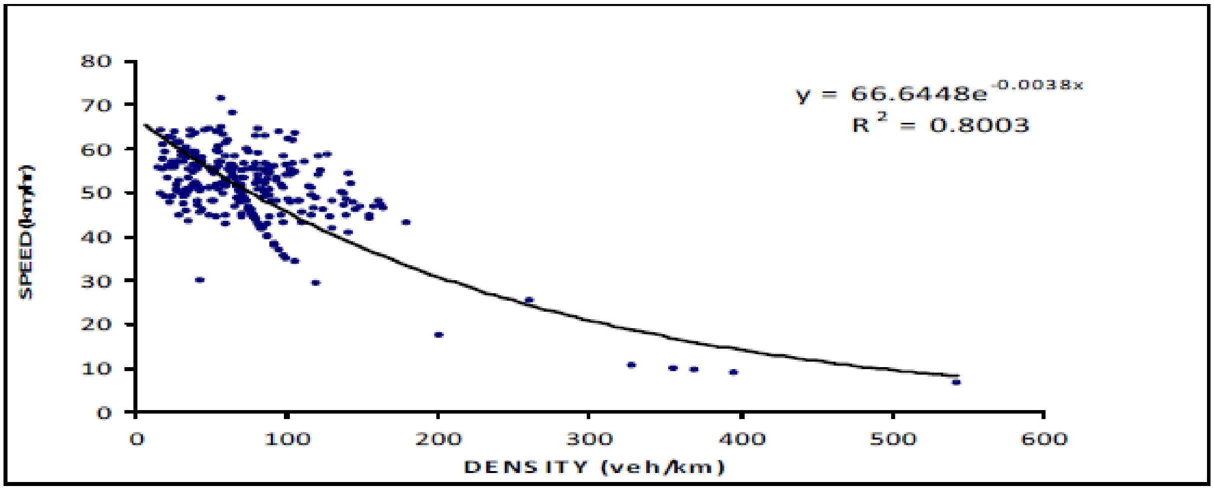


Figure 2.3 FD Obtained by Thankappan et al. (2010)

The exponential model was as:

$$v = 66.6448e^{-0.0038\rho} \tag{2.16}$$

In another study the same author Ajitha Thankappan and Lelitha Vanajakshi (2015) investigate the FD model for the same road with both peak and off-peak traffic data. This time they used video data of 1 hour for each of five week days and 2 hours for each of 3 other week days. They extracted traffic data manually from video footage in laboratory. It was found that an exponential model similar to the Drake model is the best fit in terms of MAPE and RMSE. The form of equation was:

$$v = v_f \exp\left[-0.5\left(\frac{\rho}{\rho_o}\right)^2\right] \tag{2.17}$$

2.4 Summary

This chapter provided an overview of modeling FD to describe the speed-density relationship of traffic flow. It is reviled that most of these models were developed and validated for lane-based homogeneous traffic conditions. But for this case, the traffic is mostly non-lane-based heterogeneous for which standard FD models have not been developed. Hence, this research work aims at developing speed-density model for non-lane-based heterogeneous traffic at different road geometry and traffic operating conditions.

CHAPTER 3

DATA COLLECTION AND PROCESSING

3.1 Introduction

This chapter presents details of the study area selected, the high-resolution data collection method and data processing techniques adopted for the research. The collected data will serve as the basis for the development of the FD models to represent speed-density relationship at different road geometry and traffic operating conditions. Some justification regarding the choice of study site and data collection methods are also provided here.

3.2 Study Area

For this study six different cases of different geometric and traffic operating conditions are considered as mentioned in chapter-1. For six cases, three different areas are considered as study area. For cases 1, 2 and 3 Tongi Diversion Road (From Kuril Flyover to Airport Roundabout) is selected as the study area (Figure 3.1). For cases 4 and 5, a segment (from Kanchpur Bridge to Gumti Bridge) of Dhaka-Chittagong National Highway (N1) is selected as the study area (Figure 3.2). For case-6, a segment (from Tongi to Joydebpur) of Dhaka-Mymensingh National Highway (N3) is selected as the study area (Figure 3.3).

Tongi Diversion Road or Airport Road is an 8-lane (4-lane in one direction) major arterial road in Dhaka that connects the capital city with Shahjalal International Airport. There are 4 through lane in each direction at the study site of this road having total width of 14.5 m to 15 m. At Kuril Flyover both the on and off ramps have two lanes in each direction having total width of 7 m. Having a considerable pedestrian movement some portion of the road does not have footpath at the road side. At some places there are road-side bus stops. The traffic stream at the study site consists of buses, minibuses, cars, jeeps, motorcycles, auto-rickshaws and utility vehicles. However the traffic stream is dominated by buses, private cars and auto-rickshaws having no non-motorized vehicle. Lane discipline is absent both on the road and on the flyover. Such geometric and traffic characteristics make the test-site an ideal study location for non-lane-based heterogeneous condition.

Figure 3.1 Locations of camera at study sites on Tongi Diversion Road

Dhaka-Chittagong Highway is a 4 lane (2 lane in each direction) major National Highway of Bangladesh connecting the capital city with the port city Chittagong which is known as commercial capital city. The road width in each direction is 7.5 m. Existing Meghna Bridge is a 2 lane bridge (1 lane in each direction). So, while approaching towards the bridge the 2 lane in each directon merges into a single lane. At many places of this highway do not have proper shoulder on the side of carriage way. The traffic stream at the study site consists of buses, trucks, minibuses, cars, jeeps, motorcycles, auto-rickshaws, covered vans, and utility vehicles. However, the traffic stream is dominated by buses, trucks and covered vans having no non-motorized vehicle. Lane discipline is absent all through. Because of such geometric and traffic characteristics the test-site is an ideal study location for non-lane-based heterogeneous condition.

Figure 3.2 Locations of camera at study Sites on Dhaka-Chittagong Highway

Dhaka-Mymensingh Highway is a 4 lane (2 lane in each direction) National Highway of Bangladesh connecting the capital city with Mymensingh district town. The road width in each direction is 7.5 m. There is a road-side market in between Tongi and Joydebpur. It is a street market for vegetable, fish, clothing and other comodities. Every morning and afternoon there is a big crowd on the road side due to the presence of this market. The traffic stream at this site consists of buses, trucks, minibuses, cars, jeeps, motorcycles, auto-rickshaws, rickshaws and vans. However, the traffic stream is dominated by buses, cars and auto-rickshaws, rickshaw and vans. Here rickshaws and vans were the non-motorized vehicle. Lane discipline is also absent here. Because of such traffic characteristics the test-site is an ideal study location for non-lane-based heterogeneous condition.

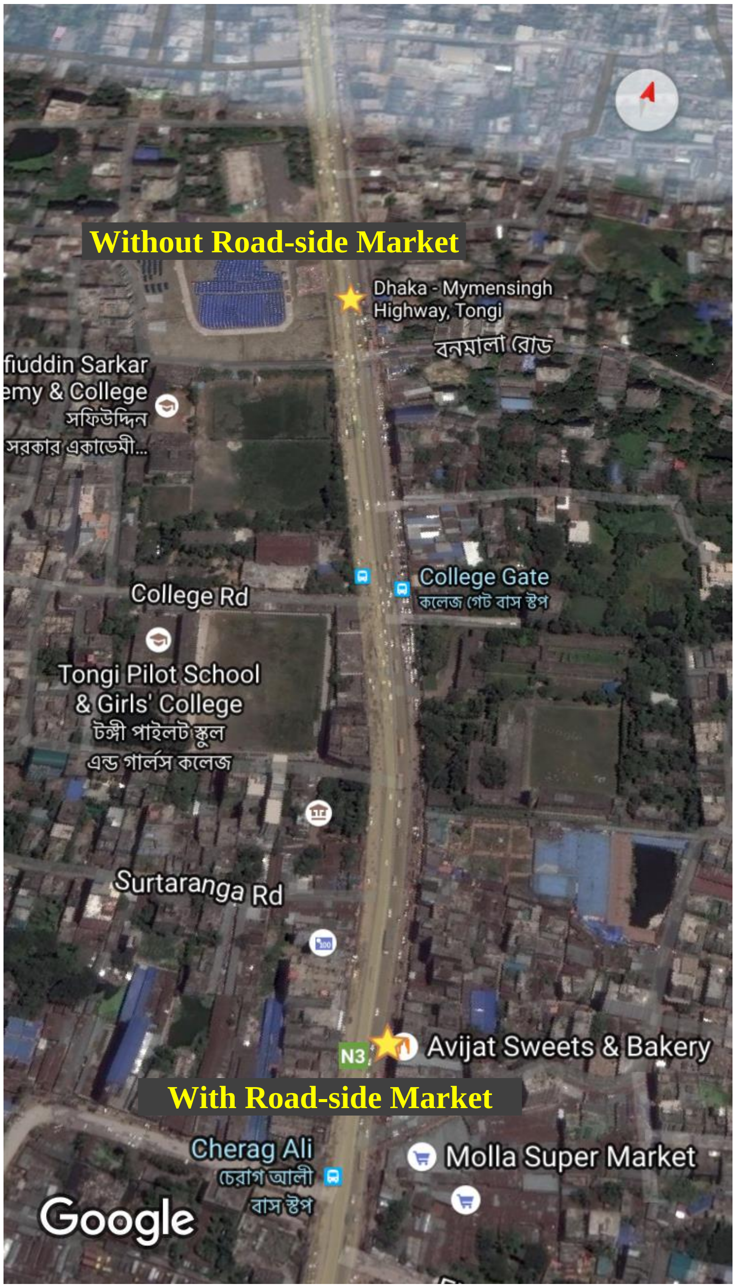


Figure 3.3 Locations of camera at study sites on Dhaka-Mymensingh Highway

3.3 Data Collection Methods

Collection of high-resolution traffic data required for modeling FD is very challenging task under the existing traffic condition of the study area. Generally traffic data is measured by means of detectors located along the road side. Traffic data technologies can be split into two categories: the intrusive and non-intrusive methods.

The intrusive methods basically consist of a data recorder and a sensor placing on or in the road. They have been employed for many years. Some important intrusive methods are pneumatic road tubes, piezoelectric sensors and magnetic loops. Pneumatic road tubes are rubber tubes placed across the road lanes to detect vehicles from pressure changes that are produced when a vehicle tire passes over the tube. The main drawback of this technology is that it has limited lane coverage and its efficiency is subject to weather, temperature and traffic conditions. This system may also not be efficient in measuring low speed flows. Piezoelectric sensors are placed in a groove along roadway surface of the lane(s) monitored. The principle is to convert mechanical energy into electrical energy. Indeed, mechanical deformation of the piezoelectric material modifies the surface charge density of the material so that a potential difference appears between the electrodes. The amplitude and frequency of the signal is directly proportional to the degree of deformation. This system can be used to measure weight and speed. Magnetic loops are the most conventional technology used to collect traffic data. The loops are embedded in roadways in a square formation that generates a magnetic field. The information is then transmitted to a counting device placed on the side of the road. This has a generally short life expectancy because it can be damaged by heavy vehicles, but is not affected by bad weather conditions. This technology has been widely deployed in Europe. However, the implementation and maintenance costs can be expensive.

Non-intrusive techniques are based on remote observations. Even if manual counting is the most used method, new technologies have recently emerged which seem very promising. Few non-intrusive methods are manual counts, passive and active infra-red, passive magnetic, microwave radar, ultrasonic and passive acoustic and video image processing. Manual counts is the most traditional methods but very ineffective for non-lane-based heterogeneous traffic conditions. Other methods are very expensive, affected by weather conditions and also not effective for heterogeneous traffic conditions.

Video cameras can record vehicle numbers, type and speed very easily. By image processing technique it is easy to get traffic data from recorded video. This is an efficient and cost-effective method of high-resolution traffic data collection in heterogeneous traffic condition. So this method is adopted for this study.

3.4 Video Recording

Locations of video camera at different study sites are shown in figure 3.1, 3.2 and 3.3. The main challenge was to install camera at desired height and desired angle. At some locations camera was installed on the foot over bridges, somewhere on the roof tops and other places on the mobile cranes (used for video shooting).

On 15th April 2015 video recording was done at the study site of Tongi Diversion Road by using 6 video cameras installed at six different locations (Figure 3.4). It was done in two phases; from 10:30 am to 1:00 pm 2.5 hours and from 3:00 pm to 5:30 pm 2.5 hours. So for each case 5 hours video was taken for the study. These videos were processed and extracted data were filtered for anomalies. Ultimately 3.5 hours data was used for modeling FD.

(a)

(b)

(c)

Figure 3.4 Video recording at study sites; (a) with bus-stop, (b) without bus-stop, (c) on-ramp

On 25th August 2015 video recording was done at the study site of Dhaka-Chittagong National Highway by using 4 video cameras installed at 4 different locations (Figure 3.5). It was done in two phases; from 10:30 am to 1:00 pm 2.5 hours and from 2:30 pm to 5:00 pm 2.5 hours. So for each case 5 hours video was taken for the study. These videos were processed and extracted data were filtered for anomalies. Ultimately 3.5 hours data was used for modeling FD.


Morning-sun
Double-lane merges
to single-lane
Google

(a)


Camera Location
Morning-sun
Google

(b)

(c)

(d)

Figure 3.5 Video recording at study sites; (a) double lane highway, (b) single lane highway, (c) roadway with shoulder, (d) roadway without shoulder

On 10th and 13th November 2015 video recording was done at the study site of Dhaka-Mymensingh National Highway for the case with and without market respectively (Figure 3.6). Here iPhone 6 with 64 GB memory and external power bank is used for video recording and video is taken from roof top of 3 storied buildings. It was done from 2:00 pm to 5:00 pm for continuous 3 hours. These videos were processed and extracted data were filtered for anomalies. Ultimately 2.5 hours data was used for modeling FD.

(a)

(b)

Figure 3.6 Video recording at study sites; (a) with market, (b) without market

3.5 Data Processing

High resolution (20 sec) traffic data is extracted from video footages. It is then aggregated in 1 minute. Extraction of high resolution traffic data is done by an object detection algorithm (Muniruzzaman et al. 2016) which operates basing on the Background Subtraction (BGS) technique of image processing. The developed algorithm can successfully detect non-lane-based movement of vehicles. It can also identify different sizes of motorized and non-motorized traffic, dark car and shadow quite accurately. Video data and vehicle geometry are provided as input to the algorithm and it gives vehicle count and time mean speed at required intervals as the output. For measuring flow, strip based counting method combining successive incremental differentiation is used. On the other hand, for measuring speed, the algorithm segments the whole field of vision and detects the change in center of area of an object in each segment to find the corresponding pixel speed. Then calibrating the pixel distance with the field distance, instantaneous and time mean speeds are obtained, which can easily be converted to space mean speed. The density of the traffic stream for the research is estimated from the measured flow and speed. The developed algorithm has been proved to give highly accurate traffic data with Mean Absolute Error (MAE) of only 14.01 and 0.88 in flow and speed measurements respectively when compared with actual field measurements. The algorithm addresses some of the major problems faced in the BGS technique, like the camouflage effect, camera jitter, sudden illumination variation, low camera angle and elevation etc. The process of traffic detection by the algorithm is briefly illustrated below.

3.5.1 Traffic detection technique

The background modeling algorithm used for traffic detection in this research is quite simple and accurate. It involves the use of static frames for object extraction from a video stream or image. Traffic is detected according to the following basic steps.

Step 1: Choosing the static background model (B)

This is the primary step of static background subtraction technique. The background model is a frame within the video having no traffic in it. This background is selected up careful inspection of the video. Figure 3.7 shows such a background model used for traffic detection from the video of the off-ramp location of the study site.

Figure 3.7 Background model (B)

Step 2: Selecting the frame (I) on which vehicle detection is to be performed

Using an iteration process, the frame on which the detection should be performed is to be selected one by one from the video file. Figure 3.8 shows a typical frame for traffic detection.

Figure 3.8 Random frame (I) for vehicle detection

Step 3: Determining the absolute difference (D) between B and I

The difference between the static background model B and the traffic detection frame I give the differential image where only the traffic exists. For example, Figure 3.9 is the differential image of the frame I of Figure 3.8.

Figure 3.9 Differential images (D) of frame I

Step 4: Converting differential image into binary image

In order to make the differential image machine readable, it is converted into binary image using a "threshold value." The selection of proper threshold value is very important for accurate vehicle detection. In the differential image, the pixels having intensities lower than the selected threshold is assigned value "0", whereas those having intensities higher than the threshold are assigned "1". Thus the differential image gets converted into a binary code as in Figure 3.10.

Figure 3.10 Binary images of D

Step 5: Performing morphological operation

Next, some morphological operations are required for enhancing the quality of the binary image by removing unwanted ―noises. For this purpose, binary opening is used. Its magnitude depends on the type of opening algorithms used i.e. square, circular, disk type opening etc. On the other hand, binary closing is needed to recover an object from the binary image. Its magnitude depends on the same factors as opening. The improvement of the quality of binary image after applying opening and closing are shown in Figures 3.11 and 3.12 respectively.

Figure 3.11 Binary image after opening

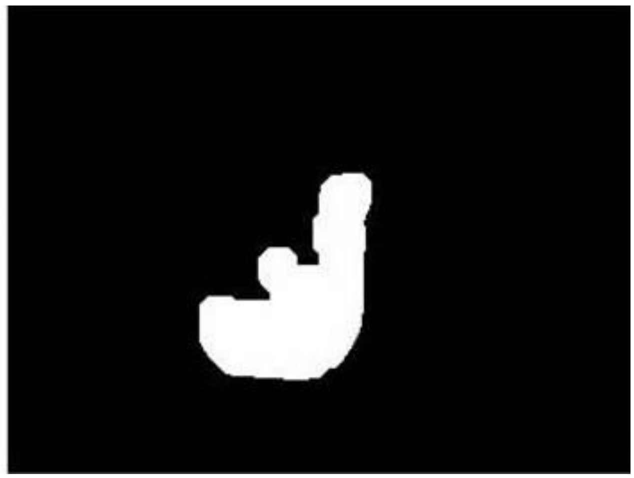


Figure 3.12 Binary image after closing

3.6 Summary

This research aims at modeling FD for non-lane-based heterogeneous traffic conditions of Bangladesh. For this high-resolution data is the pre-requisite. The current chapter introduced the test section used in this research along with details of the video-based data collection method adopted. It then briefly discussed the image processing technique used here for extracting speed and density data from the video footages of the test site. The measured high-resolution data will be used for the development and analysis of the FD model in the subsequent chapters.

CHAPTER 4

MODELING FUNDAMENTAL DIAGRAM AND ANALYSIS

4.1 Introduction

FD is the basic tool in understanding the behavior of traffic stream characteristics in both microscopic and macroscopic traffic flow models. In order to investigate traffic flow parameters finding the shape and structure of FD is one of the most important requirements. FD gives functional relationships between three basic parameters (speed, density and flow rate) of traffic flow for an equilibrium state. However, speed-density relationship is the main focus of this research. This chapter presents developments of FD models for different road geometry and traffic operating conditions for non-lane based heterogeneous traffic of Bangladesh. Then the shape and structure of best fitted model will be investigated for all the cases. Finally, it will also investigate, how the flow parameters e.g. the free-flow speed and jam-density change with the change of road geometry and traffic operating conditions.

4.2 FD Investigation for Different Road Geometry and Traffic Operating Conditions.

Six different cases are considered for this research. Six different FD models namely, linear, polynomial of 2nd and 3rd degree, exponential of 1st degree and 2nd degree and logarithmic models are developed from the extracted data. Correlation coefficient (R^2) and root mean square error (RMSE) are used for evaluating fitness of different FD structures.

4.2.1 Case-1: Roadway with and without footpath

For this case Airport Road (From Hotel Radisson to Airport Roundabout) of Dhaka city is selected as the study site.

