STUDY OF VEHICLE ARRIVAL PATTERN AND FREE SPEED CHARACTERISTICS ON SELECTED NATIONAL HIGHWAYS

BY

GAZI ARIF IQBAL

A Project thesis submitted to the Department of Civil Engineering of Bangladesh University of Engineering & Technology, Dhaka in partial fulfilment of the requirements for the degree

of

MASTER OF ENGINEERING IN CIVIL ENGINEERING

August, 1998

STUDY OF VEHICLE ARRIVAL PATTERN AND FREE SPEED CHARACTERISTICS ON SELECTED NATIONAL HIGHWAYS

A THESIS
BY
GAZI ARIF IQBAL

Approved as to the style and content by:

Hossain 12.08.98
.... Chairman (Supervisor)
Dr. Moazzem Hossain
Assistant Professor,
Department of Civil Engineering
BUET, Dhaka.

12.8.98
.... Member
Dr. Md. Shamsul Hoque
Associate Professor,
Department of Civil Engineering
BUET, Dhaka.

.... Member
Dr. Hasib Mohammed Ahsan
Associate Professor,
Department of Civil Engineering
BUET, Dhaka.

DECLARATION

I do hereby declare that the work embodied in this thesis is the result of investigation carried out by me and this has not been submitted in candidature for any degree at any other university.

August, 1998

Signature of the student

ACKNOWLEDGEMENT

This work was carried out under the direct supervision of **Dr. Moazzem Hossain**, Assistant professor, Department of Civil Engineering of the Bangladesh University of Engineering & Technology.

The author wishes to express his sincerest debt of gratitude to **Dr. Moazzem Hossain** for his continuos guidance and valuable suggestions and affectionate encouragement at all stages of this study. Without his valuable direction and cordial assistance it would have been impossible to carry out this study under a number of constrains, time limitation in particular.

The author would like to express his sincere gratitude to **Dr. Md. Shamsul Hoque**, Associate professor, Department of Civil Engineering of BUET for his kind help with the operation of video camera and accessories and also for useful advice regarding field data collection.

The author likes to express his thanks to **Mr. Arifur Rahman** for his co-operation in traffic data collection.

ABSTRACT

Analysis and interpretation of traffic Operations on national highways require a sound understanding of the traffic flow parameters. Such traffic flow parameters are traffic arrival headways, free speed of vehicles, operating speed and speed-flow-density relationship. No significant study has yet been made to investigate these traffic parameters of Bangladeshi national highways. In this study, effort has been given to investigate the traffic arrival pattern and free speed characteristics of vehicles on two-lane two-way national highways of Bangladesh. The research study has been based on field data. Both video and manual data on the traffic flow of selected national highways have been collected for a net period of approximately twenty five hours. The analysis of collected data has been made using different statistical softwares. Analysis of traffic arrival pattern using the vehicular time headway data has revealed that the pattern follows more than one statistical distribution models for all the highways. Generally, it has been observed that the vehicles maintain close headways when they are in following situation. It has been observed that the traffic arrival pattern on selected Bangladeshi national highways can be described by one or more of the two statistical distributions, namely, exponential and lognormal. The relevant parameters of the corresponding arrival headway distributions have been estimated. Analysis of free speed data of vehicles on a typical section of Dhaka-Aricha highway has revealed that the free speed of the commonly found vehicles(bus, minibus, truck, passenger-car, nonmotorised vehicles) follow normal distribution pattern. Corresponding parameters of the normal distribution have also been estimated. From regression analysis, it has been found that free speed of vehicles depends on the pavement and shoulder width. In a pavement width range of 5.8m to 7.5m, free speed of commonly found motorised vehicles increases in a range of 7.25 kmph to 10.29 kmph for each metre of pavement widening for flat, straight and disturbance free highway section. The analysis has also revealed that free speed of vehicles increases with the increase in shoulder width except for the case of bus(the reason of which has been identified as a local phenomenon on a particular highway).