(a) With footpath

Figure 4.1 represents the FDs modeled for the traffic flow with footpath and Table 4.1 shows other details of these FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.9045) and least RSME (3.189) values. So the best fitted structure of FD for this case is 2nd degree exponential and the equation is:

$$v = 26.31e^{-0.1832\rho} + 50.86e^{-0.01642} \tag{4.1}$$

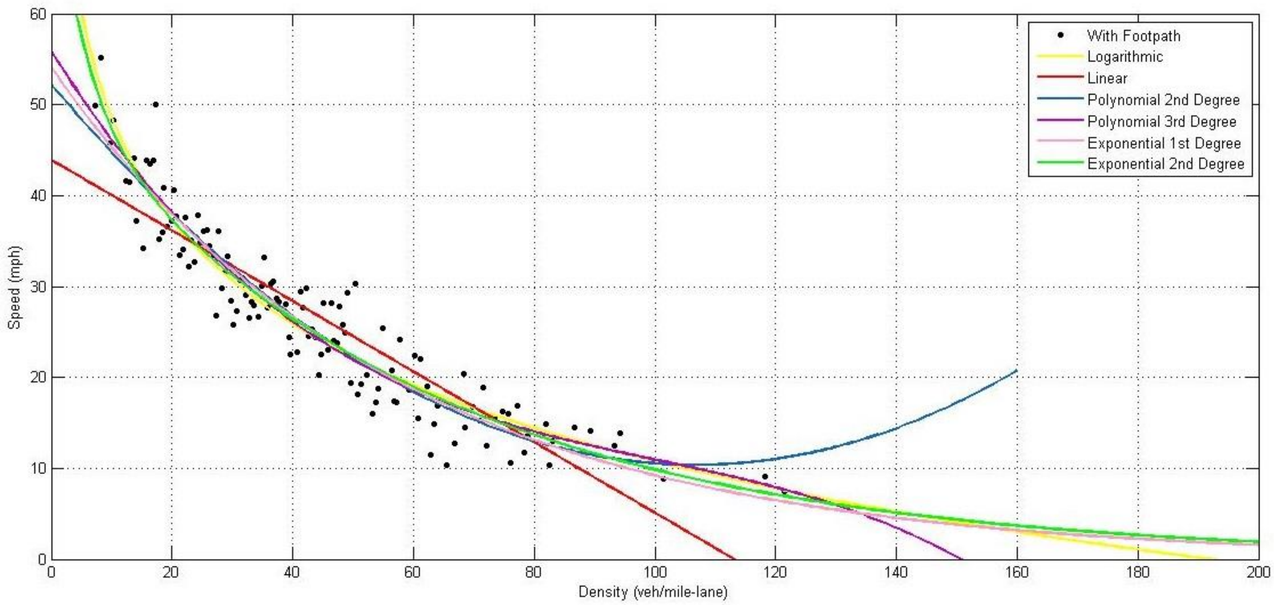


Figure 4.1 FDs for the Traffic Flow in Roadway with Footpath

Table 4.1 Model fitting for the traffic flow on roadway with footpath

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear Model	$v = -0.3882\rho + 43.9$	**0.8248**	**4.283**	**43.9**	**113**
2nd Degree Polynomial	$v = 0.003667\rho^2 - 0.7831\rho + 52.18$	**0.8949**	**3.304**	**52.18**	**106.78**
3rd Degree Polynomial	$v = -3.029\times10^{-5}\rho^3 + 0.009139\rho^2 - 1.06\rho + 55.85$	**0.8994**	**3.233**	**55.85**	**150.68**
1st Degree Exponential	$v = 54.05e^{-0.0177\rho}$	**0.8991**	**3.25**	**54.05**	∞
2nd Degree Exponential	$v = 26.31e^{-0.1832\rho} + 50.86e^{-0.01642}$	**0.9045**	**3.189**	**81.17**	∞
Logarithmic	$v = 86.6 - 16.47\ln\rho$	**0.9041**	**3.214**	∞	**192.1**

(b) Without footpath

Similarly, Figure 4.2 represents the FDs modeled for the traffic flow without footpath and Table 4.2 shows other details of the FD models.

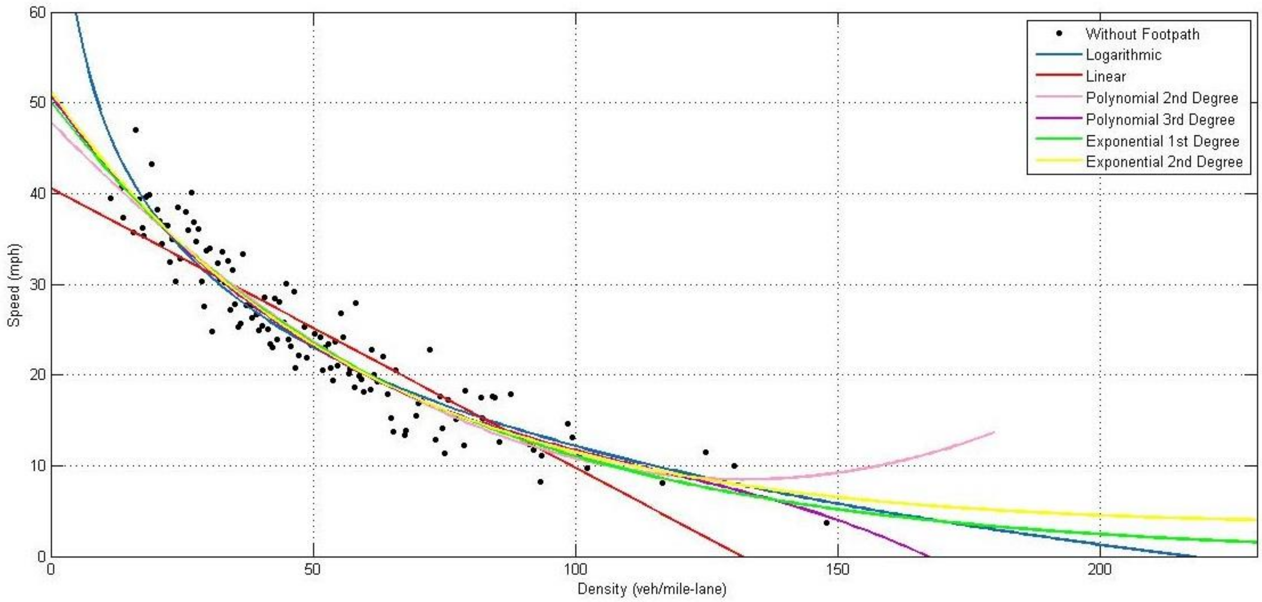


Figure 4.2 FDs for the Traffic Flow in Roadway without Footpath

Table 4.2 Model fitting for the traffic flow on roadway without footpath

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.3082\rho + 40.6$	**0.8345**	**3.695**	**40.60**	**113.73**
2nd Degree Polynomial	$v = 0.002769\rho^2 - 0.5966\rho + 47.86$	**0.8981**	**2.912**	**47.86**	**107.73**
3rd Degree Polynomial	$v = -1.647\times10^{-5}\rho^3 + 0.005697\rho^2$ $-0.7959\rho + 50.78$	**0.8811**	**3.067**	**50.78**	**173.68**
1st Degree Exponential	$v = 50.12e^{-0.01513\rho}$	**0.9004**	**2.867**	**50.12**	∞
2nd Degree Exponential	$v = 49.26e^{-0.01689\rho} + 1.986e^{0.00178\rho}$	**0.9011**	**2.879**	**51.19**	∞
Logarithmic	$v = 84.41 - 15.69\ln\rho$	**0.9041**	**3.214**	∞	**216.99**

Among six models, logarithmic model has the highest R^2 (0.9041) value but RSME (3.214) value is much higher than that of 2nd degree exponential model. On the other hand, R^2 (0.9011) value of 2nd degree polynomial model is slightly less than that of logarithmic model. Considering both R^2 and RSME values the best fitted structure of FD for this case is 2nd degree exponential and the equation is:

$$v = 49.26e^{-0.01689\rho} + 1.986e^{0.00178\rho} \tag{4.2}$$

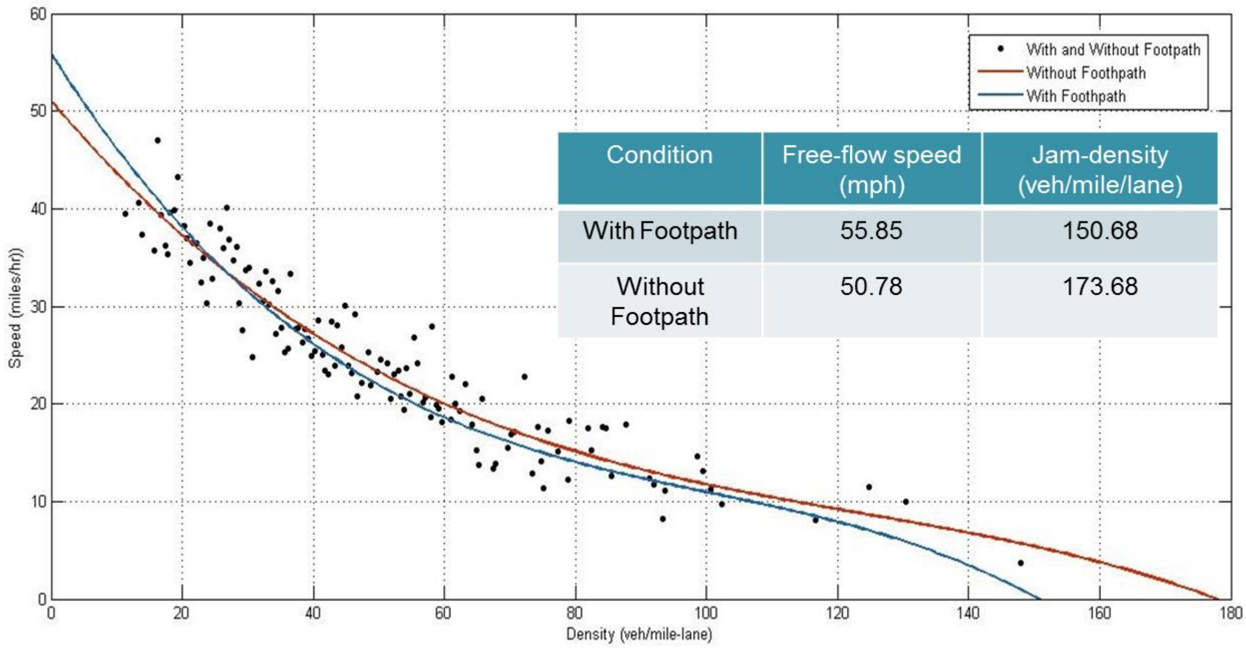


Figure 4.3 Comparison between traffic flow on roadway with and without footpath

(c) Comparisons between two conditions:

In case of both the best fitted models for roadway with and without footpath, jam-densities are infinity as the speed never reaches zero. Among other models 3rd degree polynomial model is the 2nd best model that gives both free-flow speed and jam-density. So for the comparison, 3rd degree polynomial models are considered and shown in figure 4.3. Free-flow speed in location with footpath is found 55.85 mph from the model, whereas it is found 50.78 mph from model in location without footpath. So, free-flow speed is reduced by 9.08 percent due to side friction if there is no footpath on the roadway. Similarly, jam density in location without footpath is found 173.68 veh/mile/lane and in location with footpath is found 150.68 veh/mile/lane. Here it is found that jam-density is increased by 15.26 percent if there is no footpath. Due to low speed the traffic stream remain more compacted and thereby jam-density is increased.

4.2.2 Case-2: Roadway with and without bus stop

For this case another segment of the same road (From Hotel Radisson to Airport Roundabout) of Dhaka city is selected as the study site.

(a) With bus stop

Figure 4.4 represents the FDs modeled for the traffic flow with bus stop and Table 4.2 shows other details of these FD models. Among six models, 2nd degree polynomial model is the best fitted model as it has the maximum R^2 (0.9199) and least RSME (3.615) values. So the best fitted structure of FD for this case is 2^{nd} degree exponential and the equation is:

$$v = 89.51e^{-0.06244\rho} + 26.06e^{-0.007735\rho} \tag{4.3}$$

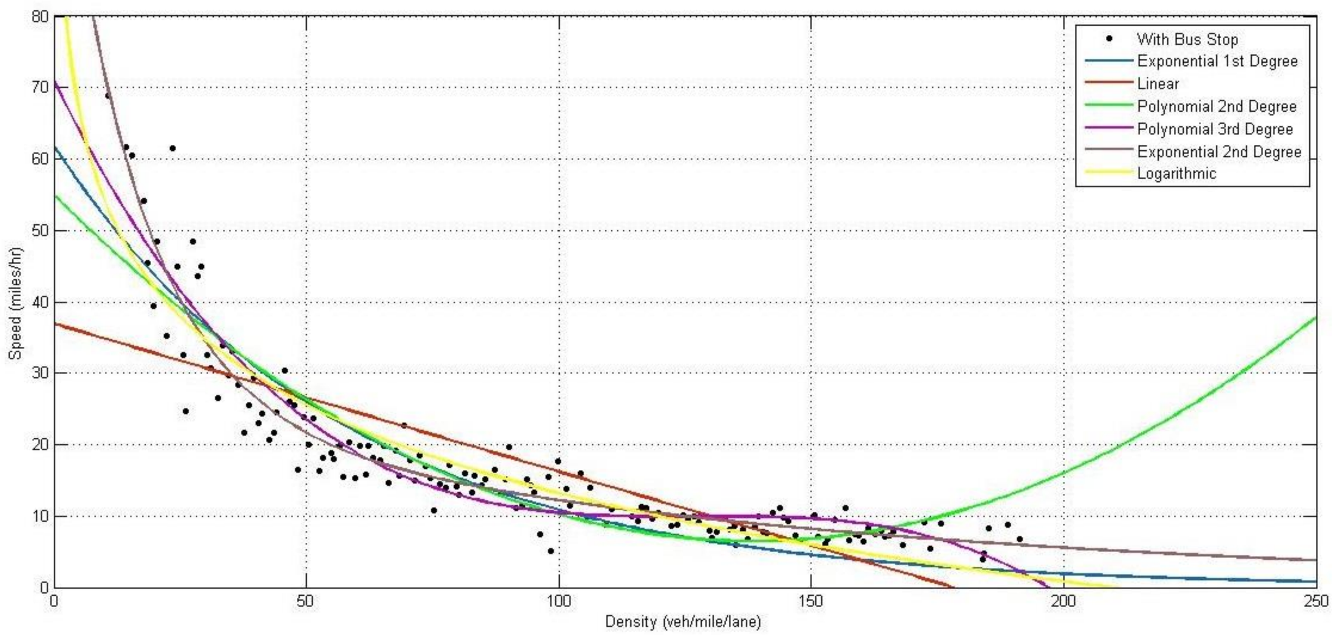


Figure 4.4 FDs for the traffic flow in roadway with bus stop

(b) Without bus stop

Similarly, figure 4.5 represents the FDs modeled for the traffic flow without bus stop and table 4.4 shows other details of the FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.9413) and least RSME (3.346) values. So the best fitted structure of FD for this case is 2^{nd} degree exponential and the equation is:

$$v = 99.9e^{-0.06713\rho} + 17.94e^{-0.008012\rho} \tag{4.4}$$

Table 4.3 Model fitting for the traffic flow on roadway with bus stop

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.2073\rho + 36.91$	**0.6372**	**7.639**	**36.91**	**178.05**
2nd Degree Polynomial	$v = 0.002524\rho^2 - 0.6992\rho + 54.91$	**0.8277**	**5.283**	**54.91**	**138.46**
3rd Degree Polynomial	$v = -2.986\times10^{-5}\rho^3 + 0.01139\rho^2$ $-1.446\rho + 71$	**0.8884**	**4.266**	**71.00**	**196.73**
1st Degree Exponential	$v = 61.8e^{-0.0174\rho}$	**0.8363**	**5.131**	**61.80**	∞
2nd Degree Exponential	$v = 89.51e^{-0.06244\rho} + 26.06e^{-0.007735\rho}$	**0.9199**	**3.615**	**115.57**	∞
Logarithmic	$v = 95.32 - 17.84\ln\rho$	**0.8479**	**4.947**	∞	**211.04**

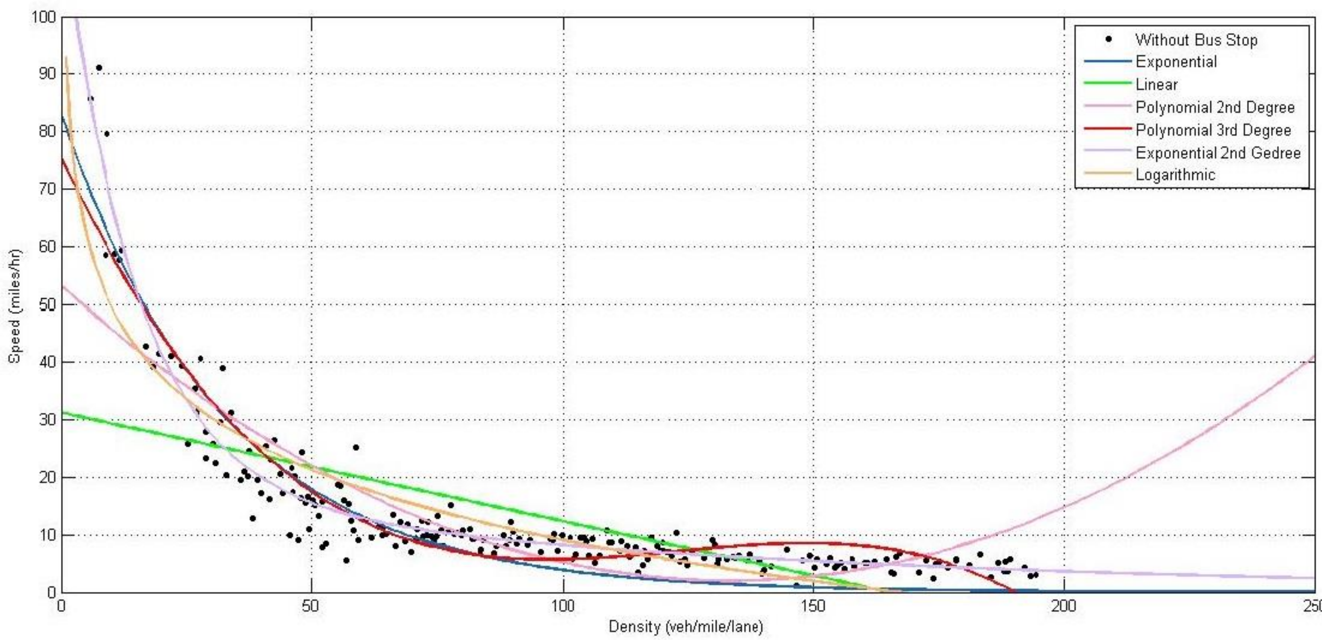


Figure 4.5 FDs for the traffic flow in roadway without bus stop

Table 4.4 Model fitting for the traffic flow on roadway without bus stop

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v=-0.1891\rho+31.23$	**0.47**	**10.01**	**31.23**	**165.24**
2nd Degree Polynomial	$v=0.002875\rho^2-0.7666\rho+53.08$	**0.7359**	**7.081**	**53.08**	**133.32**
3rd Degree Polynomial	$v=-4.227\times10^{-5}\rho^3+0.01559\rho^2$ $-1.833\rho+75.36$	**0.8753**	**4.877**	**75.36**	**189.92**
1st Degree Exponential	$v=82.95e^{-0.03074\rho}$	**0.8486**	**5.348**	**82.90**	∞
2nd Degree Exponential	$v=99.9e^{-0.06713\rho}+17.94e^{-0.008012\rho}$	**0.9413**	**3.346**	**117.84**	∞
Logarithmic	$v=90.23-17.63\ln\rho$	**0.7942**	**6.235**	∞	**167.00**

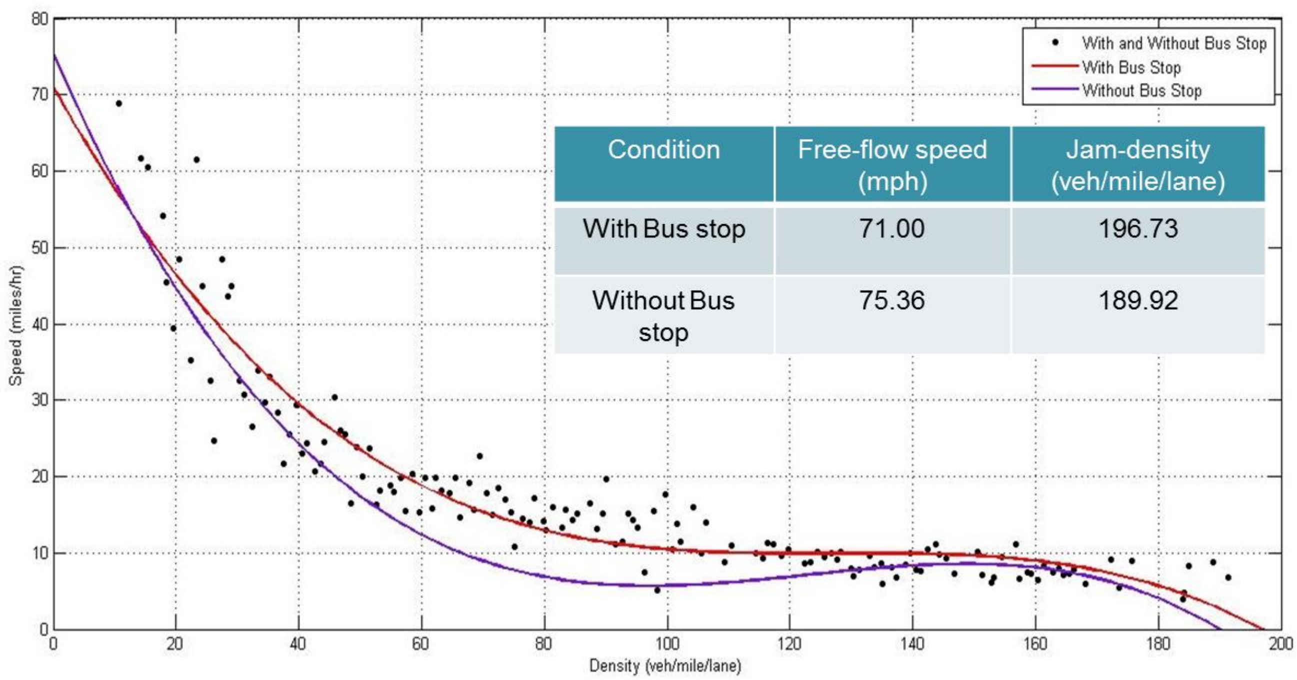


Figure 4.6 Comparison between traffic flow on roadway with and without Bus Stop

(c) Comparisons between two conditions:

In case of both the best fitted models for roadway with and without bus stop, jam-densities are infinity as the speed never reaches zero. Among the other models 3rd degree polynomial model is the 2nd best fitted model that gives both free-flow speed and jam-density. So for the comparison, 3rd degree polynomial models are considered and as shown in figure 4.6. Free-flow speed in location with bus stop is found 71.00 mph from the model, whereas it is found 75.36 mph in location without bus stop. So free-flow speed is increased by 6.14 percent due to absence of road-side bus stop on the roadway. Similarly, jam density in location without bus stop is found 196.73 veh/mile/lane and in location with bus stop it is found 189.92 veh/mile/lane. Here it is found that jam-density is increased by 3.59 percent if there is a bus stop on the road side. Due to low speed for the presence of road-side bus stop, the traffic stream remain more compacted and thereby jam-density is increased.