CONTENTS

APPENDIX C SPEED-FLOW-DENSITY OBSERVATION

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Road transportation plays a major role in the land and overall transportation sector of Bangladesh. With the increased traffic demand roads of Bangladesh are running at or near to capacity situation. To cater the increased traffic demand each year a significant portion of national development budget is spent to build and maintain the highway infrastructure. Analysis and interpretation of traffic operation of inter-city highways require a sound understanding of the traffic flow parameters. Such traffic flow parameters are traffic arrival headways, free speed, operating speed and speed-flow-density relationship. In order to make a mathematical or simulation study of highway traffic operation, these parameters are required to be estimated first. Till now, no significant effort have been made to establish these highway traffic parameters. It is, therefore, necessary to make a research study to investigate these parameters. However, determination of an overall speed-flow-density relationship for the highways needs huge relevant data over a broad range of traffic flow condition. Collection of such huge data base is out of the scope of the present research study considering the time and budget limitations. Therefore, a research study has been undertaken to investigate the vehicle arrival headway pattern and free speed characteristics of vehicles on selected national highways of Bangladesh.

1.2 OBJECTIVES OF THE RESEARCH

The objectives of the present research study are as follows:

i) To develop vehicle arrival patterns for the selected national highways of Bangladesh.

ii) To develop spot speed distribution model for the free flowing vehicles along straight highway sections.

iii) To investigate the speed-flow and speed-density conditions for limited period of time.

1.3 METHOD OF APPROACH

Three types of research approach are generally used in the field of traffic engineering. They are :

(i) Analytical approach
(ii) Simulation approach
(iii) Empirical approach

The analytical modelling approach may be based on macroscopic theories such as fluid flow analogy, which handles traffic flow as a one dimensional expandable fluid. Although this approach helps to understand traffic behaviour as a whole, there are underlying assumptions of homogeneity which are far from the high variations of driver-vehicle characteristics in mixed traffic conditions of Bangladesh.

The approach of Computer Simulation may be either Macroscopic or Microscopic in nature. The Macroscopic approach deals with traffic in an aggregate form employing a fluid flow analogy similar to the analytical approach, and hence, subject to the simplifying assumptions as the analytical approach. Microscopic simulation approach replicates the individual vehicle movements along the road system by processing every vehicle with its own characteristics for each real time interval. However, the basic flow parameters for such a simulation study of highways are not established yet.

Therefore, a study based on real field data remains as the only option for this research study. Such field is not available from any source. So, a field data collection programme has been undertaken as a part of the present research study.

1.4 SCOPE AND LIMITATIONS OF THE STUDY

The present research study aims at establishing the highway traffic flow parameters such as vehicle arrival headway, free speed characteristics of vehicles and speed-flow-density conditions for the data collection periods. These parameters are the basic elements of the study and understanding of highway traffic operation. Apart from the use of all these parameters in analysing highway traffic operation, the free speed data of vehicles can be used in designing the relevant speed control measures. Also, these parameters can be used in any future mathematical and simulation modelling of traffic operations on Bangladeshi national highways.

However, the present study is limited to the flat, horizontal and disturbance free sections on five selected national highways. And, national highways comprises only eleven percent of total highway network. Also, as far available information, more than two third (71%) of the national highways even have pavement width below the prescribed specification limits viz. 5.5 m (Bangladesh Transport Sector Study, 1994). But the pavement width of the five highway sections in this study are in the range of 5.8m to 7.5m.

1.5 ORGANISATION OF THESIS

The research work is divided into different topics and presented in five chapters.

Chapter 1 represents Background and objectives of the study. A brief review of the traffic characteristics prevailing in the highway of Bangladesh is presented in the first chapter with special emphasis placed on the objective of the study.

Chapter 2 incorporates literature review related to different traffic headway arrival pattern and speed models along with the definition of related useful terms.

Chapter 3 details description of data collection, surveying, reconnaissance survey, data processing, data extraction, site description etc. are presented.

Chapter 4 deals with the data analysis and interpretation of the results.

Chapter 5 includes the conclusions of the entire study and some recommendations for the further study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Transportation service is measured in terms of the ability of a highway to accommodate vehicular traffic safely and efficiently. Determination of the functional effectiveness of any highway needs the vehicular analysis of the traffic. In undertaking such an analysis, various dimension of traffic, such as type, speed, flow, density and arrival pattern must be addressed, since, they influence analysis, operation and control of highways. A through understanding of these elements or parameters will provide a valuable foundation for the comprehension and critical assessment of the various traffic analysis techniques and procedures. This chapter deals with the review of traffic arrival pattern and free speed characteristics of vehicles starting with the definition of related useful terms.