4.2.3 Case-3: Highway section with on-ramp and off-ramp

For this case, ramps of Kuril Fly-over on Airport Road at Dhaka city are selected as the study sites.

(a) On-ramp

Figure 4.7 represents the FDs modeled for on-ramp traffic flow and table 4.5 shows other details of the FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.7505) and least RSME (3.956) values. So the best fitted structure of FD for this case is 2nd degree exponential and the equation is:

$$v = 34.02e^{-0.08381\rho} + 15.3e^{-0.007293\rho} \tag{4.5}$$

(b) Off-ramp

Similarly, Figure 4.8 represents the FDs modeled for off-ramp traffic flow and Table 4.6 shows other details of the FD models. Among six models, 2nd degree Exponential model is the best fitted model as it has the maximum R^2 (0.7936) and least RSME (2.502) values. So the best fitted structure of FD for this case is 2nd degree exponential and the equation is:

$$v = 36.46e^{-0.06646\rho} + 6.38e^{-0.006742\rho} \tag{4.6}$$

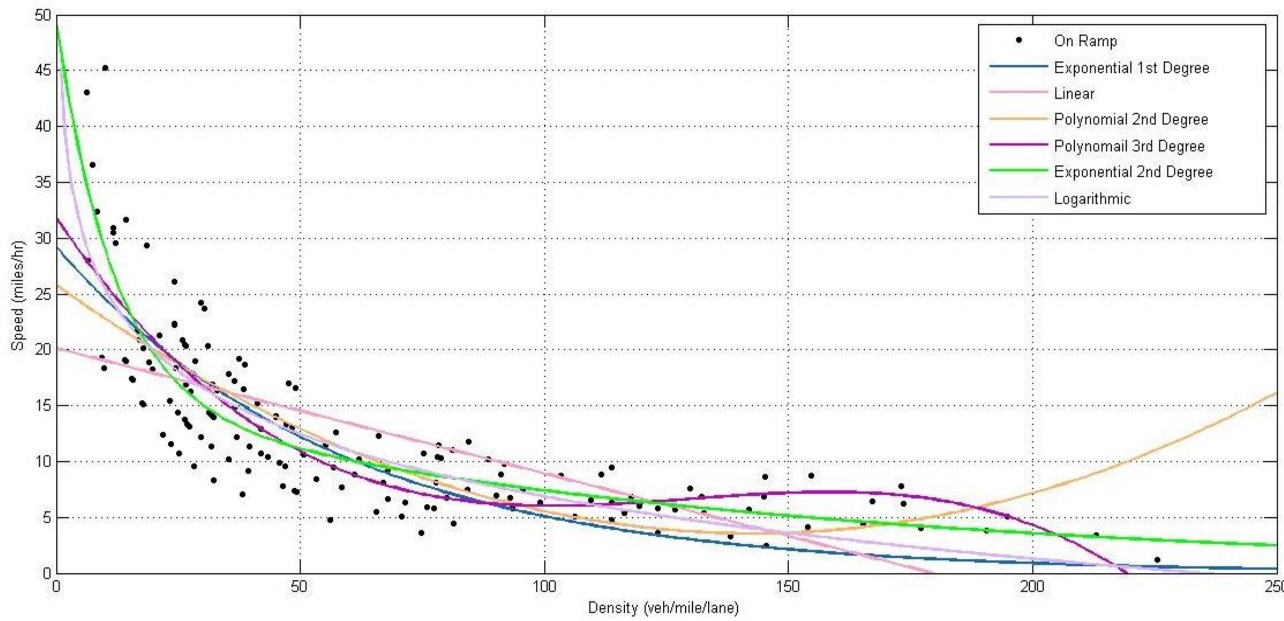


Figure 4.7 FDs for the on-ramp traffic flow

Table 4.5 Model fitting for the on-ramp traffic flow

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.1121\rho + 20.12$	**0.4903**	**5.617**	**20.12**	**179.48**
2nd Degree Polynomial	$v = 0.001092\rho^2 - 0.3116\rho + 25.76$	**0.6371**	**4.755**	**25.76**	**142.67**
3rd Degree Polynomial	$v = -1.341\times 10^{-5}\rho^3 + 0.005225\rho^2 - 0.6461\rho + 31.79$	**0.7154**	**4.226**	**31.79**	**194.81**
1st Degree Exponential	$v = 29.21e^{-0.01749\rho}$	**0.6621**	**4.574**	**29.21**	∞
2nd Degree Exponential	$v = 34.02e^{-0.08381\rho} + 15.3e^{-0.007293\rho}$	**0.7505**	**3.956**	**49.32**	∞
Logarithmic	$v = 43.97 - 8.058\ln\rho$	**0.7113**	**4.228**	∞	**234.32**

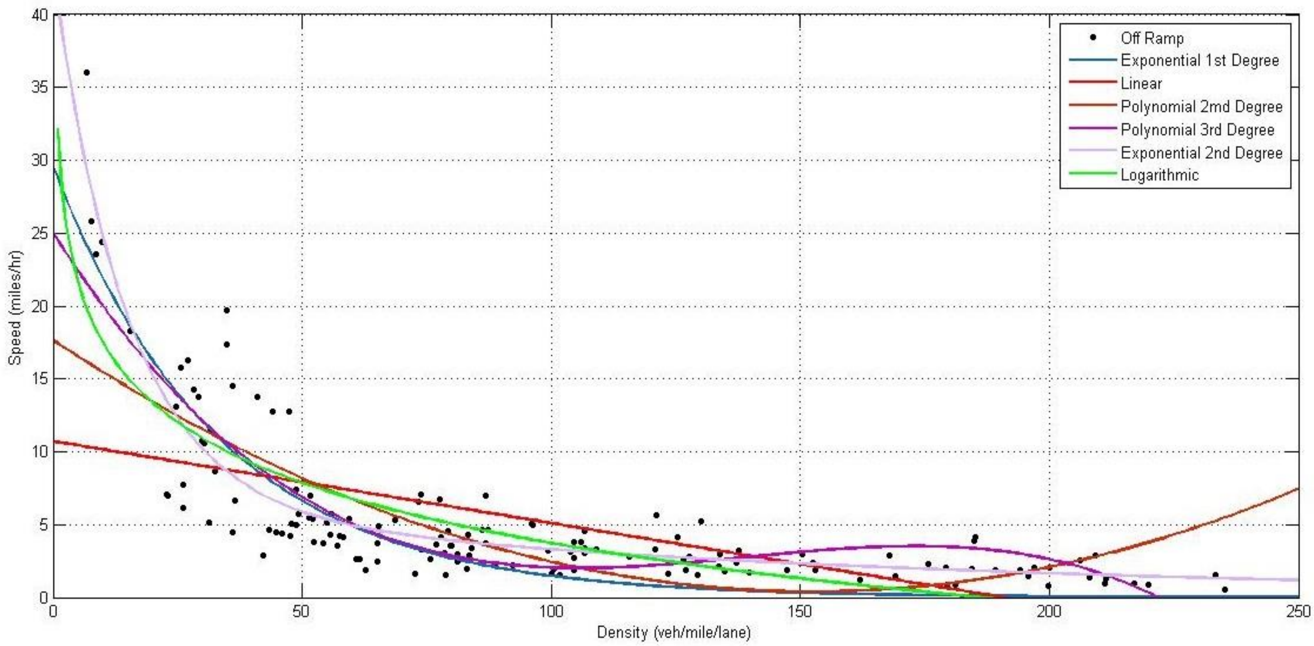
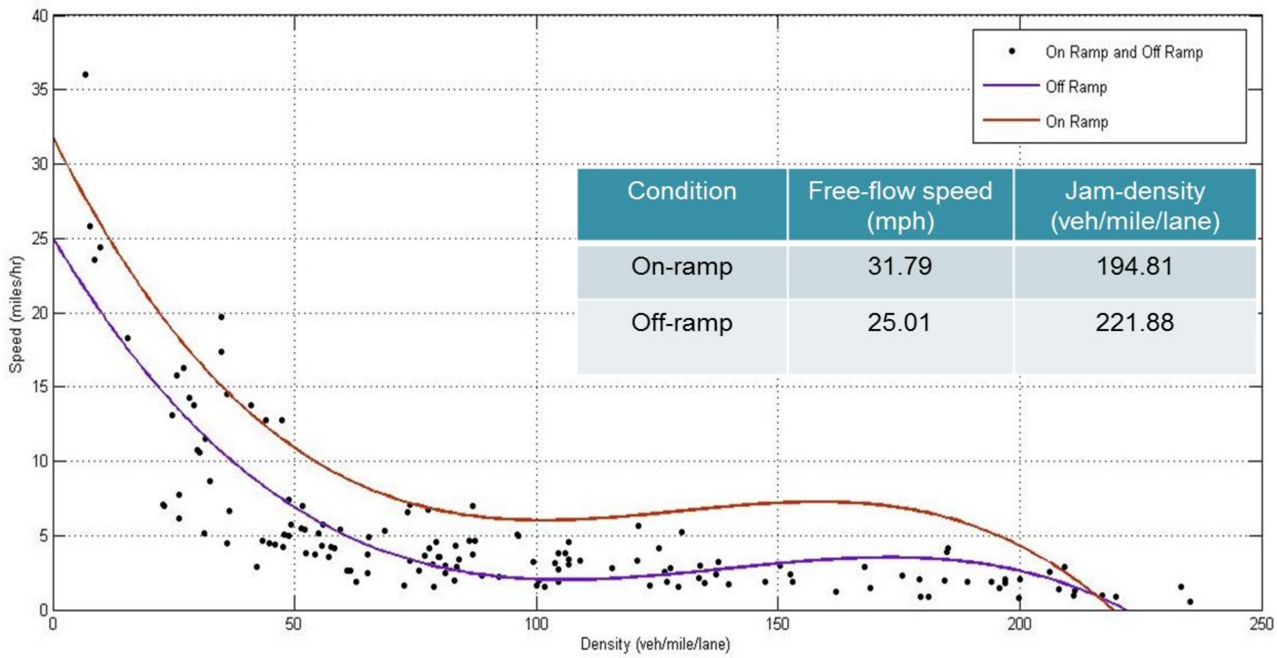


Figure 4.8 FDs for the off-ramp traffic flow

Table 4.6 Model fitting for the off- ramp traffic flow

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.05618\rho + 10.71$	**0.3689**	**4.344**	**10.71**	**190.63**
2nd Degree Polynomial	$v = 0.0007417\rho^2 - 0.2261\rho + 17.63$	**0.587**	**3.527**	**17.63**	**152.42**
3rd Degree Polynomial	$v = -9.913\times10^{-6}\rho^3 + 0.00415\rho^2$ $-0.5455\rho + 25.01$	**0.715**	**2.941**	**25.01**	**221.88**
1st Degree Exponential	$v = 29.58e^{-0.03\rho}$	**0.7038**	**2.976**	**29.58**	∞
2nd Degree Exponential	$v = 36.46e^{-0.06646\rho} + 6.38e^{-0.006742\rho}$	**0.7936**	**2.502**	**42.78**	∞
Logarithmic	$v = 31.22 - 5.971\ln\rho$	**0.6559**	**3.208**	∞	**186.70**



Condition	Free-flow speed (mph)	Jam-density (veh/mile/lane)
On-ramp	31.79	194.81
Off-ramp	25.01	221.88

Figure 4.9 Comparison between on-ramp and off-ramp traffic flow

(c) Comparisons between two conditions:

In case of both the best fitted models for highway section with on-ramp and off-ramp, jam-densities are infinity as the speed never reaches zero. Among the other models, 3rd degree polynomial model is the 2nd best fitted model that gives both free-flow speed and jam-density. So for the comparison, 3rd degree polynomial models are considered and as shown in figure 4.9. Free-flow speed for on-ramp traffic flow is found 31.79 mph from model, whereas it is found 25.01 mph for off-ramp traffic flow. So free-flow speed is decreased by 21.33 percent. Due to over consciousness of driver during off-ramp driving the free-flow speed is decreased. Similarly, jam density for on-ramp traffic flow is found 194.81veh/mile/lane from model and it is found 221.88 veh/mile/lane off-ramp traffic flows. Here it is revealed that jam-density is increased by 13.89 percent from on-ramp to off-ramp traffic flow while the most suitable FD model is considered. Due to low free-flow speed traffic stream remain more compacted in case of off-ramp and thereby jam-density is increased.

4.2.4 Case-4: Multi-lane merged to a single-lane highway

For this case a segment of Dhaka-Chittagong National Highway (N1) beyond Meghna Bridge is selected as the study site (Figure 3.2).

(a) Multi-lane

Figure 4.10 represents the FDs modeled for the traffic flow for multi-lane (double-lane) and table 4.7 shows other details of the FD models. Among six models, both 3rd degree polynomial and 2nd degree exponential models have the same maximum R^2 (0.7947) and least RSME (3.759) values. So here both the models are best fitted models as shown below:

$$v = -1.072 \times 10^{-5} \rho^3 + 0.004096 \rho^2 - 0.5589 \rho + 30.67 \tag{4.7}$$

and

$$v = 30.89 e^{-0.01967 \rho} + 0.0958 e^{0.0958 \rho} \tag{4.8}$$

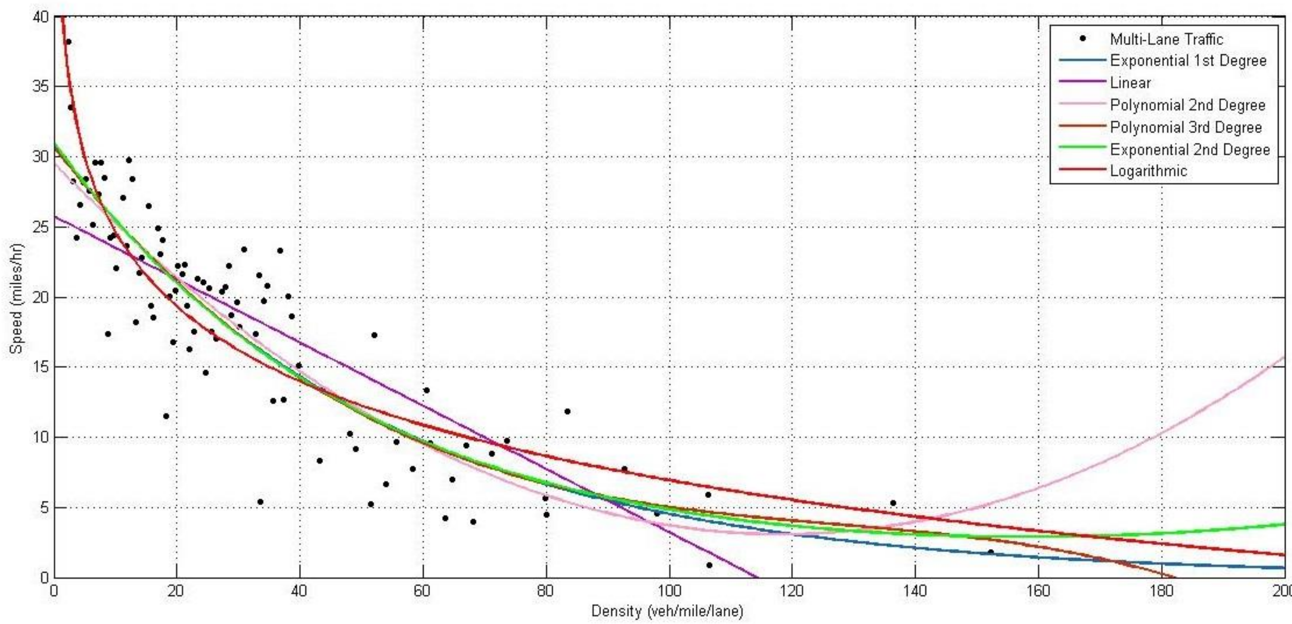


Figure 4.10 FDs for the multi-lane traffic flow

Table 4.7 Model fitting for the multi-lane traffic flow

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.2253\rho + 25.75$	**0.695**	**4.53**	**25.75**	**114.29**
2nd Degree Polynomial	$v = 0.00189\rho^2 - 0.4472\rho + 29.51$	**0.7897**	**3.783**	**29.51**	**118.31**
3rd Degree Polynomial	$v = -1.072\times10^{-5}\rho^3 + 0.004096\rho^2 - 0.5589\rho + 30.67$	**0.7947**	**3.759**	**30.67**	**182.00**
1st Degree Exponential	$v = 30.81e^{-0.01919\rho}$	**0.7942**	**3.721**	**30.08**	∞
2nd Degree Exponential	$v = 30.89e^{-0.01967\rho} + 0.0958e^{0.0958\rho}$	**0.7947**	**3.759**	**30.98**	∞
Logarithmic	$v = 42.35 - 7.693\ln\rho$	**0.7701**	**3.933**	∞	**245.92**

(a) Single-lane

Similarly, figure 4.11 represents the FDs modeled for the traffic flow of single-lane merged from multi-lane and table 4.8 shows other details of the FD models. Among six models, 3rd degree polynomial model is the best fitted model as it has the maximum R^2 (0.7951) and least RSME (3.14) values. So the best fitted structure of FD for this case is 3rd degree polynomial and the equation is:

$$v = -3.227\times10^{-5}\rho^3 + 0.009119\rho^2 - 0.8055\rho + 28.49 \tag{4.9}$$

(c) Comparisons between two conditions:

For both the conditions of single-lane and multi-lane traffic, 3rd degree polynomial model is found as the best model that gives both free-flow speed and jam-density. Comparison between both the conditions is as shown in figure 4.12. Free-flow speed for multi-lane traffic is 30.67 mph whether it is 28.49 mph in case of single-lane traffic flow. So free-flow speed is decreased by 7.11% when multi-lane (double-lane) traffic merged into single-lane traffic. Similarly, jam density in case multi-lane traffic is 182.00 veh/mile/lane and in case of single-lane jam density is 162.31 veh/mile/lane. Here it is found that jam-density is also decreased by 10.82 % for the case multi-lane traffic merged into single-lane traffic.