2.2 DEFINITIONS

At the beginning of the review definitions of some related useful terms have been presented.

2.2.1 Traffic Flow

Traffic flow, q, is defined as the number of vehicles, n, passing some designated highway point in a time interval of duration t, or

$$q = \frac{n}{t} \qquad \text{.......(2.1)}$$

where q is generally expressed in vehicles per unit time. Normally, vehicles/hour is widely used as traffic flow unit.

2.2.2 Headway

Aside from knowing the total number of vehicles arriving in some time interval, the amount of time between the arrival of successive vehicles (or the temporal distribution of traffic flow) is also of interest. The time between the passing of the front bumpers of two successive vehicles, past some designated highway point, is known as the time headway, h_i. This parameter of time headway h_i can be interrelated with Equation (2.1)

$$t = \sum_{i=1}^{n} h_i \qquad ....(2.2)$$

and

$$q = \frac{n}{\sum_{i=1}^{n} h_i}$$

or

$$q = \frac{1}{\bar{h}} \qquad ....(2.3)$$

where $\bar{h}$ is the average headway ($\frac{\sum h_i}{n}$). The importance of time headways in traffic analysis will be extensively demonstrated in forthcoming sections of this chapter.

2.2.3 Traffic Speed

The average traffic speed can be defined in two ways. The first is the arithmetic mean of speeds observed at some point. This is refereed to as the time mean speed, $\bar{u}_t$ and is expressed as

$$\bar{u}_t = \frac{1}{n}\sum_{i=1}^{n} u_i \quad \text{.........(2.4)}$$

The second measure is more useful in the context of traffic analysis and is defined on the basis of the time necessary for a vehicle to traverse some known length of roadway. This measure is known as the space mean speed, u_s, and is given by,

$$u_s = \frac{(1/n)\sum_{i=1}^{n} l_i}{\bar{t}} \quad \text{............(2.5)}$$

where l_i is the length of roadway used for the speed measurement of vehicle i, and

$$\bar{t} = \frac{1}{n}\left[t_1(l_1) + t_2(l_2) + \cdots\cdots + t_n(l_n)\right] \quad \text{.....(2.6)}$$

with $t_n(l_n)$ being the time necessary for vehicle n to traverse a section of roadway of length l. Note that if all vehicle speeds are measured over the same length of roadway ($L = l_1 = l_2 = l_n$),

$$u_s = \frac{1}{(1/n)\sum_{i=1}^{n}\left[1/(L/t_i)\right]} \quad \text{..........(2.7)}$$

which is the harmonic mean of speed.

2.2.4 Traffic Density

Traffic density, also refers to as traffic concentration is defined as the number of vehicles occupying a length of a roadway at a specified time. This is stated simply as

$$k = \frac{n}{l} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.8)$$

where k = traffic density

n = number of vehicles

l = length of roadways

2.3 HEADWAY MODELS OF TRAFFIC FLOW

With the basic relationships between traffic flow, speed, and density formalised, attention can now be directed toward a more microscopic view of traffic flow. That is, instead of simply modelling the number of vehicles passing a point in some time interval, there is considerable analytic value in modelling the time between the arrivals of successive vehicles (i.e., the notion of vehicular headways presented earlier). The most simplistic approach to vehicle arrival modeling is to assume that all vehicles are equally or uniformly spaced. This results in what is termed a deterministic and uniform arrival pattern. Under this assumption, if the flow is 360 veh/hr the number of vehicles arriving in any 5-min time interval is 30 and the headway between all vehicles in 10 sec (since h will equal to 3600/q). However, experience tells us that, in many instances, such uniformity of flow may not be an entirely realistic representation of traffic, since some 5-min intervals are likely to have more or less flow than other 5-min intervals. Thus a elaborate model of vehicular arrivals is often warranted.