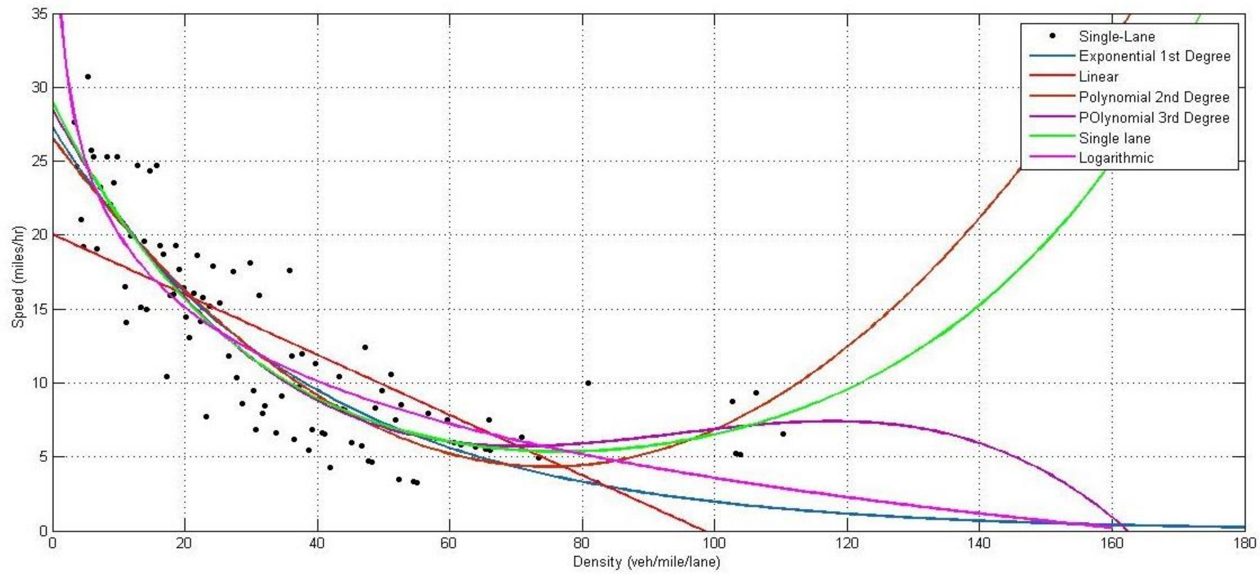


Figure 4.11 FDs for the single-lane traffic flow

Table 4.8 Model fitting for the single-lane traffic flow

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.2037\rho + 20.04$	**0.552**	**4.595**	**20.04**	**98.38**
2nd Degree Polynomial	$v = 0.003965\rho^2 - 0.5938\rho + 26.55$	**0.7855**	**3.196**	**26.55**	**74.88**
3rd Degree Polynomial	$v = -3.227\times10^{-5}\rho^3 + 0.009119\rho^2 - 0.8055\rho + 28.49$	**0.7951**	**3.14**	**28.49**	**162.31**
1st Degree Exponential	$v = 27.291e^{-0.02642\rho}$	**0.7517**	**3.421**	**27.29**	∞
2nd Degree Exponential	$v = 28.64e^{-0.03256\rho} + 0.4267e^{0.0254\rho}$	**0.7931**	**3.156**	**29.07**	∞
Logarithmic	$v = 36.52 - 7.156\ln\rho$	**0.7196**	**3.637**	∞	**165.58**

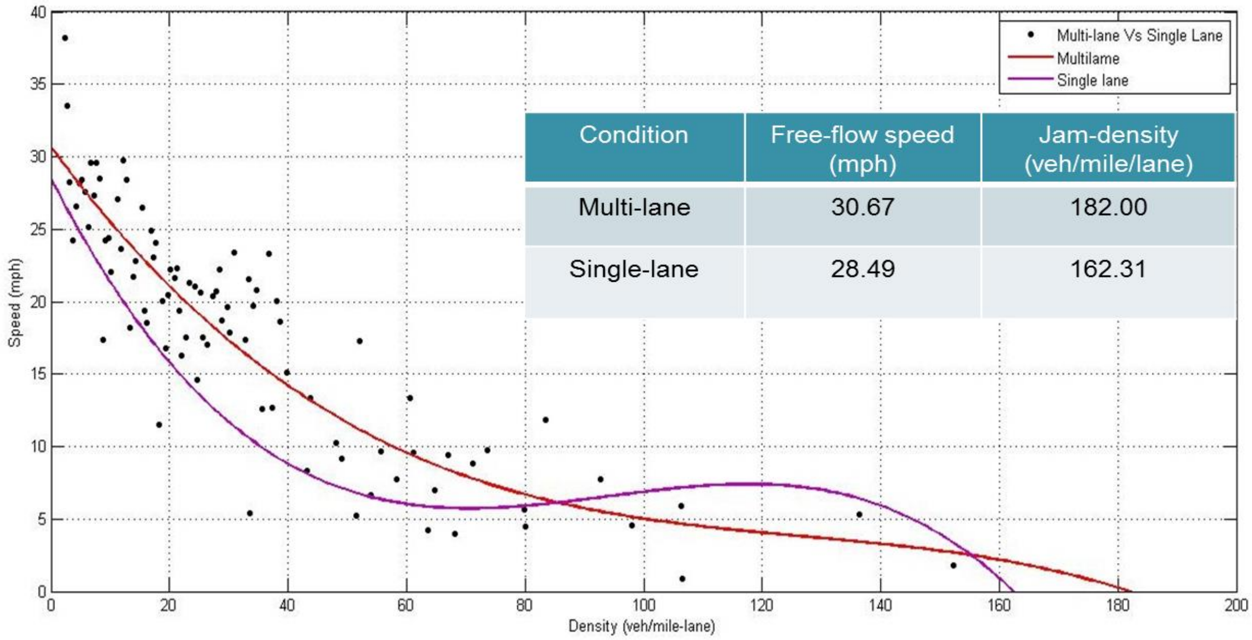


Figure 4.12 Comparisons between multi-lane merging to single-lane traffic flow

4.2.5 Case-5: Roadway with and without shoulder

For this case a segment of Dhaka-Chittagong National Highway (N1) in between Kanchpur Bridge and Meghna Bridge is selected as the study site (Figure 3.2).

(a) With shoulder

Figure 4.13 represents the FDs modeled for the traffic flow on the highway with shoulder and table 4.9 shows other details of the FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.7348) and least RSME (6.157) values. So the best fitted structure of FD for this case is 2^{nd} degree exponential and the equation is:

$$v = 37.46e^{-0.07186\rho} + 12.59e^{-0.01007\rho} \tag{4.10}$$

(b) Without shoulder

Similarly, figure 4.14 represents the FDs modeled for the traffic flow on highway without shoulder and table 4.10 shows other details of the FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.7676) and least RSME

(3.08) values. So the best fitted structure of FD for this case is 2nd degree exponential and the equation is:

$$v = 18.64e^{-0.009431\rho} + 27.8e^{-0.2547\rho} \tag{4.11}$$

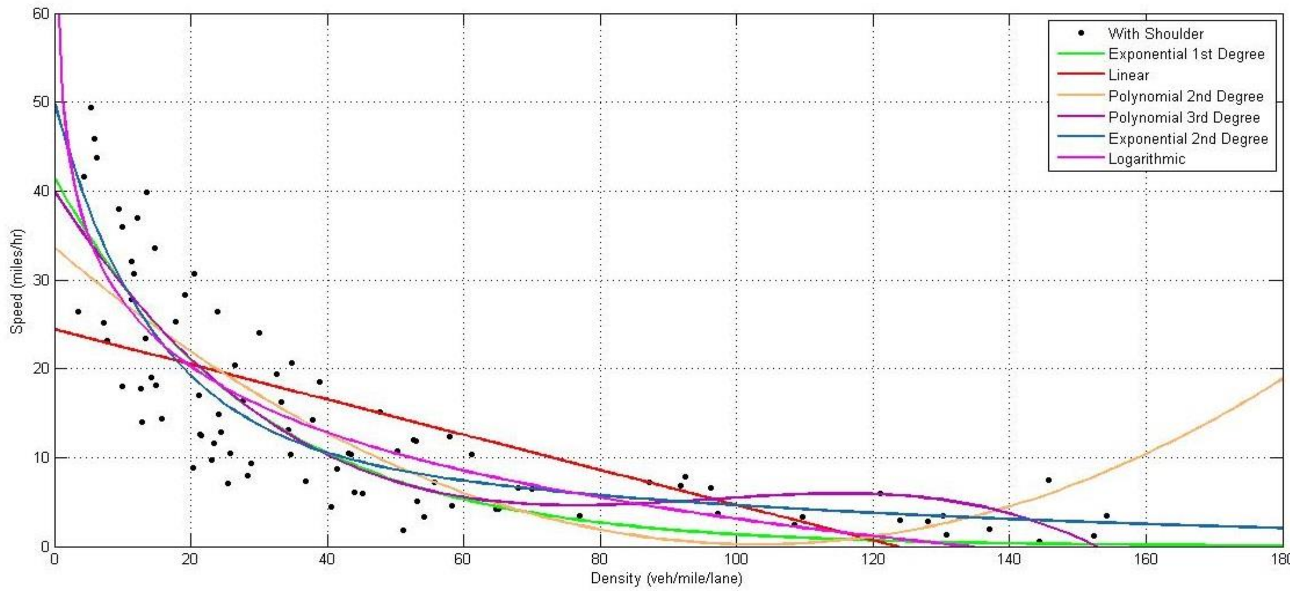


Figure 4.13 FDs for the traffic flow in roadway with shoulder

Table 4.9 Model fitting for the traffic flow on roadway with shoulder

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.1978\rho + 24.42$	**0.4719**	**8.586**	**24.42**	**122.55**
2nd Degree Polynomial	$v = 0.003144\rho^2 - 0.648\rho + 33.59$	**0.6585**	**6.945**	**33.59**	**103.05**
3rd Degree Polynomial	$v = -4.483\times10^{-5}\rho^3 + 0.0129\rho^2$ $-1.187\rho + 39.98$	**0.7138**	**6.396**	**39.98**	**152.43**
1st Degree Exponential	$v = 41.6e^{-0.0338\rho}$	**0.7065**	**6.401**	**41.6**	∞
2nd Degree Exponential	$v = 37.46e^{-0.07186\rho} + 12.59e^{-0.01007\rho}$	**0.7348**	**6.157**	**50.05**	∞
Logarithmic	$v = 52.07 - 10.64\ln\rho$	**0.7**	**6.472**	∞	**133.46**

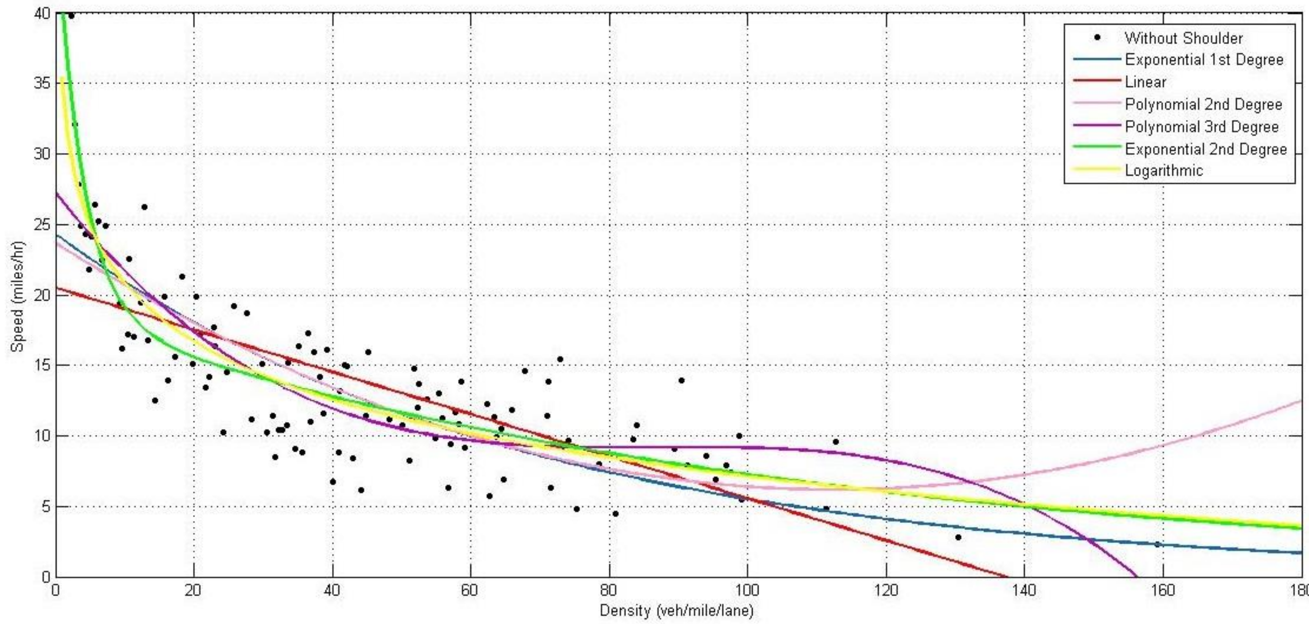


Figure 4.14 FDs for the traffic flow on roadway with shoulder

Table 4.10 Model fitting for the traffic flow on roadway without shoulder

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.1495\rho + 20.49$	**0.5466**	**4.263**	**20.49**	**137.06**
2nd Degree Polynomial	$v = 0.001384\rho^2 - 0.311\rho + 23.65$	**0.6348**	**3.844**	**23.65**	**112.36**
3rd Degree Polynomial	$v = -2.806\times10^{-5}\rho^3 + 0.007306\rho^2 - 0.6312\rho + 27.28$	**0.7131**	**3.423**	**27.27**	**156.21**
1st Degree Exponential	$v = 28.28e^{-0.01484\rho}$	**0.6479**	**3.757**	**28.28**	∞
2nd Degree Exponential	$v = 18.64e^{-0.009431\rho} + 27.8e^{-0.2547\rho}$	**0.7676**	**3.08**	**46.44**	∞
Logarithmic	$v = 34.49 - 5.943\ln\rho$	**0.7542**	**3.139**	∞	**331.45**

(c) Comparisons between two conditions:

In case of both the best fitted models for traffic flow in roadway with and without shoulder, jam-densities are infinity as the speed never reaches zero. Among the other models, 3rd degree polynomial model is the 2nd best fitted model that gives both free-flow speed and jam-density. So for the comparison, 3rd degree polynomial models are considered and are shown in figure 4.15. Free-flow speed for traffic flow in roadway with shoulder is found 39.98 mph whereas; it is found 27.28 mph in case of traffic flow in roadway without shoulder. So free-flow speed is decreased by 31.76 percent. Due to absence of shoulder the free-flow speed is decreased. Similarly, jam density in case of traffic flow in roadway with shoulder is found 152.43 veh/mile/lane and in case of traffic flow in roadway without shoulder jam density is 156.21 veh/mile/lane. Here it is found that jam-density is increased by 2.48 percent if there is no shoulder on highway. Due to low free-flow speed traffic stream remain more compacted in case of without shoulder and thereby jam-density is increased.

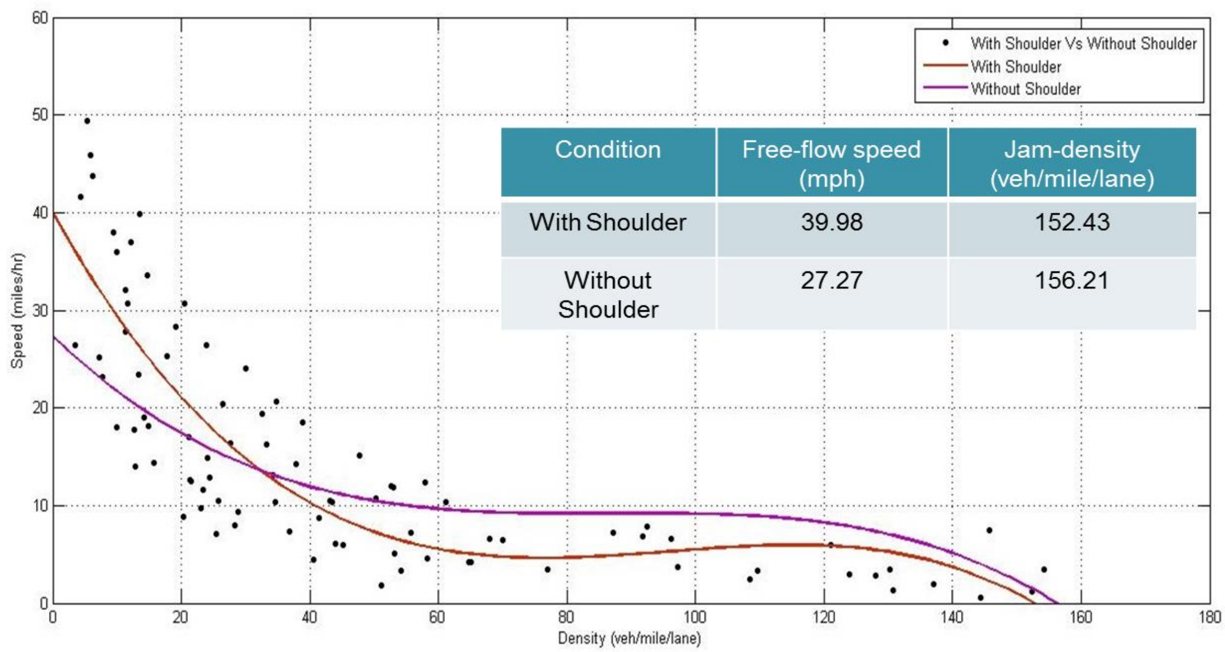


Figure 4.15 Comparison between traffic flow on roadway with and without Shoulder

4.2.6 Case-6: Roadway with and without road-side market

For this case, a segment of Dhaka-Mymensingh Highway is selected as the study site (Figure 3.3).

(a) With road-side market

Figure 4.16 represents the FDs modeled for the traffic flow on the highway with road-side market and Table 4.11 shows other details of the FD models. Among six models, 3rd degree polynomial model is the best fitted model as it has the maximum R^2 (0.8142) and least RSME (2.62) values. So the best fitted structure of FD for this case is 3rd degree polynomial and the equation is:

$$v = -4.598 \times 10^{-6} \rho^3 + 0.002147 \rho^2 - 0.3619 \rho + 27.33 \tag{4.12}$$

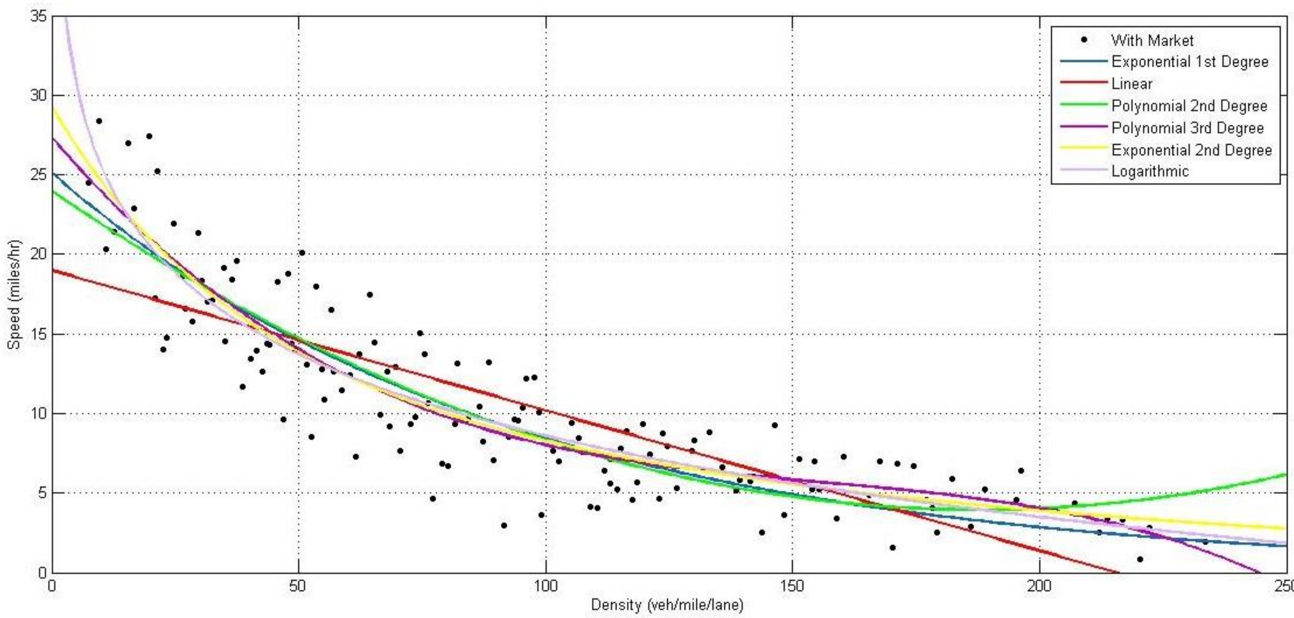


Figure 4.16 FDs for the traffic flow on roadway with road-side market

(b) Without road-side market

Similarly, figure 4.17 represents the FDs modeled for the traffic flow on highway without road-side market and table 4.10 shows other details of the FD models. Among six models, 2nd degree exponential model is the best fitted model as it has the maximum R^2 (0.8225) and least RSME (3.503) values. So the best fitted structure of FD for this case is 2^{nd} degree exponential and the equation is:

$$v = 20.08e^{-0.04527\rho} + 17.09e^{-0.008299\rho} \tag{4.13}$$

Table 4.11 Model fitting for the traffic flow on roadway with road-side market

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.08809\rho + 18.98$	**0.6908**	**3.36**	**18.98**	**215.46**
2nd Degree Polynomial	$v = 0.0005676\rho^2 - 0.2131\rho + 23.95$	**0.7927**	**2.762**	**23.95**	**187.72**
3rd Degree Polynomial	$v = -4.598\times10^{-6}\rho^3 + 0.002147\rho^2$ $-0.3619\rho + 27.33$	**0.8148**	**2.62**	**27.33**	**244.41**
1st Degree Exponential	$v = 25.1e^{-0.01089\rho}$	**0.8000**	**2.703**	**25.1**	∞
2nd Degree Exponential	$v = 14.54e^{-0.02962\rho} + 14.72e^{-0.006712\rho}$	**0.8142**	**2.624**	**29.26**	∞
Logarithmic	$v = 42.49 - 7.36\ln\rho$	**0.8105**	**2.631**	∞	**321.53**