Model that accounts for the nonuniformity of flow are derived by assuming that the pattern of vehicle arrivals corresponds to some random process. The problem then becomes one of selecting a probability distribution that is a reasonable representation of observed traffic arrival patterns. An example of such a distribution is the Poisson distribution which is expressed as(Mannering and Kilreski 1993)

$$p(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad \text{..................(2.9)}$$

where t is the duration of the time interval over which vehicles are counted, p(n) is the probability of having n vehicles arrive in time t, and λ is the average flow or arrival rate in vehicles per unit time. The assumption of Poisson distributed vehicle arrivals also implies a distribution of the time intervals between the arrivals of successive vehicles (i.e., time headway). To show this, let the average arrival rate, λ, be in units of vehicles per second, so that

$$\lambda = \frac{q}{3600} \qquad \text{.....................(2.10)}$$

where q is the flow in vehicles per hour. Substituting Equation (2.10) into Equation. (2.9) gives

$$p(n) = \frac{(qt/3600)^n e^{-qt/3600}}{n!} \qquad \text{...............(2.11)}$$

It can be noted that the probability of having no vehicles arrive in a time interval of length t (i.e., p(0) is the equivalent of the probability of a vehicle headway, h, being greater than or equal to the time interval t(Mannering and Kilreski 1993). So from Equation (2.11)

$$p(0) = p(h \geq t)$$

$$= e^{-qt/3600} \qquad \text{.......................(2.12)}$$

This distribution of vehicle headways is known as the negative exponential distribution and is often simply referred to as an exponential distribution.

Empirical observations shows that the assumption of Poisson-distributed traffic arrivals is most realistic in lightly congested traffic condition. If traffic flow become heavily congested other distributions of traffic flow become more appropriate(Mannering and Kilreski 1993).

2.4 TRAFFIC ARRIVAL PATTERN

Adams has reported that [Hossain 1996] free flowing traffic corresponds to a random arrival pattern, where the arrival of one vehicle is independent of the arrival of any other vehicle. This means that equal time intervals are equally likely to contain equal number of arrivals. But at higher flow situation where vehicles are not in a free flow condition, traffic arrival patterns are not random. This discrepancy led to the formulation of other headway distribution models. Generally, these may be classified as single distribution models and mixed distribution models.

2.4.1 Single Distribution Models

2.4.1.1 Negative exponential distribution

If the arrival of traffic is considered to be random then the traffic arrival is described as a Poisson process. And, under this circumstances, headways are distributed according to the negative exponential distribution [Hossain 1996]. This distribution model is simple as it can be defined by only one parameter of mean arrival rate and also random variates of this distribution can be easily generated. But it suffers from serious limitations. It predicts higher probability density in the range of values very near to zero than those in any other range. Also, at higher flows the random arrival pattern breaks down. A variable x is said to be exponentially distributed if its density function is given by ,

$$f_X(t) = \begin{cases} \lambda e^{-\lambda t} & \lambda > 0, \quad t \geq 0 \\ 0 & \textit{otherwise} \end{cases} \qquad \cdots\cdots\cdots\cdots(2.13)$$

where, λ is the rate of arrivals in veh/sec as described earlier.

2.4.1.2 Shifted negative exponential distribution

In the negative exponential distribution the physical finite length of the vehicle is ignored by taking vehicles as points. But as the vehicles have certain lengths it is obvious that a real minimum time headway between vehicles exists, and this minimum headway is incorporated in the negative exponential distribution with a Shifted negative exponential distribution[Hossain 1996]. As it requires only two parameters to define this model, i.e. mean headway and a minimum headway, it is a relatively easy model to calibrate; and, its simple mathematical expression still allows easy generation of random deviates during simulation. However, this distribution function still assigns a higher probability density to the smaller headways. The density function for the shifted negative exponential distribution is given by,

$$f(t) = \begin{cases} (1/\beta)\, e^{-(t-\tau)\beta} & t \quad \tau \\ 0 & t < \tau \end{cases} \qquad ....(2.14)$$

where, $\beta = \bar{t} - \tau$

$\bar{t}$ = the average time spacing between arrivals

t = headway between successive arrival

τ = the minimum headway

The corresponding cumulative distribution function is

$$F(t) = 1 - e^{-(t-\tau)/\beta} \qquad \text{..............................(2.15)}$$

2.4.1.3 Gamma distribution

In this distribution, a variation of minimum headways is incorporated. Tolle [Hossain 1996] fitted a set of observed data to this distribution function and found that the fit was not good statistically. However, an improved fit was reported when the distribution was shifted by a minimum headway. The Erlang distribution is the simplified form of the Gamma distribution. The density function of gamma distribution is

$$f(t) = \begin{cases} \dfrac{\lambda^k e^{-\lambda t} t^{k-1}}{(k-1)!} & t \geq 0, \quad \lambda > 0, \quad k = 1,2,.. \\ 0 & otherwise \end{cases} \qquad \text{.........(2.16)}$$

where, k and λ are the parameters required to be estimated.