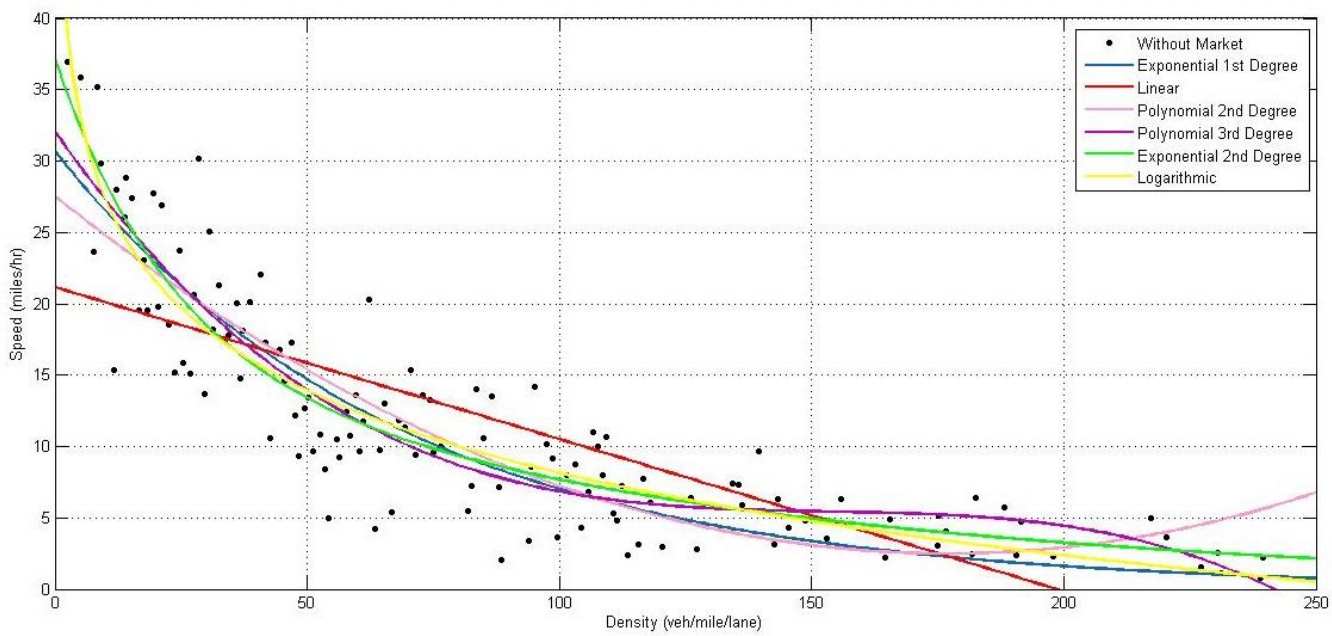


Figure 4.17 FDs for the traffic flow on roadway without road-side market

Table 4.12 Model fitting for the traffic flow on roadway without road-side market

Model	Equation	R2	RMSE	Free-flow Speed (miles/hr)	Jam Density (veh/mile/lane)
Linear	$v = -0.1066\rho + 21.15$	**0.6183**	**5.096**	**21.15**	**198.41**
2nd Degree Polynomial	$v = 0.0007991\rho^2 - 0.2828\rho + 27.51$	**0.7696**	**3.975**	**27.51**	**176.95**
3rd Degree Polynomial	$v = -7.108\times10^{-6}\rho^3 + 0.003272\rho^2 - 0.508\rho + 32.03$	**0.8132**	**3.594**	**32.03**	**241.36**
1st Degree Exponential	$v = 30.68e^{-0.01475\rho}$	**0.7967**	**3.719**	**30.06**	∞
2nd Degree Exponential	$v = 20.08e^{-0.04527\rho} + 17.09e^{-0.008299\rho}$	**0.8225**	**3.503**	**37.17**	∞
Logarithmic	$v = 46.48 - 8.325\ln\rho$	**0.818**	**3.519**	∞	**265.92**

(c) Comparisons between two conditions:

In case of the best fitting models for traffic flow in roadway with and without road-side market, jam-densities are infinity as the speed never reaches zero. Among the other models, 3rd degree polynomial model is the 2nd best fitted model that gives both free-flow speed and jam-density. So for the comparison, 3rd degree polynomial model is considered and is shown in figure 4.15. Free-flow speed for traffic flow in roadway with road-side market is 27.33 mph, whereas it is 32.03 mph in case of traffic flow in roadway without road-side market. So free-flow speed is increased by 17.20 percent. Due to absence of road-side market the free-flow speed is increased. Similarly, jam density in case of traffic flow in roadway with road-side market is 244.41 veh/mile/lane and in case of traffic flow in roadway without road-side market jam density is 241.36 veh/mile/lane. Here it is found that jam-density is increased by 1.26 percent if there is a road-side market on highway. Due to low free-flow speed traffic stream remain more compacted in case of road-side market and thereby jam-density is increased.

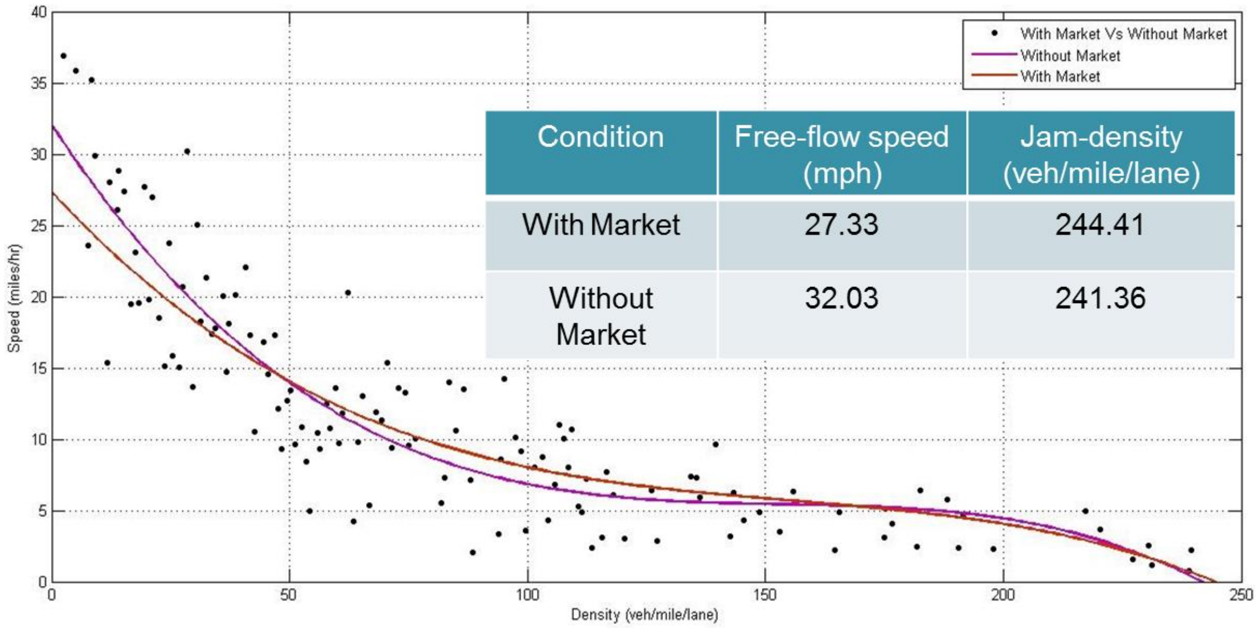


Figure 4.18 Comparison between traffic flow on roadway with and without road-side market

4.3 Results and Findings

From the above analysis it is found that for most of the conditions 2nd degree exponential model is the best fitted FD model except for three conditions, e.g. traffic flow in a multi-lane roadway, traffic flow in a single-lane roadway and traffic flow in a roadway with road-side market. For these three cases 3rd degree polynomial model is the best fitted model. For 2nd degree exponential model, jam-density is infinity as the speed never reaches zero. So for the comparison of flow parameters, free-flow speed and jam-density are calculated from 2nd best fitted 3rd degree polynomial model. The results are compiled in the table 4.13.

The important findings from the study are:

(a) For heterogeneous traffic of Bangladesh, the best fitted FD model is 2nd degree exponential model. The 2nd best model is 3rd degree polynomial model.

(b) If the free-flow speed is decreased, the jam-density is increased except for the case where multi-lane merges to a single lane. When a vehicle moves from multi-lane to single-lane both the free-flow speed and jam-density are reduced.

(c) If there is no footpath along road-side, free-flow speed is decreased by 22.88 percent due to side friction and jam-density is increased by 15.26 percent.

(d) When there is a bus stop along road-side, free flow speed is decreased by 5.78 percent and jam-density is increased by 3.58 percent.

(e) On-ramp free flow speed is more than off-ramp free-flow speed. When the vehicles move from on-ramp to off-ramp the free-flow speed is reduced by 21.32 percent and jam-density is increased by 13.89 percent.

(f) When vehicles move from double-lane road merges to a single-lane road the free-flow speed reduced by 7.11 percent and jam-density is also reduced by 10.82 percent.

(g) If there is no shoulder along road-side, free-flow speed is decreased by 31.76 percent and jam-density is increased by 2.48 percent.

(h) If there is a market on road-side, free-flow speed is decreased by 17.20 percent and jam-density is increased by 1.26 percent.

4.4 Summary

This chapter represents the analysis of different FD models, structures of those models and the best fitted FD model for heterogeneous traffic of Bangladesh. It also represents the results and findings of this research. From extensive analysis of FD models, based on the model validation parameters, it is found that for heterogeneous non-lane-based traffic 2nd degree exponential FD model is best representative. The 2nd best fitted model is 3rd degree polynomial model. It is also found that if the free-flow speed decreases, the jam-density is increased except in a case multi-lane merges to a single lane. When a vehicle moves from multi-lane to single-lane, both the free-flow speed and the jam-density are reduced.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research investigated shape and structure of FD representing speed-density relationships for six different road geometry and traffic operating conditions. It also studied the trends in flow parameters, i.e., the nature of changing flow parameters due to change in road geometry and traffic operating conditions. The research is conducted for existing traffic conditions of Bangladesh which is mostly non-lane based and highly heterogeneous. Free-flow speed and jam density for different conditions that has been obtained from this research will provide a guideline to estimate highway capacity which will be required for better geometric design of new roads. Main conclusions from this research are summarized chapter-wise below.

Chapter 2 provides an overview of basic relationships between traffic flow parameters and modeling FD to describe speed-density relationship of traffic flow. Few classical and non-classical FD models are reviewed in details in this chapter. For the review purposes, special emphasis is given on speed-density models. Modeling speed-density relationship began with the Greenshields (1935) linear model: 'A Study in Highway Capacity' more than eighty years before. There has been a fairly large amount of effort afterwards to revise or improve such an over simplified model. As a result many models exist to represent speed-density relationship. Greenshields Model, Greenberg Model, Underwood Model and Drake model are the classical FD models. There are many modifications and combinations of these classical models known as non-classical models; such as, Edie Model (combination of Greenberg and Underwood Model), Modified Greenberg Model, Underwood model with Taylor Series Expansion, Drake Model with Taylor Series Expansion and many more. From the literature that is reviewed in this chapter, it can be seen that most of the models were developed and validated using the data collected from western countries with homogeneous and lane disciplined traffic conditions. Only limited amount of research has been reported from non-lane-based heterogeneous traffic conditions in recent years in India.

Chapter 3 focuses on study area in details, data collection methods and data processing techniques adopted in this research. For this study six different geometric and traffic conditions were considered. For each case there are two conditions as below:

Case-1:	Roadway with and without footpath
Case-2:	Roadway with and without bus stop
Case-3:	Highway section with on-ramp and off-ramp
Case-4:	Multi-lane merged to a single lane highway
Case-5:	Roadway with and without shoulder
Case-6:	Roadway with and without road-side market

For those six cases, study was conducted on three different highways, i.e. Tongi Diversion Road (Airport Road), Dhaka-Chittagong National Highway (N1) and Dhaka-Mymensingh National Highway (N3). Airport Road is an 8-lane highway with 4-lane in each direction and other two are 4-lane highway with 2-lane in each direction. The traffic stream of these highways consists of buses, micro-buses, cars, trucks, covered vans, utility vehicles, auto-rickshaws, rickshaws and vans. Lane discipline is totally absent in case of all the highways.

Generally traffic data is measured by means of detectors located along the road side. But installation and maintenance cost of these detectors are very high. Video cameras can record number, type and speed of vehicle very easily. By image processing technique, it is easy to get traffic data from recorded videos. This is an efficient and cost-effective method of high-resolution data collection in heterogeneous traffic condition.

For this research video footages are recorded from 12 different locations for about 4 to 5 hours each in two phases. These videos were processed and extracted data were filtered for anomalies. Ultimately 3.5 hours data was used for modeling FD. High-resolution (20 sec) traffic data was extracted from video footages. It is then aggregated in 1 minute. Extraction of high resolution traffic data is done by an object detection algorithm which operates basing on the Background Subtraction (BGS) technique of image processing. The developed algorithm can successfully detect non-lane-based movement of vehicles. It can also identify different sizes of motorized and non-motorized traffic, dark car and shadow quite accurately.

Chapter 4 presents developments of FD models for different road geometry and traffic operating conditions for non-lane based heterogeneous traffic of Bangladesh. Then the shape and structure of best fitted models are investigated for all the cases. Finally, it is investigated, how the flow parameters e.g. the free-flow speed and jam-density have been changed with the change of road geometry and traffic operating conditions. Six different cases were considered for this research. With the extracted data, six different FDs namely, linear, polynomial 2nd degree, polynomial 3rd degree, exponential 1st degree, exponential 2nd degree and logarithmic were plotted using MATLAB R2013b. Correlation coefficient (R^2) and root mean square error (RMSE) were used for evaluating fitness of different FD models.

Table 4.13 Best fitted FD models

Cases	Geometric/ Traffic Condition	Best Fitted Model	R^2	RSME	Free-flow Speed (Miles/hr)	Jam-density (veh/mile / lane)
1	With Footpath	$v = 26.31e^{-0.1832\rho} + 50.86e^{-0.01642}$	0.9045	3.189	65.85	150.68
	Without Footpath	$v = 49.26e^{-0.01689\rho} + 1.986e^{0.00178\rho}$	0.9011	2.879	50.78	173.68
2	With Bus Stop	$v = 89.51e^{-0.06244\rho} + 26.06e^{-0.007735\rho}$	0.9199	3.615	71.00	196.73
	Without Bus Stop	$v = 99.9e^{-0.06713\rho} + 17.94e^{-0.008012\rho}$	0.9413	3.346	75.36	189.92
3	On-Ramp	$v = 34.02e^{-0.08381\rho} + 15.3e^{-0.007293\rho}$	7505	3.956	31.79	194.81
	Off-Ramp	$v = 36.46e^{-0.06646\rho} + 6.38e^{-0.006742\rho}$	0.7936	2.502	25.01	221.88
4	Multi-lane (double-lane)	$v = -1.072\times10^{-5}\rho^3 + 0.004096\rho^2 - 0.5589\rho + 30.67$	0.7947	3.759	30.67	182.00
	Single-lane	$v = -3.227\times10^{-5}\rho^3 + 0.009119\rho^2 - 0.8055\rho + 28.49$	0.7951	3.14	28.49	162.31
5	With Shoulder	$v = 37.46e^{-0.07186\rho} + 12.59e^{-0.01007\rho}$	0.7348	6.157	39.98	152.43
	Without Shoulder	$v = 18.64e^{-0.009431\rho} + 27.8e^{-0.2547\rho}$	0.7676	3.08	27.27	156.21
6	With Market	$v = -4.598\times10^{-6}\rho^3 + 0.002147\rho^2 - 0.3619\rho + 27.33$	0.8148	2.62	27.33	244.41
	Without Market	$v = 20.08e^{-0.04527\rho} + 17.09e^{-0.008299\rho}$	0.8225	3.503	32.03	241.36

From the analysis it is found that, for most of the conditions 2nd degree exponential model is the best fitted FD model except for three conditions, e.g., multi-lane, single-lane and with road-side market. For 2nd degree exponential model, jam-density is infinity as the speed never reaches zero. So for the comparison of flow parameters; free-flow speed and jam-density is taken from 2nd best 3rd degree polynomial model.

5.2 Recommendations for Further Research

FD models have been studied for more than eighty years in the developed countries. But hardly any study was conducted to model FD for non-lane-based heterogeneous traffic prevailing in most South Asian countries, especially in Bangladesh. This is mainly due to the complexity of data collection and processing and the wide variations of driver population, vehicle components and traffic environment. Even though the current study tries to focus its effort in this sector; it cannot be viewed as a complete understanding of FD models for highly complex heterogeneous traffic operation under wide variety of road geometry. In fact, this study mainly focuses on developing deterministic speed-density FD models which lack the power to address the uncertainty brought about by random factors in traffic flow. Therefore, there is a scope to develop stochastic speed-density relationships. In this section some recommendations are provided for future research:

Modeling FD will be more representative, if data from different season and weather conditions are available. If possible, it will be more appropriate to select more test sites throughout each corridor. Then the operational and geometric variations can be captured more accurately. The model FD developed from this data set will then be more representative to this variation.

(a) Some uncertainty has been missing from the modeled FDs. If more stochastic parameters can be added to the equation; these model can capture and predict traffic state more accurately.
(b) Capacity drop phenomenon is not analyzed in this study. There is a huge scope of study in analyzing the change of capacity in stated traffic and geometric condition. It would be more versatile if the capacity issues can be incorporated in the modeled FDs.
(c) One of the main functions of FD is that, the macroscopic flow parameters estimated from FD are being used in many microscopic and macroscopic models. So the more accurate, reliable and complete the FD is, the traffic models will yield more accurate results. If the

modeled FD can be tested in other traffic model, it will ascertain the appropriate applicability of FD.

(d) Various agencies use FD for network management and signal control. There is a scope of research of using the modeled FDs in signal control in stated traffic condition.

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APPENDX

Extracted Traffic Data

Data for Roadway with Footpath

Speed (mph)	Flow (veh/hr-density)	Density veh/mile-density)
49.95053014	360	7.207130715
55.22869555	450	8.147938233
45.79609572	450	9.826165155
48.2150579	495	10.26925805
41.61503167	517.5	12.43758285
41.44022926	540	13.03081594
44.06223244	607.5	13.78459274
37.18000362	525	14.11200911
27.32651435	405	14.82077058
34.14254807	517.5	15.15300542
43.90717804	693	15.78670769
43.49534379	707.1428571	16.26500414
43.87221	742.5	16.92494163
50.07425972	866.25	17.29691519
35.20206165	630	17.89672416
35.97109666	660	18.35187068
40.91039824	765	18.69822095
36.5956446	705	19.26727939
37.27513919	742.5	19.9123633
40.61343318	825	20.2979557
37.72544327	780	20.69196287
33.38949022	712.5	21.34696378
34.13897846	745.7142857	21.84165723
37.64287696	835	22.17705446
32.1590778	731.25	22.73948214
35.04760044	810	23.11579095
32.74012833	776.25	23.72604644
37.81578336	919.2857143	24.30894058
34.85251119	860.625	24.68927531
36.06449001	911.25	25.28084132
36.23668322	932.1428571	25.73954565
34.41677486	904.5	26.27101086
33.41516382	900	26.93688426
26.77953009	729	27.24184937
36.10712562	1002.857143	27.78119358
29.77273165	840	28.21689222
31.62434589	909	28.74994771
33.3334112	973.125	29.17735587
28.36992211	847.5	29.85877924
25.74869697	777.8571429	30.17907874
27.35173066	840	30.72134293
30.64820078	957.8571429	31.26013535
30.97247071	981.8181818	31.7018943

Location of study site : Dhaka-Tongi Diversion Road
GR : 23.8341270, 90.4189710
Date of video recording : 15th April 2015
Time : 10:30am to 1:00pm and 3:00pm to 5:30pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

29.11127343	937.5	32.22255588
26.55771157	870	32.73438966
28.24695572	939.375	33.24826249
27.87051641	937.5	33.64202604
26.67761786	915	34.2919371
30.03956238	1046.25	34.83311684
33.17046359	1170	35.27358389
27.6649314	990	35.80991348
30.3299752	1102.5	36.34794531
30.59386614	1125	36.78411994
28.63673065	1068.75	37.31087736
28.35537527	1068.75	37.69717289
27.25390527	1044	38.29468842
28.04979736	1089	38.83198098
24.39271065	960	39.35339043
22.54322738	894.375	39.68853231
26.00741449	1050	40.38289034
22.74286113	927	40.75774544
29.42870168	1215	41.2898668
27.66368694	1155	41.75025725
29.86427555	1260	42.19335386
24.56275816	1046.25	42.58734512
25.34501938	1095	43.23196738
24.40444662	1067.142857	43.77272022
20.32471186	900	44.29282969
22.56910623	1008	44.68035805
28.22393338	1275	45.17350921
23.08722702	1057.5	45.80691017
28.16329407	1305	46.33690919
24.02803452	1125	46.81882926
23.74988196	1125	47.37638179
27.80208708	1327.5	47.72761819
25.80775758	1245	48.24545973
24.93126704	1215	48.73401623
29.33358446	1440	49.09048882
19.33790572	960	49.64193589
30.36687248	1530	50.38385171
18.08319902	918	50.7503604
19.27999242	990	51.35792081
20.23217841	1057.5	52.27041614
16.04334341	855	53.29313087
17.27773305	930	53.83500193
18.79792741	1020	54.23824063
25.35957484	1395	55.00880865
20.71389725	1170	56.48381789
17.41193421	990	56.8575546
17.30093548	990	57.22310656
24.12959162	1395	57.81283089

18.5988308	1102.5	59.27716381
22.43408786	1350	60.16748313
15.53172549	945	60.85260262
22.04520567	1350	61.23780473
18.97611605	1181.25	62.24503242
11.44282201	720	62.92154148
14.91224787	945	63.37072776
16.87678605	1080	63.99322695
10.31103725	675	65.463831
12.78458985	855	66.8773899
20.39509131	1395	68.3988112
14.44523427	990	68.53471404
16.74900113	1170	69.85491198
15.21788627	1080	70.96912022
18.85456926	1350	71.61785681
12.47683627	900	72.15112527
15.62284263	1147.5	73.44937437
16.23450226	1215	74.84060679
16.05991286	1215	75.65420873
10.64147263	810	76.11728454
16.91157272	1305	77.16609342
11.76499242	922.5	78.40979062
13.67270218	1080	78.98950666
14.83463802	1215	81.90290847
10.35767148	855	82.547511
12.99259305	1080	83.12428442
14.53496014	1260	86.68754424
14.11179048	1260	89.28703993
12.53522492	1170	93.33697698
13.84089994	1305	94.28577661
7.967923871	765	96.00995346
8.872088136	900	101.4417335
9.129190227	1080	118.3018398
7.411314365	900	121.4359499

Data for Roadway without Footpath

Speed (mph)	Flow (veh/hr-lane)	Density veh/mile-lane)
39.5033398	450	11.39144189
22.52514283	270	11.98660546
25.47702494	315	12.34327164
40.64678116	540	13.28518482
37.35233225	517.5	13.86299563
35.73203019	562.5	15.74086189
46.97782743	765	16.28427796
39.29617954	660	16.76240373
36.21792503	630	17.39470164
35.34385318	630	17.82488165
39.62914513	720	18.17080738
39.80575906	750	18.83318249
43.2703031	832.5	19.23401693
47.58861605	945	19.85769031
38.2583861	774	20.26320271
36.91885995	765	20.72149233
34.39559163	727.5	21.15097802
36.48975502	792.6923077	21.72188081
36.50163648	810	22.19695314
32.4337655	739.2857143	22.80173294
35.00247122	810	23.1380107
30.34111152	720	23.73883942
38.43872356	932.1428571	24.24391816
32.85639916	810	24.63425878
30.3123747	770.625	25.4199815
38.00269822	981	25.80233839
35.95266597	945	26.26474014
40.1051606	1073.571429	26.75877862
36.79633883	1001.25	27.21192899
34.71203941	963	27.73792522
36.12269375	1020	28.25035394
30.35568369	871.875	28.70330282
27.54261411	802.5	29.14192132
33.76387945	1005	29.77181511
33.99401478	1029.375	30.26934247
24.85169991	765	30.79350325
40.32339447	1260	31.25025323
32.31220162	1026	31.79174726
30.56561749	990	32.37957235
33.60482491	1102.5	32.79399799
30.16594379	1002.857143	33.25693218
32.61753271	1099.285714	33.71428377
27.22926919	932.1428571	34.22553936

Location of study site : Dhaka-Tongi Diversion Road
GR : 23.8291621, 90.4198365
Date of video recording : 15th April 2015
Time : 10:30am to 1:00pm and 3:00pm to 5:30pm
Data type : Data is extracted at 20 sec interval, it the then aggregated to 1 minute.