2.4.1.4 Log-normal distribution

This model represents the distribution function of deviates whose natural logarithms follow the normal distribution. Greenberg [Hossain 1996] proposed this model and suggested its relation to traffic headways and car following theory. Two parameters i.e. mean headway and standard deviation of headways are required to apply this model to traffic headways. Tolle [Hossain 1996] has tested the distribution model and reported that although the Kolmogorv-Smirnov test produced statistically good fits, the chi-square test did not at higher flows. A recent study by Bullen and Mei [Hossain 1996] suggested that shifted lognormal distribution gives better fit at high flow situation. They suggested a shift of 0.3-0.5 second after their study. This distribution however requires three parameters i.e. mean, standard deviation and shift of the headways to be defined. A random variable x is said to have a log normal distribution if its logarithm is normally distributed. If y is a random variable representing that normal distribution of natural logarithm then the random variable of lognormal distribution is given by the following equation.

$$x = e^{y} \qquad \text{..................(2.17)}$$

2.4.2 Mixed Distribution Models

Mixed distribution models are based on the concept of bunching of vehicles [Hossain 1996] in a traffic stream. This concept views two distinct categories of vehicles in the traffic stream: followers and non-followers. The former group consists of the vehicles which are impeded by front vehicles and are not able to maintain their desired speed for that reason. The latter group consists of free-flowing vehicles that are able to maintain their desired speeds. The general form of the probability density function of these models is as follows:

$$f(t) = \Phi g(t) + (1-\Phi)\,h(t) \qquad \text{............... (2.18)}$$

where, Φ is the proportion of restrained traffic, and h(t) and g(t) are the free and restrained headway distributions respectively. Depending on how the two distributions are specified, there could be three classes of mixed distribution models which are described below.

2.4.2.1 Composite distribution models

These mixed distribution models treat the distributions of free and restrained headways independently. Examples of this type of models are the double exponential distribution model and hyperlang model.

2.4.2.1.1 Double exponential model

This model, proposed by Schull [Hossain 1996] was the first model which classified the vehicles into free and following groups. He took the headways of both the groups to be exponentially distributed. Four parameters such as proportion of constrained traffic, minimum headway, mean follower headway and mean non-follower headway are necessary to define this model.

2.4.2.1.2 Hyperlang model

This mixed distribution model is obtained by linear combination of the Erlang and Negative exponential functions, for the restrained and free headways function respectively. This model was reported to conform well with the headway data including high traffic volume, the only disadvantage being the number of parameters involved.

2.4.2.2 Moving queue models

This mixed distribution model was first introduced by Miller [Hossain 1996] with the basic assumption that the traffic stream forms a process comprising random bunches and gaps. The model involves moving randomly placed vehicles backwards in time in order to maintain a minimum headway. This resembles a Poisson process modified by imposing a classical queuing system with a single server having finite serving time before entry. The following headways distribution on the road is analogous to the service time distribution of a queue. Whereas each non-following headway is made up of a following headway and a gap which is exponentially distributed. A number of moving queue models have been proposed with different following headway patterns.

Assuming a constant following headway while the non-following traffic is exponentially distributed, Tanner [Hossain 1996] proposed a mixed distribution model which is known as Constant headway queuing model. A generalisation of Tanner's model is the assumption that following headways form a distribution instead of having a constant value. The Normal, Gamma and Lognormal distributions were proposed to represent the following headway distribution. And, it was claimed that the best fit for a wide range of flows was achieved with the log-normal distribution [Hossain 1996].

Studying the vehicle headways in urban areas, Griffiths and Hunt [Hossain 1996] proposed a mixed distribution model named DDNED (Double Displaced Negative Exponential Distribution) which consists of two displaced (shifted) negative exponential distribution. But again, a number of parameters are involved.