31.54601962	1092.857143	34.65439984
27.80823691	978.75	35.19062492
25.23327598	900	35.68935138
25.67001855	930	36.22450759
33.26433423	1215	36.52422172
27.72802769	1035	37.31997165
27.80484707	1046.25	37.63143191
26.3341401	1009.285714	38.32662468
27.64567073	1068.75	38.65972204
26.69362409	1046.25	39.20011916
24.9020504	990	39.75140739
25.42741676	1023.75	40.25963139
28.51187037	1161	40.72516836
25.01807943	1035	41.3560308
23.39134652	977.1428571	41.77897902
23.08551568	975	42.24191877
28.42156021	1215	42.7557388
23.93594013	1035	43.24009641
28.09043076	1226.25	43.6359797
25.85552086	1147.5	44.37346713
30.10765292	1350	44.84148575
23.86299167	1080	45.26757339
23.10175704	1057.5	45.78795064
29.12892157	1350	46.33602519
20.81887426	972	46.69389742
22.18493744	1050	47.34110124
16.74365381	798.75	47.72300889
25.33431601	1224	48.32337152
21.90639253	1068.75	48.78975801
16.50914515	810	49.06371545
23.29894017	1158.75	49.72900764
24.60228205	1237.5	50.29789407
24.11618422	1237.5	51.31160178
20.53550137	1065	51.84996462
23.0530634	1206	52.30347848
23.35572372	1237.5	52.98495742
20.83469586	1110	53.2782914
19.45090542	1046.25	53.81496142
23.65398606	1282.5	54.21953552
20.97442776	1147.5	54.70282705
26.83894191	1485	55.33005007
24.1886385	1350	55.80709854
20.20038653	1147.5	56.81919264
20.68076879	1181.25	57.12146476
18.65287697	1080	57.90314831

27.90539768	1620	58.05328483
19.92768389	1170	58.71494132
19.52607872	1155	59.14743699
18.09286191	1080	59.69204903
18.44906707	1125	60.97869315
22.82771515	1395	61.1127821
20.05251834	1237.5	61.68480399
19.25705274	1200	62.31178194
22.04599925	1395	63.27678707
17.85901746	1147.5	64.25259746
15.235295	990	64.98069122
13.79872886	900	65.22339916
20.52821547	1350	65.76314448
13.33838198	900	67.47445091
13.93165359	945	67.81875379
15.51337183	1080	69.60873243
16.8979692	1185	70.11187792
17.18995639	1215	70.6808076
10.42965934	742.5	71.20222439
22.74095396	1642.5	72.23670465
9.574530181	697.5	72.85083753
12.88416799	945	73.34583038
17.57781385	1305	74.24131413
14.16285651	1057.5	74.70261924
11.39261464	855	75.04861937
17.20947483	1305	75.83032095
15.1316517	1170	77.32136738
12.282349	967.5	78.79003452
18.20817141	1440	79.08537147
17.56174415	1440	81.9964115
15.29320909	1260	82.38950977
17.64358461	1485	84.16657006
17.54129481	1485	84.65737656
12.62184003	1080	85.56597116
17.94527397	1575	87.7668406
12.32515247	1125	91.2767613
11.73905688	1080	92.00057648
8.194319404	765	93.35735676
11.0600836	1035	93.57976283
14.60241576	1440	98.61382008
13.1225456	1305	99.44716824
11.17442878	1125	100.6762871
9.678004444	990	102.2938154
16.90897487	1755	103.7910349
8.099690664	945	116.6711223
11.53883818	1440	124.7959264
10.01009758	1305	130.3683595

10.0189307	1395	139.2364157
3.652323046	540	147.8511055
11.50419925	1890	164.287836
8.350748785	1395	167.050888
4.892963882	900	183.9375932

Data for Roadway with Bus Stop

Speed (mph)	Flow (veh/hr-lane)	Density (veh/mile-lane)
241.318358	1485	6.153696769
90.79332216	900	9.912623292
68.79576746	738	10.74294461
113.6197148	1305	11.48568276
81.69958609	1035	12.66836283
82.11494302	1125	13.70030787
61.70696412	877.5	14.20965906
60.4678786	933.75	15.4235163
72.11977662	1185	16.37691422
54.10844188	967.5	17.87160448
45.50647505	840	18.49065978
39.39484596	774	19.63621908
48.37937513	990	20.51240711
35.24654666	790.7142857	22.42007257
61.49992547	1440	23.41588114
44.86797638	1091.25	24.37699934
32.53586341	832.5	25.62185391
24.7571197	648	26.17610838
48.53553637	1335	27.53270097
43.61892942	1237.5	28.38164103
44.85584589	1305	29.09319787
32.62143459	990	30.41701767
30.68027011	956.25	31.16369833
26.5508228	862.5	32.49326036
33.93157322	1132.5	33.3772573
29.66960035	1023.75	34.5412585
33.10369378	1170	35.32143888
28.38192631	1035	36.55104623
21.73934496	817.5	37.5930971
25.46189544	981	38.52396996
29.34679485	1161	39.5632474
23.01164807	933.75	40.57781582
24.3730246	1008	41.34773238
20.74540339	885	42.64026743
21.70373808	945	43.51253836
24.45757607	1080	44.16237812
30.42321677	1395	45.83523847
26.01951289	1215	46.6957243
25.57380099	1215	47.52812
16.4017737	795	48.43940741
23.83547571	1179	49.45155868
20.05080166	1009.285714	50.36521037
23.60340995	1215	51.45497037

Location of study site : **Dhaka-Tongi Diversion Road**
GR : **23.8458508, 90.4122539**
Date of video recording : **15th April 2015**
Time : **10:30am to 1:00pm and 3:00pm to 5:30pm**
Data type : **Data is extracted at 20 sec interval, it is then aggregated to 1 minute.**

16.31732654	857.1	52.55565847
18.16266444	967.5	53.25612406
18.87272209	1035.031579	54.83856062
17.95965955	996.4285714	55.51089248
19.8263069	1125	56.70556297
15.44658141	886.2039474	57.39365987
20.359445	1192.5	58.57288608
15.24897535	908.1578947	59.57296695
19.89032211	1204.615385	60.5392367
15.86391945	979.7105263	61.76647647
19.83952113	1237.5	62.36389744
18.24135521	1155	63.29905991
17.87381135	1155.631579	64.61335519
19.84592592	1298.571429	65.4274699
14.6110079	969.7781955	66.32028526
19.09032062	1293.75	67.76054826
15.56841293	1067.621053	68.48448197
22.68202756	1575	69.45434371
17.80915085	1255.460526	70.52580208
14.90094921	1065	71.50105713
18.52741947	1342.484211	72.42658375
16.9378091	1248.75	73.70309717
15.32340449	1142.415789	74.53556647
10.7766846	810	75.16226279
14.49147791	1106.467105	76.37071915
14.05499557	1090.697368	77.64008739
17.23029666	1350	78.31726002
14.14031243	1128.684211	79.81283929
12.89051592	1035	80.2915885
16.02289931	1305	81.45954738
13.29236189	1102.5	82.93366328
15.64903559	1305	83.39292369
14.35926507	1215	84.61191655
15.18024153	1296	85.39176222
16.47998035	1440	87.38640622
13.21782639	1170	88.47656923
15.08573451	1350	89.48851639
19.63509644	1770	90.14215923
11.05127544	1012.5	91.61944271
11.3962698	1057.5	92.80481308
15.13961572	1417.5	93.62871628
14.31598677	1350	94.37895562
13.23712629	1260	95.17778388
7.472501331	720	96.3539093
15.40424168	1507.5	97.87434672
5.029854748	495	98.41238461
17.59006043	1755	99.77225529
10.49369496	1057.5	100.7757341

13.7318668	1395	101.5885182
11.44999814	1170	102.1834227
15.961687	1665	104.3122823
10.02399555	1057.5	105.4902211
13.97478343	1485	106.2628275
8.845574399	967.5	109.3996837
10.99630835	1215	110.491627
10.02495647	1147.5	114.4601177
9.33441015	1080	115.5717694
11.21516343	1305	116.3342854
11.1315029	1305	117.2348434
9.674257566	1147.5	118.5524034
10.52305667	1260	119.7370725
8.637821986	1057.5	122.320682
8.755029095	1080	123.3576712
10.11138969	1260	124.5651006
9.453545887	1188	125.661884
9.940763072	1260	126.750833
9.166000781	1170	127.6456361
10.17973208	1305	128.1967395
7.967607172	1035	129.9009825
6.907149022	900	130.2997803
7.709171681	1012.5	131.3307698
9.649978638	1282.5	132.9008494
8.074534161	1080	133.7538462
8.677864732	1170	134.828146
5.99705617	810	135.0662687
8.074932438	1102.5	136.4989232
6.713917242	922.5	137.3933297
8.42331597	1170	138.9001676
9.995848989	1395	139.5412628
7.8431499	1102.5	140.5668525
7.647823063	1080	141.2155898
10.4323575	1485	142.345582
11.11587401	1597.5	143.6864836
9.868847531	1425	144.3781797
9.284820339	1350	145.3942881
7.359018415	1080	146.7587033
10.1625835	1530	150.5522685
7.136200667	1080	151.3410357
6.180673314	945	152.8619493
6.755809662	1035	153.2014743
9.4592918	1462.5	154.538509
11.05090519	1732.5	156.7812928
6.575169587	1035	157.399466
7.517695929	1192.5	158.6488689
7.201718231	1147.5	159.3425277
6.455257187	1035	160.3344328

8.225247751	1327.5	161.3888137
7.463782966	1215	162.7759482
7.96836805	1305	163.7693334
7.112502589	1170	164.4990614
7.338764933	1215	165.559193
7.853299354	1305	166.1721961
5.885484012	990	168.2104646
9.139674038	1575	172.3256205
5.445397938	945	173.5410361
8.963040038	1575	175.7216294
3.913043478	720	184
4.760674845	877.5	184.2738489
8.267441721	1530	185.0632943
8.812730474	1665	188.9312291
6.81995468	1305	191.3502452
7.734415567	1530	197.8171443
4.06791642	810	199.1191353
5.609242521	1147.5	204.5835392
4.500848807	945	209.9603965
5.467494573	1170	213.991982
4.64012396	1035	223.0543858
5.092126754	1170	229.7664722
5.844243335	1350	230.9965418
6.536967115	1530	234.053495
6.315121442	1485	235.1498722
3.416149068	810	237.1090909
4.062623698	1005	247.3904358

Data for Roadway without Bus Stop

Speed (mph)	Flow (veh/hr-lane)	Density (veh/mile-lane)
85.71428571	495	5.775
103.9633245	630	6.059829303
91.07142857	675	7.411764706
58.56763032	517.5	8.780436332
79.68676674	720	9.035377259
58.67057377	630	10.73792124
57.55454684	675	11.72800477
59.32507175	720	12.13652135
34.95016869	450	12.87547433
26.24222077	360	13.71835117
12.18313355	180	14.77452408
42.85293637	720	16.80164911
39.18034605	720	18.37656051
16.475761	315	19.11899547
41.51187199	810	19.51249031
30.93042924	630	20.36829153
26.1945305	540	20.6149906
25.36164755	540	21.29199213
41.17627468	900	21.85724685
22.42894489	495	22.06969621
21.91221514	495	22.58918924
39.44372906	945	23.95818099
25.84036225	652.5	25.21743796
35.55939833	945	26.57662624
31.51600615	855	27.129072
40.62344848	1125	27.69336533
23.36811061	675	28.88551888
27.87757072	810	29.05561636
25.76358957	780	30.26085543
22.43753627	690	30.73736287
15.8949176	495	31.14202996
29.63290544	945	31.88745216
38.96200754	1260	32.33919604
15.77391821	517.5	32.84892526
20.4241267	675	33.04914868
31.30260065	1057.5	33.80888533
15.43642377	540	34.98219587
15.28103857	540	35.30146018
19.471514	697.5	35.81950183
20.93315587	765	36.5448958
20.210816	753.75	37.25396904
24.5773377	922.5	37.53106556
12.96573841	495	38.17754024

Location of study site : Dhaka-Tongi Diversion Road
GR : 23.8407141, 90.4164797
Date of video recording : 15th April 2015
Time : 10:30am to 1:00pm and 3:00pm to 5:30pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

19.53409669	765	39.19317881
17.30492498	690	39.89823008
25.41232366	1035	40.72827081
16.28294392	675	41.45442024
23.20190964	967.5	41.709258
26.53105911	1125	42.40313194
8.307944518	360	43.33201783
20.66995002	900	43.54146958
17.35952359	765	44.06802963
9.898564169	450	45.46113884
21.59166821	990	45.85511398
17.50368119	810	46.27597995
20.20349997	945	46.77695603
9.022801872	427.5	47.35871121
16.4556503	787.5	47.83589502
24.34643624	1170	48.05631463
15.68703814	765	48.78755089
16.61305361	817.5	49.22055369
10.90824479	540	49.50383954
16.09398135	810	50.32953519
15.07876686	765	50.71860768
13.36005112	686.25	51.37303657
7.788668803	405	51.99861623
15.81569792	825	52.16750406
8.504947689	450	52.91037834
18.73010074	1035	55.25864567
18.56516093	1035	55.74958407
15.99687561	900	56.25120412
5.55431843	315	56.71262892
15.34760433	877.5	57.19958728
12.46181869	720	57.83249089
10.798697	630	58.34037198
25.25335077	1485	58.80407767
9.13972577	540	59.08273547
12.61645963	765	60.63507692
9.476792087	585	61.71874383
11.4118111	720	63.092527
9.846268064	630	63.98363278
11.22157074	720	64.16214061
10.06137942	652.5	64.85785079
13.5565339	900	66.38865118
8.103821865	540	66.66229494
12.28936887	832.5	67.73500447
8.842935551	607.5	68.74425975
11.71582463	810	69.14947329
7.098077288	495	69.78113906
9.232613571	652.5	70.67768726
11.08441569	787.5	71.03669804

12.50861869	900	71.95039056
9.675424516	697.5	72.10627271
9.863317737	720	72.99774976
12.31681873	900	73.07081637
9.735301011	720	73.95765156
9.073642151	675	74.3912961
9.826109777	735	74.80199256
13.19424427	990	75.02998569
10.70058458	810	75.69679898
7.965962462	607.5	76.21934932
10.4853764	810	77.25704597
15.06451648	1170	77.66595111
10.06537507	787.5	78.27030361
10.29219581	810	78.70040709
10.01582226	798.75	79.74672783
10.67475433	855	80.0955201
11.04435521	900	81.489592
9.34152261	765	81.89243146
9.316770186	765	82.11
7.009966198	585	83.45261354
7.52918854	630	83.67435569
9.07763106	765	84.28253676
6.769649573	585	86.41510816
8.041620355	697.5	86.73712972
9.950727234	877.5	88.16202624
8.107135831	720	88.81064966
9.054559258	810	89.45769496
12.29984489	1102.5	89.63419927
10.4837965	945	90.13910181
8.426624548	765	90.81306092
9.36701229	855	91.2777707
8.233741719	765	92.90288825
9.142080745	855	93.52356688
7.066579492	675	95.52004626
9.237838294	900	97.41640685
9.196996327	900	97.85803626
10.08456972	990	98.16978088
7.286427867	720	98.81385133
9.92152171	990	99.78308055
9.5354603	967.5	101.4626284
5.73943144	585	101.9264724
6.575514038	675	102.6535714
9.545303781	990	103.7263331
9.49691871	990	104.2173186
8.794239956	922.5	104.8781718
6.417469209	675	105.1837332
9.34523049	990	105.9363919
5.077761899	540	106.3462114

6.280117041	675	107.4820733
10.74451448	1170	108.8927752
8.650649591	945	109.2403798
8.613957411	945	109.7060029
7.277099859	810	111.3250406
8.872194085	990	111.5845743
7.981030265	900	112.7673959
6.227220434	705	113.2120028
6.520791952	742.5	113.8679383
7.860918688	900	114.490435
3.523473254	405	114.9434013
4.658385093	540	115.92
7.162826907	832.5	116.2309615
5.778632858	675	116.8096359
9.575025409	1125	117.4931608
7.958074534	945	118.7473171
7.162266782	855	119.3738063
8.633633381	1035	119.8800035
7.122609053	855	120.0402821
7.073108053	855	120.8803815
7.049740194	855	121.2709874
6.467646102	787.5	121.7455263
10.25828982	1260	122.827491
5.289844145	652.5	123.3648444
5.788473073	720	124.3851342
4.683232113	585	124.9137318
6.978988995	877.5	125.7368495
5.971585475	765	128.1066818
9.007009965	1170	129.8988238
8.281573499	1080	130.41
4.813526681	630	130.8837468
5.836788074	765	131.0652349
5.762936587	765	132.7556794
6.161621738	825	133.8871411
6.033176791	810	134.2576271
6.325824754	855	135.1476271
5.597594716	765	136.6658429
6.558219815	900	137.2420021
5.490126727	765	139.3410458
3.222283288	450	139.6525258
3.850033509	540	140.2585195
4.44996441	630	141.574166
7.463975608	1080	144.6950066
1.227289335	180	146.664682
5.478877425	810	147.840504
6.482363631	967.5	149.2430664
4.197330268	630	150.0954082
5.825903478	877.5	150.6198511

5.017357311	765	152.4707037
5.876249218	900	153.1589228
4.233825238	652.5	154.0849167
4.654830159	720	154.6780388
5.072717357	787.5	155.2797006
4.035731507	630	156.1055285
5.704089893	900	157.7830976
4.411004504	697.5	158.1267922
5.051623076	810	160.3421462
5.174607236	832.5	160.8579514
5.270319103	855	162.2404707
5.739720708	945	164.6563825
3.536197088	585	165.4319557
3.253475303	540	165.9763636
6.220765279	1035	166.3782435
6.726420979	1125	167.2558642
6.33919133	1080	170.3687338
3.422347179	585	170.935317
5.484427313	945	172.3060488
2.329192547	405	173.88
4.903189432	855	174.3762936
5.399239382	945	175.0246531
4.325120211	765	176.8736966
5.79901626	1035	178.4785477
5.542014983	990	178.6353886
4.719250224	855	181.1728473
6.631433568	1215	183.2183023
2.670405112	495	185.3651335
5.06014699	945	186.7534682
3.591667994	675	187.9349654
5.262550742	990	188.1217015
3.575928327	675	188.7621726
5.713144221	1080	189.0377624
4.217348171	810	192.06382
6.776227672	1305	192.5850286
2.795031056	540	193.2
4.642278126	900	193.8703317
3.008444367	585	194.4526568
4.351601347	855	196.479395
4.100793413	810	197.5227519
3.962804105	787.5	198.7369764
5.417373471	1080	199.3586017
2.916015397	585	200.6162247
2.905959864	585	201.3104197
4.558710277	922.5	202.3680512
3.772083177	765	202.8057082
5.538345279	1125	203.129264
2.618786264	540	206.2024149