2.5 SPEED MODELS

In this section, highway speed models established in different parts of the world will be discussed. However, these models represent both free and other operating speed conditions and are mostly used for evaluation, design and maintenance purpose.

2.5.1 The Indian Speed Model

In India, one of the objectives on speed models and empirical speed/flow relationships in road user cost study (1982) (Xishi SHI, 1995) was to determine the effect of road width, surface type, gradient, curvature, road roughness, traffic and environmental conditions on the vehicle speeds. About 23 sites of different road types were selected, and sample size of speed /flow and highway data was ranged through 30-200 sets. Traffic flow ranged 0-5000 vehicles /hr / two-way (the highest hourly flow) on the single and dual carriageways in 1982.

In the analysis of speed/flow experimental data, the most useful tool for multivariate analysis seems to be the multiple linear regression techniques. Since a large number of road characteristics were known to influence vehicle speeds, the multiple linear regression technique assume that the relationship of the dependent variable to the independent variable was linear. The method provides an overall picture displaying the importance of each variable and its relationships to the vehicle speed. In the Indian speed models, considering all the above factors, equations for mean free speed were derived to take account of geometric effect on low flow roads.

Another objective on speed models on road user cost study in India was to develop simple mathematical relationships between the speeds of different vehicles types in a traffic stream and the volume with certain vehicle compositions under typical road and traffic conditions. However, speed/flow relationships were not fully consistent on the free speed items compared with those from the free speed equations. Adjustment should be made to the Indian speed models.

The Indian study concluded that the multiple linear regressions equations developed were not fully satisfactory. The correlation coefficients were not high (R^2 ranged to 0.16-0.90) because the speed data were scattered up to 40 km/hr. Enormous error may occur in the sampling, measurement, and processing. However the total traffic flow can itself be used as the variable to determine the speed/flow relationships and showed the levels of vehicle interactions on different road types. The mean speed for cars would decrease some 8.4 km /hr per 100 total vehicles increased (while only some 1.28 km/hr on two lane roads and some 0.345 km / hr on four lane carriageways with low curvatures). On two lane roads in hilly terrain, mean speed will decrease some 2.38 km /hr for cars, 1.78 km/hrs for buses and 1.31 km/hr for trucks per 100 vehicles increased. Speed/flow slopes actually represents the amount of vehicles interactions to different type of vehicles on roads under the non-free-flowing condition. One reason for these high reductions of speed with traffic increasing would be a range of mixed vehicles travelled on the same roads in this developing country. Another reason for these might be that the lower the class of roads the more vehicles interactions. This means that speed / flow effects may not be ignored when traffic flows have frequent interactions under the mixed traffic (low or high flow) conditions in developing countries.

2.5.2 The Brazilian Speed Models

The Brazilian models conducted between 1975 and 1984 (Xishi SHI, 1995), were a major advance of the development of new model form for the prediction of vehicle speeds. The method was based on what may be described as an aggregate probabilistic limiting velocity approach to steady state speed prediction, which represented a probabilistic minimum of a number of constraining speeds. To predict a vehicle mean speed for a round trip, a given road of various vertical and horizontal alignments consisting of two idealised homogenous segments of positive grade (uphill) and negative grade (downhill) was considered. The steady state speed for each type of vehicle can be predicted for each of these road segments as a function of road and vehicle characteristics.

The Brazilian speed models were derived as the following form :

$$v_u = \exp(0.5a^2) / [(1/VDRIV_U)^{1/b} + (1/VBRAK_U)^{1/b} + (1/VCURV)^{1/b} + (1/VROUG)^{1/b} + (1/VDESI)^{1/b}]^b$$

$$v_d = \exp(0.5a^2) / [(1/VDRIV_d)^{1/b} + (1/VBRAK_d)^{1/b} + (1/VCURV)^{1/b} + (1/VROUG)^{1/b} + (1/VDESI)^{1/b}]^b$$

where v_u , v_d are the vehicle speeds for uphill and downhill ;

$\exp(0.5a^2)$ is the bias correction factor of prediction ;

a is the standard error of residuals in estimation ;

b is the coefficient which determines the speed curve shape for a type of vehicle ;

VDRIV is the constraining speed of vertical gradient and engine power ;

VBRAK is the constraining speed of vertical gradient and braking capacity ;

VCURV is the constraining speed of road curvature ;

VROUG is the constraining speed of road roughness and associated ride severity ;

VDESI is the desired speed in the absence of other constraints .

Details of the model parameters and constraining speed models were defined in relevant Brazilian speed studies, which have been adopted as the major speed models in the highway design and maintenance (HDM-III) model. Obviously, the Brazilian speed models did not take any account of traffic flow effects and, therefore, the models can only be used for vehicle speed predictions under the very low flow conditions.

From the above uphill and downhill speeds (v_u and v_d) , the average speed for a round trip (using both segments) can then be calculated to correspond to the mean space speed over the two segments, that is, the round trip length divided by the round trip time.

2.5.3 The Ethiopian Speed Models

The Ethiopian traffic speed surveys and studies were reported during 1970s and 1980s (Xishi SHI, 1995). A total of about 100 traffic counting stations and 7000 km of roads were used in the studies of vehicle operating characteristics, sizes, weights etc. It was observed that traffic volume was less than 100 vehicles/day as recorded on 14.4% of the roads, 101-200 on 23.4% of the roads, 201-300 on 8.5% of the roads, 301-400 on 7.5% of the roads, 401-500 on 23% of the roads and 500-4862 (the highest daily flow) on 23.2%of the roads in 1981. Traffic compositions varied from 19-82% of cars, 10-28% of buses, and 8-65% of trucks on different type of roads. The vehicle mean free speeds were about 110 km/hr for cars, 90 km /hr for light goods vehicles, and 75 km /hr for trucks and buses on rural paved roads in plain terrain. However, models of vehicle mean free speeds and speed/flow relationships were not conducted for each type of vehicle and roads.

2.5.4 The Kenyan Speed Models

Several studies in Kenya were made to relate speed to the type of vehicle and the road characteristics. Vehicles were classified (Xishi SHI, 1995) in numerous different ways, normally either light vehicles (cars and light goods vehicles) or heavy vehicles (buses, medium and heavy goods vehicles).

A total of 880 km of road with different types of surface was initially selected from maps to provide a representative sample of road geometry under terrain conditions in Kenya (Abaynayaka etal,1974) (Xishi SHI, 1995). It was reduced by field inspection to 598 km compassing 348 of bitumen (108 sections) and 250 km(78 sections) of murram roads. Traffic flow ranged 22-178 vehicles/ hr /two-way with proportion of heavy vehicles varied from 4.3-57.9%. Road user sample was selected to reflected the complete range of vehicles type, operation and fleet size on the widest possible range of road types, which consisted of 43 cars, 47 light goods vehicles, 28 medium goods vehicles, 50 heavy goods vehicles and 121 buses (Hide et al, 1975) (Xishi SHI, 1995).

Abaynayka et al (1974) (Xishi SHI, 1995) found that the speeds of both light And heavy vehicles were significantly affected by the physical characteristics of roads under low flow conditions. The most important factors were the type of road surface, the rise and fall of the road, the horizontal curvature, and the width of roads. They produced a series of regressions equations by using the following form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \cdots\cdots + b_nX_n \quad \cdots\cdots(2.19)$$

where Y is the dependent variable ;

X_i is the independent variable ;

a , b_i are the regression constants .

The multiple regression equations as described can be used to quantify the effect of the independent variables acting together on the dependent variable. However, in order to investigate the effect of any one individual independent variable on the dependent variable, simple regression analysis must be carried out . Equations derived take the following form :

$$Y = a + bX \quad \cdots\cdots(2.20)$$

where Y, X, a, b, are as above

Further studies in Kenya (Xishi SHI, 1995) found that vehicles speeds were not related to traffic flows under the low flow conditions and the speed models were similar to Caribbean models. It was concluded from Kenyan studies that it is possible to use the regression models developed above to obtain satisfactory predictions of vehicle speeds in developing countries where traffic and road conditions are similar (Xishi SHI, 1995).

Meanwhile, Hide et al (1975, TRRL, UK) (Xishi SHI, 1995) also found that, for paved roads in Kenya, increase in rise, horizontal curvature and altitude reduced speeds for both classes of vehicles. An increase in fall reduced speeds for light vehicles but increased speeds for heavy vehicles. For gravel roads they found that altitude had no significant effect but that increases in surface roughness and the depth of loose material also had the effect of reducing speeds.