2.787151218	585	209.8917332
5.988152615	1260	210.4154789
2.968540163	630	212.2255268
3.993607963	855	214.0921212
4.189894973	900	214.8025231
4.350457823	945	217.2185178
3.924001933	855	217.8898009
4.124324485	900	218.2214051
3.083594078	675	218.9004074
3.054816533	675	220.9625333
4.445430346	990	222.7005988
3.219838564	720	223.6136955
2.789416473	630	225.8536888
3.17634067	720	226.6759378
3.12756529	720	230.2110214
3.88847951	900	231.4529362
3.292005728	765	232.3811292
2.869309051	675	235.2482734
3.806017035	900	236.4676752
3.965194046	945	238.3237715
2.792594861	675	241.7197074
3.329693081	810	243.2656645
4.382730796	1080	246.4217061
2.996250816	742.5	247.824769
2.161228544	540	249.8578883
2.278001502	585	256.8040449
3.829738866	990	258.5032647

Data for Highway Section with On-Ramp

Speed (mph)	Flow (veh/hr-lane)	Density (veh/mile-lane)
7.598948533	90	11.84374386
5.081874647	180	35.42
12.60097489	0	0
23.65766644	720	30.43410903
15.45685849	360	23.29063181
14.15274767	450	31.79594595
5.081874647	540	106.26
13.71291425	360	26.25262532
4.743321388	540	113.8442783
21.01566911	360	17.13007557
10.16374929	900	88.55
6.348890948	630	99.22992931
36.57572544	270	7.381945177
10.16374929	360	35.42
14.38639514	360	25.02364189
7.622811971	990	129.8733333
11.0877265	900	81.17083333
13.36699283	360	26.93201116
5.712459275	810	141.7953216
5.809506699	450	77.45924453
8.711163374	900	103.3157067
25.70922167	810	31.50620468
27.96759585	180	6.436019778
6.025719804	720	119.4877995
26.0923213	630	24.14503458
17.27102376	270	15.63312076
7.706492925	450	58.39231987
19.08865665	900	47.14841995
17.03224527	810	47.55685391
13.37862918	630	47.0900263
6.57302393	720	109.5386245
10.70679846	450	42.02937058
16.79507674	180	10.71742647
9.864070854	450	45.62011026
20.32749859	1170	57.5575
9.815516604	900	91.69155698
71.18153586	540	7.586236986
1.196915213	270	225.5798883
20.32749859	810	39.8475
117.0100145	630	5.384154535
20.32749859	630	30.9925
15.24562394	270	17.71
6.672542728	180	26.97622291

Location of study site : Dhaka-Tongi Diversion Road
GR : 23.8210958, 90.4180461
Date of video recording : 15th April 2015
Time : 10:30am to 1:00pm and 3:00pm to 5:30pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

11.50681617	270	23.46435331
18.25352228	360	19.72222098
238.8481084	540	2.260851064
5.928853755	450	75.9
10.3590636	810	78.19239568
69.09759447	270	3.907516638
17.41738736	270	15.50175089
22.26999658	540	24.24787081
20.91825198	360	17.20985101
12.87680804	540	41.93585852
6.775832863	630	92.9775
16.39067541	0	0
16.30205047	450	27.60388952
8.890562781	810	91.10784322
11.47276866	900	78.44662664
18.94522868	270	14.25160944
197.9511172	360	1.818630807
13.160954	360	27.35364017
24.2007571	720	29.75113535
4.810502117	270	56.127197
41.60627631	720	17.30508144
5.558031076	90	16.1927846
19.27607625	180	9.338
12.26097425	810	66.06326574
20.32749859	630	30.9925
23.6667211	1080	45.63369786
21.27397072	450	21.15260973
57.69422393	630	10.91963731
4.065499718	720	177.1
5.428906176	720	132.6234009
19.11060223	270	14.12828317
5.402611563	1170	216.5619324
7.072341272	270	38.17689074
10.65458905	540	50.6823865
6.619371205	450	67.98228806
13.04717825	630	48.28630283
8.469791078	90	10.626
5.081874647	360	70.84
16.41423886	270	16.44913312
18.93095288	360	19.01647541
9.597431895	270	28.13252576
18.99653142	810	42.63936306
14.34052068	450	31.37961376
7.313597376	360	49.22338235
4.355892555	720	165.2933333
8.062589584	540	66.976
6.832749279	990	144.8904328
16.7098904	900	53.86031735

55.90062112	450	8.05
8.346954342	270	32.34712794
14.01960241	630	44.93708034
6.233956508	90	14.43705934
7.75055855	360	46.44826533
30.92889963	360	11.63959935
4.092536937	630	153.938745
13.97515528	450	32.2
20.40763584	540	26.46068384
3.654459828	450	123.1372135
19.21456954	720	37.47156544
45.23874125	450	9.947226371
20.16920335	360	17.84899452
5.41295187	630	116.3875119
10.37549407	450	43.37142857
7.3767832	360	48.80175955
5.633056205	90	15.97711735
8.081856619	630	77.95238516
20.32749859	540	26.565
10.16374929	630	61.985
16.61253339	990	59.59355968
7.487125413	630	84.14444332
18.66260794	180	9.644954265
30.5089647	360	11.79981043
19.82319042	90	4.540136986
17.30438986	270	15.60297718
5.487608618	360	65.60234614
14.00389376	630	44.98748781
16.33474181	540	33.05837375
10.70143208	270	25.23026806
8.437864535	450	53.33102921
16.5300538	810	49.00165541
3.608130999	270	74.83098592
18.37107159	450	24.49503273
9.488459155	540	56.91124251
15.24562394	630	41.32333333
11.33633966	360	31.75628209
16.90170967	540	31.9494306
10.75707201	810	75.29930072
20.89835106	540	25.83935921
1.998238621	450	225.1983299
8.86901821	990	111.6245312
21.73092312	360	16.56625437
7.525083612	720	95.68
12.16792081	450	36.9824892
12.55736756	720	57.33685796
5.674693488	720	126.8790995
6.878989601	810	117.7498509

11.42017878	630	55.16551119
4.234895539	90	21.252
48.34817357	540	11.16898448
9.2883003	630	67.82726437
12.89682717	90	6.978460579
19.5416223	900	46.05554166
14.83482432	540	36.40083552
18.69189481	720	38.51936934
49.31899337	360	7.299419056
42.99921677	270	6.27918414
9.17588585	360	39.23326923
6.813380985	900	132.0930096
17.22355452	630	36.57781553
14.0693332	1170	83.15959138
4.423406946	360	81.38523187
11.72383311	990	84.44337196
5.784781256	540	93.3483871
8.678236573	1260	145.1907873
7.801999458	1350	173.0325678
4.068937196	900	221.1879802
8.729951674	1350	154.6400313
1.270468662	630	495.88
3.260629051	450	138.0101793
5.846776325	720	123.1447827
4.021094988	180	44.76392638
15.06498124	270	17.92235886
32.39818125	270	8.333801146
2.474129648	360	145.5057136
11.34079623	450	39.67975361
12.37251158	270	21.82257
12.16994654	360	29.58106667
6.28885924	450	71.55510766
8.853695504	540	60.99148088
17.00552672	1080	63.508765
6.219437138	1080	173.6491544
6.464158173	1080	167.0751196
16.4627574	540	32.80130946
3.379626849	720	213.0412712
5.081874647	990	194.81
22.39951796	810	36.16149246
29.29390514	540	18.43386866
31.59353039	450	14.24342245
10.29392026	810	78.68722307
6.750211196	540	79.99749702
9.572273209	450	47.01077687
15.34629612	1260	82.10450195
13.28296406	360	27.10238455
13.070205	990	75.74479513

3.779469617	720	190.5029205
16.86315548	450	26.68539707
24.06378381	990	41.14066216
29.51788918	360	12.19599402
6.984646433	630	90.19783693
18.94153278	540	28.50878049
18.5188746	990	53.45897208
13.7458006	810	58.92708788
21.30705241	990	46.46348922
4.550492362	1170	257.1150343
17.8127281	630	35.36796815
16.43916037	630	38.32312514
22.29889441	540	24.21644725
6.332585455	720	113.6976366
9.487103026	1080	113.8387553
18.39366379	180	9.785978588
9.460105112	180	19.02727273

Data for Highway Section with Off-Ramp

Speed (mph)	Flow (veh/hr-lane)	Density (veh/mile-lane)
1.923076923	450	104.65
3.846153846	450	52.325
4.492788462	450	44.79400749
1.581373172	180	50.90512563
1.727262045	540	139.8166542
2.538423818	1170	206.1318509
0.829388183	450	242.648743
3.920353539	1620	184.8047613
4.310109548	360	37.35403897
45.20100919	1080	10.68560213
13.73856708	1260	41.0159223
7.391357757	1440	87.12878217
7.728491708	180	10.41600393
5.276435156	810	68.65430718
4.487189837	450	44.84989655
2.013276298	900	199.9228821
3.530650636	450	57.00082527
4.458197635	360	36.11324871
3.708028001	720	86.83861068
2.307492062	1260	244.2045238
23.52103476	450	8.556171191
12.80243016	1260	44.01508097
13.07692308	720	24.62352941
5.651413492	1530	121.0759045
1.937817085	360	83.08317707
2.794868113	180	28.80279023
2.874131893	180	28.00845716
25.53499132	1980	34.67790487
4.632703554	450	43.44115648
2.374783826	810	152.5402001
6.490966473	1980	136.4203626
1.119871537	630	251.5913572
14.23950276	0	0
0.513089372	270	235.3391177
0.953623922	450	211.0370717
0.194622555	0	0
1.629330392	450	123.5169987
1.923076923	270	62.79
0.515646905	180	156.1145799
1.90236514	540	126.9472379
1.841549449	630	152.9961631
5.026401043	1080	96.09261097
2.270308969	450	88.6443223

Location of study site : Dhaka-Tongi Diversion Road
GR : 23.8254931, 90.4203575
Date of video recording : 15th April 2015
Time : 10:30am to 1:00pm and 3:00pm to 5:30pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

3.320670195	810	109.0894243
6.953762293	1350	86.82350281
10.61153674	720	30.34433258
4.670521635	900	86.17881073
3.661572217	630	76.94782005
2.180121577	450	92.31136564
1.913366806	630	147.2535215
4.34840997	810	83.30631254
2.894116753	540	83.44514773
2.019838099	810	179.3460575
6.99399123	1170	74.8142202
3.26879231	540	73.88049686
1.354190595	630	208.057862
7.424696254	810	48.78987471
2.346855855	720	137.2048476
19.68118525	1530	34.76670694
3.528236747	630	79.85575238
5.729166667	630	49.17818182
7.087257387	1170	73.82968777
3.418980451	180	23.54503079
3.704254784	540	65.19529947
2.884615385	1350	209.3
2.876129078	1080	167.9340485
2.292290091	900	175.5885965
14.23816568	900	28.26909091
4.132398157	720	77.92085558
5.761980568	720	55.88356229
4.922515537	720	65.41370922
1.791958042	540	134.7687805
2.783215526	720	115.6935196
36.00461417	540	6.707473627
3.33121291	900	120.8268612
7.710548259	450	26.10060831
2.867270313	270	42.11322507
4.570475217	810	79.25871661
1.157097454	90	34.78531549
15.73771024	900	25.57551218
4.202864716	540	57.4608074
17.37942613	1350	34.73935189
13.74746357	900	29.27812814
6.578179572	1080	73.42456901
2.54383677	720	126.5804488
3.217535243	990	137.6053303
3.356178151	630	83.94965562
3.104064995	720	103.7349413
4.12890239	1710	185.2187162
13.27113481	1800	60.6579627
3.008944768	900	133.767826

2.837369457	810	127.6710719
7.02202215	810	51.58770397
2.942160116	990	150.484672
0.805720277	360	199.8212091
5.058692968	540	47.73960419
2.953882222	90	13.6261357
48.38600676	540	4.991112435
6.151101923	360	26.17417205
6.986324215	360	23.04502268
1.838235294	810	197.064
6.835171755	180	11.77731927
7.044782796	360	22.8537919
16.30847037	990	27.14846887
5.088296151	270	23.73093004
18.30486047	630	15.39208673
2.000878825	450	100.5808035
2.692307692	630	104.65
7.823495241	360	20.57903725
2.109847035	630	133.5404868
7.064935103	270	17.09145211
1.607486929	360	100.1563354
1.531073998	270	78.86620775
25.85470085	450	7.783884298
3.084935897	90	13.04727273
2.004159035	180	40.16647311
0.660103785	270	182.9257803
7.731633623	450	26.02942791
0.896978022	360	179.4915773
24.35674036	540	9.915119859
3.847366852	900	104.6170057
6.613905433	540	36.51397838
1.813842816	990	244.0950209
2.475478437	360	65.03793271
5.425840766	720	59.34564133
1.439109939	630	195.7807338
14.54030984	1170	35.98616574
5.020679445	1080	96.20211871
3.39326327	810	106.7556423
2.649585647	360	60.76421805
4.348901099	540	55.53126974
2.619328346	360	61.46613892
4.216977824	450	47.72375109
6.747094693	1170	77.55189808
1.799450549	90	22.36793893
3.714817081	450	54.17494202
0.576923077	90	69.76666667
0.915550732	450	219.8130513
1.24245922	450	161.9771472

2.676523813	0	0
10.73631805	720	29.99165993
4.174180905	1170	125.3539346
1.429005777	540	168.998617
4.955598347	540	48.73276305
5.257193677	1530	130.1549918
4.520070541	90	8.904728286
11.47447517	810	31.57007136
3.075144298	540	78.53290011
1.556460131	450	129.2998105
5.413044278	630	52.05019312
1.660276007	270	72.72887128
3.24098624	720	99.35247364
0.874732906	270	138.0421374
4.389393718	450	45.84915661
5.62682531	180	14.30646867
3.800806014	900	105.8985906
0.889000912	360	181.1021765
0.619861772	270	194.8014951
5.153723394	360	31.23955007
4.153320531	540	58.14624664
1.332629209	630	211.4241517
8.492584776	270	14.21828609
0.927250874	450	217.0394288
5.475135285	630	51.45991566
5.128205128	90	7.84875
1.601669008	180	50.26007222
2.476774459	450	81.25487537
1.583748188	360	101.6575748
3.015632031	720	106.7769531
4.526941848	1080	106.6945448
0.566418875	90	71.06048502
2.971078823	540	81.28360586
3.321678322	90	12.11736842
4.604867788	900	87.40750408
0.460897028	90	87.32970184
3.524446974	630	79.9416198
5.129480872	630	54.92758566
1.866139709	810	194.1172991
2.654907364	450	75.80302151
0.206043956	90	195.3466667
1.965254765	810	184.3272468
8.691997538	630	32.41487343
1.913964304	810	189.2668527
2.044599214	900	196.8600972
12.75808044	1350	47.32294978
12.54521017	270	9.625187494
1.552508524	810	233.3320522

Data for Multi-lane Highway

Agg Speed (mph)	Agg Flow (Veh/hour-lane)	Agg Density (Veh/mile-lane)
38.20534281	90	2.35823973
33.48744959	90	2.690210167
28.21124542	90	3.196156565
24.21039493	90	3.720894315
26.58177554	112.5	4.239761053
28.12911283	135	4.757234642
28.43076656	147.2727273	5.191956818
27.57634842	160	5.804031243
25.16132134	157.5	6.266468061
29.55927543	200	6.747966236
27.34782126	198	7.21612584
29.6032128	225	7.606327475
28.50060805	234	8.226046232
17.33103763	150	8.698363588
24.22930823	225	9.25902195
24.42013324	236.25	9.649018189
22.03252176	225	10.2064254
23.00148608	247.5	10.77290986
27.10641134	306	11.30603239
23.62712677	280	11.81042335
29.70838128	360	12.1384568
28.37106263	360	12.68323125
18.17019607	240	13.24831704
21.703273	300	13.84064908
22.82617563	326.25	14.27394474
20.73547674	306	14.75819544
26.47661416	405	15.31602746
19.33642515	306	15.78962555
18.50864116	300	16.2350762
24.91888534	420	16.85469681
23.08324338	398.5714286	17.22924806
24.09797677	427.5	17.72083586
11.47667406	210	18.29519575
20.06076723	378	18.83101234
16.75126368	324	19.32781087
20.48065426	405	19.79604141
22.25640689	450	20.17745705
21.62531041	450	20.79918293
22.30246412	472.5	21.18163068
19.38606	420	21.68407947
16.287955	360	22.10222217
17.55412753	398.5714286	22.71207534
21.27095615	495	23.27041612

Location of study site : Dhaka-Chittagong National Highway (N1)
GR : 23.5950060, 90.6256480
Date of video recording : 25th August 2015
Time : 10:30am to 1:00pm and 2:30pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

16.64249952	396	23.7914899
21.07330644	510	24.20677015
14.57094715	360	24.72961478
20.66467635	522	25.26847831
17.51761428	450	25.69862022
17.04223576	450	26.4049862
26.88810793	720	26.77763724
20.36269238	555	27.26266057
20.67197969	576	27.84328634
22.21795056	630	28.35545062
18.7054269	540	28.83219607
19.62209102	585	29.82539131
17.85995531	540	30.23523804
23.36291518	720	30.8180719
30.17320653	945	31.32823168
26.56859175	840	31.62713145
17.40368733	570	32.82621405
21.53813137	720	33.42908388
5.360220329	180	33.58070918
19.69432171	675	34.20534701
20.80689891	720	34.60390725
12.62667218	450	35.63884399
29.91699625	1080	36.09988086
23.31169981	855	36.68356537
12.68602454	472.5	37.2945525
25.16592199	945	37.54920586
20.0670166	765	38.13991276
18.64739618	720	38.61128884
15.09606593	600	39.73102304
26.38672002	1080	40.92967975
8.327223074	360	43.2322068
13.37057073	585	43.75473267
10.28020763	495	48.17681903
9.189041571	450	48.97137493
1.827843599	90	49.23834843
5.2465496	270	51.4623935
20.90975237	1080	51.65053995
17.26613907	900	52.12514485
6.659590806	360	54.05737535
9.699591408	540	55.6724482
7.721409062	450	58.2795182
13.35249734	810	60.66280935
9.572119503	585	61.14941705
20.36548242	1260	61.86939125
4.238597185	270	63.7003207
6.956057775	450	64.69214918
9.394347084	630	67.0616057
3.965089438	270	68.0943026

8.859606175	630	71.1092556
9.768932227	720	73.7030397
5.640277264	450	79.78331185
4.494320934	360	80.10108875
11.85306673	990	83.5226885
7.770660113	720	92.65622168
4.587001847	450	98.103296
5.929389439	630	106.2504001
0.844861632	90	106.5263193
5.279249914	720	136.3830112
1.773781932	270	152.2171329
5.672131726	900	158.6705041
5.594581485	900	160.8699422
5.316745845	900	169.2764759
8.285654979	1440	173.7943474
3.292380926	720	218.6867243
2.640310069	900	340.8690557
0.835586998	360	430.8348512
0.562596376	360	639.8903645

Data for Single-lane Highway

Agg Speed (mph)	Agg Flow (veh/hour-lane)	Agg Density (veh/mile-lane)
37.17212422	90	2.422211737
33.60186335	90	2.683382434
27.6391677	90	3.261519565
24.61159007	90	3.657969656
21.07065838	90	4.276249824
19.23898137	90	4.682130489
30.68657888	162	5.297894184
25.74685714	150	5.800711767
25.26702485	157.5	6.245127083
19.08038332	128.5714286	6.723417141
23.23121207	167.1428571	7.189065196
28.90604348	225	7.773522999
25.27565218	210	8.301792921
22.09467258	192.8571429	8.681473912
23.55847027	218.5714286	9.2775734
25.26462112	247.5	9.743301751
32.2828323	330	10.21971203
16.54725466	180	10.89898036
14.11870808	157.5	11.20148429
19.94916522	234	11.74404395
29.03545342	360	12.39863538
24.70326709	315	12.7704425
15.13587577	202.5	13.34830381
19.55341615	270	13.80547981
14.99695765	212.7272727	14.2526199
24.36059627	360	14.77476646
5.933515528	90	15.16853905
24.73140373	390	15.75793169
19.31623603	315	16.31658927
18.70736646	315	16.84290531
10.42831677	180	17.26339339
15.9352866	282.8571429	17.73970977
16.00921118	292.5	18.3014677
19.25862112	360	18.68148299
17.69729813	337.5	19.09770735
16.43178634	324	19.73952204
14.46898137	292.5	20.19974042
13.03363975	270	20.71464069
16.08196025	342	21.29083777
18.66745342	405	21.79783432
14.13491925	315	22.35013852
15.75145342	360	22.77801019
7.755130435	180	23.17232801

Location of study site : Dhaka-Chittagong National Highway (N1)
GR : 23.5990540, 90.6198490
Date of video recording : 25th August 2015
Time : 10:30am to 1:00pm and 2:30pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

15.17755528	360	23.72285734
17.93299379	435	24.2783946
7.272111801	180	24.75244017
15.40136646	390	25.27050725
7.048397516	180	25.53771969
11.82331677	315	26.63265626
17.50561491	480	27.37221872
10.38494907	288	27.7331668
9.628434783	270	28.04198268
8.637149069	247.5	28.67661571
4.621975155	135	29.22231256
18.1256646	540	29.79201106
9.499036023	288	30.29658592
6.851925466	210	30.66843765
15.90987577	495	31.17444251
7.943433541	252	31.72855248
8.424223602	270	32.05043132
7.851801243	257.1428571	32.7671489
8.11990062	270	33.23679989
6.65910559	225	33.7526696
5.26315528	180	34.20004169
9.117391304	315	34.54664844
5.099925466	180	35.29463346
17.6310559	630	35.7324033
11.82767702	427.5	36.18160809
6.151639752	225	36.56467665
9.679751553	360	37.22275703
11.94372671	450	37.67668258
5.425639752	210	38.73629649
6.870335404	270	39.27957045
11.33027329	450	39.71669889
8.935937889	360	40.28676773
6.636186336	270	40.68664543
6.560049689	270	41.15822483
4.292944099	180	41.92926715
8.415726708	360	42.7770545
10.40467081	450	43.24980659
8.222086957	360	43.78509427
8.16484472	360	44.09146926
5.973652174	270	45.20950405
5.775875777	270	46.7534077
12.38008696	585	47.24682662
4.711304348	225	47.78515985
4.663229814	225	48.21159787
8.30426087	405	48.75927038
9.490807452	472.5	49.73482914
7.162658385	360	50.2606687
10.57103106	540	51.08300195

7.533614907	390	51.7768387
3.443590063	180	52.27105005
8.539378882	450	52.6970411
19.81721739	1080	54.4980649
3.297018634	180	54.5947779
3.269515528	180	55.0540282
7.932521739	450	56.7284925
7.539875776	450	59.6826809
5.93273292	360	60.67018743
5.832391304	360	61.70941784
5.639701863	360	63.83316155
5.509341615	360	65.343561
7.504658386	495	65.96140173
5.448074534	360	66.07839115
6.345838509	450	70.9126145
4.906509317	360	73.37191815
10.02029814	810	80.83591815
3.27957764	270	82.32767435
8.762310559	900	102.7126343
5.229391304	540	103.2624963
5.198086957	540	103.8843722
9.317962733	990	106.2464005
6.527403727	720	110.304193

Data for Roadway with Shoulder

Speed (mph)	Flow (veh/hr-lane)	Density (veh/mile-lane)
76.57056259	180	2.350772855
66.35023787	180	2.712876484
56.60335811	180	3.181277629
26.38058885	90	3.411599358
41.59783834	180	4.327147928
61.66035774	315	5.139666059
49.38639742	270	5.425171961
45.85001206	270	5.887919465
43.74174737	270	6.172592916
13.90341876	90	6.473228026
25.10806996	180	7.169009815
12.24961483	90	7.347169787
23.20029959	180	7.7585205
11.08065551	90	8.122957334
10.51150531	90	8.562046761
9.825561633	90	9.159781737
38.03115021	360	9.465924591
36.01189552	360	9.996696781
17.98165366	180	10.01020281
32.00958979	360	11.2466296
27.79578575	315	11.33693025
30.6763638	360	11.73541957
36.90457582	450	12.19360987
17.77380603	225	12.65687327
13.9453773	180	12.90750305
13.65019965	180	13.18662031
23.47029399	315	13.41084176
39.86006017	540	13.5473955
19.00838902	270	14.20425475
33.59470072	495	14.73308149
18.13109864	270	14.89154107
5.88503249	90	15.29303367
14.31362249	225	15.72381714
25.23487658	450	17.85123768
28.25862897	540	19.10920734
4.510607114	90	19.95296813
8.836021466	180	20.34387446
30.63031492	630	20.56370907
16.95641816	360	21.23089891
12.65864383	270	21.32929907
12.50714155	270	21.58766645
9.740900841	225	23.08586772
11.55446042	270	23.3890256

Location of study site : Dhaka-Chittagong National Highway (N1)
GR : 23.6576058, 90.5719596
Date of video recording : 25th August 2015
Time : 10:30am to 1:00pm and 2:30pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

26.36296118	630	23.89716374
14.90763585	360	24.14869827
12.91945898	315	24.39329539
7.074088208	180	25.44497534
10.50531015	270	25.70128783
20.42956402	540	26.43228213
16.32390578	450	27.56693196
7.93845061	225	28.32852222
9.340985266	270	28.90487377
23.99165512	720	30.01043473
19.34554486	630	32.56563743
16.25024657	540	33.230265
13.09924654	450	34.3531209
10.40164756	360	34.60396841
20.70890668	720	34.76764906
7.315203905	270	36.90942912
14.26299544	540	37.86020983
18.55798329	720	38.79731912
4.440119705	180	40.53944757
8.674778351	360	41.49961941
10.44731288	450	43.07327686
10.35578532	450	43.45397147
24.72003985	1080	43.68924995
6.138526946	270	43.98449374
22.26120204	990	44.47199205
5.967851278	270	45.2424143
15.06526705	720	47.79205026
10.72467871	540	50.35558346
1.761733185	90	51.08605591
11.97220304	630	52.62189404
11.89594036	630	52.95924331
5.077766191	270	53.17298786
3.322990195	180	54.16808038
7.27500082	405	55.67104809
12.41650745	720	57.98732073
4.638337412	270	58.21051295
10.30801182	630	61.1175085
4.165685668	270	64.81526008
4.150635923	270	65.05027301
6.624147155	450	67.93327344
6.429150688	450	69.99369307
3.506253508	270	77.00527054
7.227891157	630	87.16235293
6.869821105	630	91.70544478
7.788627356	720	92.44247633
6.548837277	630	96.2002831
3.702341155	360	97.23577188
2.488421768	270	108.5025069

3.280940784	360	109.7246259
5.949101603	720	121.0266773
2.903848656	360	123.9734031
2.811062029	360	128.0654771
3.45620409	450	130.2006445
1.377187295	180	130.7011768
1.969339637	270	137.1017954
0.623195432	90	144.4169764
7.40737045	1080	145.8007274
1.180816086	180	152.4369477
3.502162904	540	154.1904288
2.271610764	450	198.0973181
1.250334144	270	215.9422754
1.788909135	450	251.5499481

Data Without Shoulder

Agg Speed (mph)	Agg Flow (veh/hr-lane)	Agg Density (veh/mile-lane)
39.78364042	90	2.265958902
32.11606553	90	2.814475154
27.85678711	90	3.238580387
24.86224968	90	3.627111355
24.33844548	105	4.320006091
21.83217303	105	4.7944461
24.15399253	126	5.231489512
26.39855173	150	5.686108579
25.25271192	157.5	6.240358408
22.48933089	150	6.677906443
24.92454897	180	7.21736527
14.60858684	112.5	7.723109905
15.34128941	126	8.123811087
10.22906563	90	8.799607863
19.38927751	180	9.303103554
16.21850655	157.5	9.683289659
17.23030764	180	10.44039912
22.58348894	240	10.63553735
17.06076525	191.25	11.23345892
12.69975394	150	11.80915217
19.41809282	240	12.29796939
26.25622058	337.5	12.8122311
16.77573673	225	13.36804575
19.70258969	270	13.70343669
12.54351817	180	14.33811677
11.18101718	165	14.75642253
35.30868339	540	15.29368836
19.90324276	315	15.81042724
13.95137987	225	16.16324017
8.028241753	135	16.85292817
15.60739763	270	17.26980607
5.058822849	90	17.79195067
21.33746774	390	18.29263725
8.01252831	150	18.73489136
9.36347909	180	19.22538726
15.08019047	300	19.89844422
19.8874775	405	20.38749325
17.23457665	360	20.81260523
7.379620919	157.5	21.27504986
13.45684267	292.5	21.73853164
14.20109431	315	22.16631515
17.72918756	405	22.85204647
16.34700209	378	23.12561678

Location of study site : Dhaka-Chittagong National Highway (N1)
GR : 23.6486170, 90.5862820
Date of video recording : 25th August 2015
Time : 10:30am to 1:00pm and 2:30pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

8.506289754	202.5	23.85089634
10.25180465	247.5	24.18666496
14.54670285	360	24.75637011
8.29765787	210	25.29948879
19.16515775	495	25.82301075
29.17003386	765	26.21930987
18.70867358	517.5	27.69084756
11.13159111	315	28.28859532
3.134220037	90	28.71527811
6.160266043	180	29.22009256
15.08469805	450	29.87497101
23.81088161	720	30.26752517
10.29041625	315	30.6127748
11.45944424	360	31.41514653
8.516215885	270	31.70422218
10.44890356	337.5	32.29355556
10.41747149	342	32.78868134
10.76790739	360	33.43267982
15.18115318	510	33.59298149
9.101282656	315	34.62452639
16.38552032	576	35.15543931
8.812921996	315	35.71439418
17.27381298	630	36.47139174
11.01958596	405	36.78661034
15.93897452	594	37.27824278
19.08371136	720	37.72851026
14.15965581	540	38.23008742
11.60967015	450	38.73018047
16.08413094	630	39.16904197
2.257924999	90	39.85960564
6.733210408	270	40.09974197
8.812109692	360	40.8351058
13.14189761	540	41.09547935
15.03610279	630	41.83934807
14.95413146	630	42.12882584
8.392720872	360	42.89302968
6.116742699	270	44.14114069
11.38683139	510	44.79327564
15.94817672	720	45.16191036
17.89369102	855	47.80977078
11.20916158	540	48.17487874
18.22920202	900	49.37133284
10.76851126	540	50.14620745
8.211353318	420	51.1300677
14.76153148	765	51.7738453
12.03007243	630	52.368762
13.70099323	720	52.55093465
12.564816	675	53.73837215

9.841446711	540	54.84107143
12.99809154	720	55.35934955
11.27963913	630	55.84118464
6.342703693	360	56.7581299
9.443733161	540	57.15038998
11.70472232	675	57.6875398
10.82727504	630	58.2218013
13.81946538	810	58.60232955
9.146756505	540	59.037321
12.28467584	765	62.28694645
5.743122634	360	62.6836693
11.36979003	720	63.3257077
9.874817277	630	63.79864885
10.48616941	675	64.37013595
6.943382833	450	64.80990765
11.8371189	780	65.89729553
18.96430501	1260	66.44061035
14.61963264	990	67.7171598
11.41382314	810	70.96658065
13.88999401	990	71.18382268
6.282967629	450	71.60822848
15.42109894	1125	72.95986845
9.221901494	675	73.18772355
9.706651341	720	74.1759413
20.49968375	1530	74.6352977
4.784946367	360	75.235953
8.019532994	630	78.5581904
4.452466018	360	80.8540702
9.712400078	810	83.3985414
10.72370433	900	83.92622295
9.058411728	810	89.4196493
13.92421185	1260	90.48986135
17.86327538	1620	90.6888555
7.881785797	720	91.3498563
8.611966917	810	94.05516855
6.923966273	660	95.35452283
7.894655824	765	96.90313288
7.381423941	720	97.54215525
10.02752112	990	98.7282887
5.446117027	540	99.1532127
15.41146388	1710	110.9563643
4.849079995	540	111.3613305
9.582344221	1080	112.7072849
2.761688579	360	130.3550309
2.26077079	360	159.2377262
8.329382508	1800	216.102454
0.514852245	180	349.6148684

Data for Roadway with Market

Agg Speed (mph)	Agg Flow (veh/hr-lane)	Agg Density (veh/mile-lane)
16.08363	90	5.59575
13.97193	90	6.441485
24.50194	180	7.40367
28.37769	270	9.522415
20.29144	225	11.1039875
21.42374	270	12.577195
26.98307	420	15.57160833
22.85039	378	16.542543
10.38223	180	17.337315
34.15248	630	18.454525
27.44512	540	19.68460667
17.24919	360	20.85963
25.25528	540	21.40675
13.99713	315	22.6143275
14.75708	342	23.184237
21.93461	540	24.68417
10.68518	270	25.268635
18.6566	495	26.547205
16.5759	450	27.147845
15.81136	450	28.42540167
21.32684	630	29.540235
18.34608	558	30.403168
17.02514	540	31.63041667
17.06391	555	32.58405833
9.832231	330	33.59301333
19.14352	666	34.788239
14.51801	510	35.195275
18.41176	675	36.60053
19.5997	735	37.558375
11.64543	450	38.64403
13.43299	540	40.18389833
13.92288	576	41.45991
12.66582	540	42.58516
14.41618	630	43.66141375
14.29588	630	44.06863
18.24909	832.5	45.65509
9.613695	450	46.808225
18.80103	900	47.86972
14.37655	697.5	48.46658
13.99777	690	49.33334
20.09375	1020	50.70375
13.08101	675	51.6302
8.546119	450	52.57366667

Location of study site : Dhaka-Mymensingh National Highway (N3)
GR : 23.9061560, 90.3989440
Date of video recording : 10th November 2015
Time : 2:00pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

17.97015	960	53.53835
12.77498	697.5	54.5863125
10.86663	600	55.24015
16.47538	930	56.48006667
12.59593	720	57.1613
11.4723	675	58.81495
4.527123	270	59.64055
12.4005	750	60.48805
7.298035	450	61.66045
13.70842	855	62.3251875
17.46539	1125	64.404675
14.44338	945	65.4327625
9.906383	660	66.58768333
12.59725	855	67.8955
9.213653	630	68.3768
12.92069	900	69.6566
7.668609	540	70.54196667
9.307327	675	72.5488875
9.776516	720	73.64585
15.08124	1125	74.569
13.69503	1035	75.560875
10.61782	810	76.280675
4.669811	360	77.0909
6.82188	540	79.15705
6.727673	540	80.2655
9.357507	765	81.5977625
13.15737	1080	82.08325
9.623815	810	84.1759
10.40308	900	86.506425
8.25295	720	87.24843333
13.23265	1170	88.41765
7.034691	630	89.50133333
2.949085	270	91.5538
8.525048	787.5	92.40205
9.598206	900	93.7675
9.534573	900	94.3933
10.38671	990	95.31415
12.18174	1170	96.0454
12.29427	1200	97.64905
10.04183	990	98.58648333
3.633142	360	99.0878
7.685853	780	101.4910833
7.014869	720	102.578125
9.39478	990	105.37765
8.432763	900	106.7266
7.544962	810	107.3564
4.122203	450	109.1649
4.071943	450	110.51235

6.436304	720	111.857575
7.17053	810	112.96235
5.572086	630	113.0636
5.242976	600	114.4440833
7.805432	900	115.30435
8.88113	1035	116.4588
4.590055	540	117.64565
5.703512	675	118.489225
9.316629	1116	119.77758
7.438425	900	120.99335
4.637118	570	122.9010333
8.723417	1080	123.8047
7.947381	990	124.56935
5.332687	675	126.57715
7.632147	990	129.7145
8.297055	1080	130.16665
8.789632	1170	133.11135
6.628975	900	135.7676
5.196468	720	138.55565
5.816388	810	139.2617
5.726002	810	141.45995
6.01183	855	142.19325
2.503591	360	143.79345
6.219525	900	144.724075
9.226661	1350	146.3151
3.642467	540	148.251175
11.34216	1710	150.76495
7.139039	1080	151.26745
5.264712	810	153.8546
6.995401	1080	154.3759
5.21464	810	155.33195
3.395941	540	159.01335
7.302299	1170	160.252225
10.93503	1800	164.60865
4.890531	810	165.567725
6.982711	1170	167.5567
1.586948	270	170.13785
6.829583	1170	171.31355
6.705513	1170	174.5128667
4.572471	810	177.1471
4.04047	720	178.1971
2.509257	450	179.33595
5.920512	1080	182.41665
2.903237	540	185.99925
5.24091	990	188.8985
4.608925	900	195.2733
6.423722	1260	196.14795
3.988457	810	203.08605

4.346852	900	207.0464
2.545592	540	212.1314
3.368933	720	213.71755
3.320905	720	216.80835
0.817261	180	220.248
2.83457	630	222.25595
1.926548	450	233.57845
4.868011	1200	246.46305

Data for Roadway without Market

Agg Speed (mph)	Agg Flow (veh/hr-lane)	Agg Density (veh/mile-lane)
36.93437562	90	2.436754338
20.70019056	90	4.347786061
35.83312839	180	5.023284544
20.36785282	135	6.528684884
23.61385439	180	7.622643766
35.23008047	300	8.50096169
29.8506477	270	9.045029867
12.85819579	135	10.6259048
15.37774865	180	11.70298758
27.99006192	342	12.21921809
26.06020131	360	13.8147767
28.82920698	405	14.16118712
27.37928655	420	15.33513475
19.51435319	324	16.59814368
23.06802865	405	17.52752488
19.57057087	360	18.42202764
27.72779977	540	19.47503965
19.80202729	405	20.43164673
26.94348664	570	21.19601795
18.50987047	414	22.46048941
15.1574036	360	23.75115313
23.74732702	585	24.6076775
15.87887557	405	25.40000267
15.07771331	405	26.84984005
20.66133785	570	27.59539349
30.18266843	864	28.58182815
13.68180579	405	29.58975766
25.02908904	765	30.57305981
18.22715858	570	31.30624735
21.32801391	690	32.43789724
17.3734575	585	33.56614809
17.81290092	612	34.36592824
20.02694583	720	35.95156277
14.73522614	540	36.64687564
18.11586552	675	37.3240744
20.11615127	774	38.5437668
22.07308114	900	40.77429314
17.26760291	720	41.69658081
10.562238	450	42.57288813
16.79692483	750	44.65289879
14.57549005	660	45.39655257
17.26451093	810	46.9170545
12.13512564	576	47.51882978

Location of study site : Dhaka-Mymensingh National Highway (N3)
GR : 23.9107308, 90.3971232
Date of video recording : 13th November 2015
Time : 2:00pm to 5:00pm
Data type : Data is extracted at 20 sec interval, it is then aggregated to 1 minute.

9.328876839	450	48.2266057
12.71705963	630	49.53985444
13.41515201	675	50.32605175
9.669285173	495	51.26678784
10.83139169	570	52.6196931
8.417783589	450	53.45825243
4.978222931	270	54.23622119
10.46355893	585	55.91801691
9.275940973	522	56.32388956
12.45061489	720	57.82847284
10.75696888	630	58.54395339
13.57766122	810	59.57283017
9.705920652	585	60.26707866
11.77771672	720	61.13239238
20.25345487	1260	62.20164999
4.253969279	270	63.47013396
9.782154662	630	64.40298909
13.05196422	855	65.36588935
5.401613863	360	66.64674838
11.86720096	810	68.25535376
11.33013062	787.5	69.46825023
15.33125586	1080	70.44432691
9.433449483	675	71.48205971
13.59392902	990	72.82683813
13.29841106	990	74.35951197
9.594412126	720	75.04368069
10.01045462	765	76.46799058
5.497312021	450	81.85818783
7.274825511	600	82.48168637
13.98803869	1170	83.64289135
10.58496043	900	85.026298
13.50443438	1170	86.63820842
7.164810049	630	87.92975609
2.03638506	180	88.39192722
17.17674139	1530	89.07393811
3.356104243	315	93.84525645
8.599117493	810	94.32191989
14.20424459	1350	95.04201304
14.93367027	1440	96.42639579
10.15375809	990	97.50084558
9.124867884	900	98.69091315
3.616324322	360	99.54859353
7.993931471	810	101.4469258
8.726346167	900	103.1359498
4.311402859	450	104.3743799
6.807764664	720	105.7615878
10.97468362	1170	106.6089958
10.0405117	1080	107.6125684

8.018219282	870	108.5520787
10.71093719	1170	109.2341388
5.285085417	585	110.6519185
4.845043498	540	111.4541077
7.210896229	810	112.3300037
2.380866472	270	113.5726899
3.118157276	360	115.6308346
7.72488674	900	116.5065625
6.105909715	720	117.9185467
2.990083004	360	120.3979955
6.426248688	810	126.0455422
2.827054326	360	127.3410265
7.372770752	990	134.2778764
7.300846233	990	135.6007192
5.941292966	810	136.3339604
9.669686507	1350	139.6115581
3.157883611	450	142.500502
6.276723682	900	143.3869078
4.32862641	630	145.544446
4.843309494	720	148.6586808
3.529193484	540	153.009463
6.355250528	990	155.7767071
2.187322134	360	164.584811
4.89114487	810	165.6053994
3.088070235	540	174.8664891
5.137057075	900	175.1975863
4.079988472	720	176.5559943
2.473876735	450	181.9007364
6.409616251	1170	182.5382292
5.736954032	1080	188.2532079
2.360974901	450	190.5992308
4.696959659	900	191.6133127
2.273470237	450	197.9352941
4.972134475	1080	217.2105371
3.677672442	810	220.248
1.584577208	360	227.1899395
2.541192634	585	230.4258482
1.167269288	270	231.3090928
0.753296895	180	238.9496109
2.25390631	540	239.5840491
2.524631323	630	249.4668277
3.199442382	810	253.1691162