2.5.5 The Caribbean Model

Morosiuk et al (1983, TRRL, U.K.) (Xishi SHI, 1995) reported an experimental study of vehicle speed and fuel consumption undertaken in the eastern Caribbean, which was designed to extend the range of the empirical relations derived in an earlier study in Kenya (54) and incorporated in the TRRL model of RTIM2 for developing countries.

The user sample size was 32 cars and light goods vehicles and 36 trucks and buses (hide, 1982) (Xishi SHI, 1995). Both Kenyan and Caribbean studies consisted of vehicles speeds ranged 5-140 km/hr under the low flow conditions on roads with curvature 0-250 degrees/ km, rise and fall 0-85 m/km, and roughness 2000-14000 mm/km (Xishi SHI, 1995). Regression coefficients (R^2) in all empirical models ranged 0.42-0.96 (Xishi SHI, 1995).

Separate analyses were carried out for three classes of vehicles (cars, light vehicles and trucks). The independent variables considered in these analysis were rise, fall, curvature, road width and surface roughness. Additionally power-to-weight ratio (PW) and gross vehicle weight (GVW) were considered in the truck analysis. The final best regression equations were derived using the statistically significant variables for speed estimation on normal paved roads under the low flow conditions (Xishi SHI, 1995).

In the Caribbean study, the only parameters found to be that were significant for both the Caribbean vehicle performance study provided a new set of relationships for estimating vehicle speed and fuel consumption under very low flow conditions. A method of vehicle operating cost tables has been evolved to make use of these to provide realistic vehicle speed estimates for intermediate physical and environmental conditions.

2.5.6 RTM 2 Speed Models

In order to estimate vehicles speeds and further user costs in a road project appraisal for developing countries, speed prediction models under rural low flow conditions were presented in the form of mathematical relationships and have been incorporated in the RTM2 model (Xishi SHI, 1995) for developing countries by the TRRL of U.K. Details of these models have been provided to enable users to program them on microcomputers or to calculate them when required.

The vehicles speed models were set for cars, light vehicles, trucks, and buses on the both unpaved and paved roads. In these models, it is necessary initially to determine the environmental free speeds of the different classes of vehicle in the environment under investigation. Having determined the vehicles speeds on the straight, flat and smooth roads, these free speeds are adjusted to take into account the effects of highway geometry, such as the rise, fall, curvature, roughness, road width, moisture content and rut depth for unpaved roads , which are the speed/highway models rather than speed/flow relationships. No traffic flows have been taken into account in the speed models. In the case of trucks and buses, this final estimate is then adjusted according to the power to weight ratio of the vehicle. The tables of environmental free speeds for cars, light vehicles, trucks and buses against the reductions in free speeds due to rise, fall, curvature, roughness, road width, moisture content or rut depth were conducted for estimates.

2.5.7 HDM-III Speed Models

Several sets of the above speed models in developing countries were incorporated in the Highway Design and Maintenance (HDM-III) (Watanatada et al, 1987) (Xishi SHI, 1995) model by the Transportation Department, World Bank, Which included the following models:

(1) Brazilian mean speed models;
(2) Indian mean speed models;
(3) Kenyan mean speed models; and
(4) Caribbean mean speed models;

Using the HDM-III, users can specify which set of the above relationships is to be used. In the consideration of more general form and more extensive empirical validation in the HDM-III, it was advised to use the Brazilian relationships with as much local calibration as possible. For applications in India, Kenya, Caribbean countries where the alternative relationships have been statistically estimated, users are encouraged to use the Brazilian relationships as parallel analysis of speed effects. However, it seems to be difficult for some other countries to get enough similar data in the model calibration. It can be seen that all speeds models incorporated in the HDM-III model can only be applied for the very low flow (free-flowing) conditions.

2.5.8 The Chinese Speed Models

In China, in order to estimate vehicle mean speed and operating costs on interurban and rural roads in traffic studies, empirical speed/flow relationships were studied with sample size varied 10-100 data sets for each type of roads (Xishi SHI, 1995). Traffic flows ranged 100-10,000 vehicles/ day (the highest daily flow) on the single and dual carriageways in 1985. Then, models for plain terrain were set up to the specified rural road classes as follows:

(1) Motorways (Dual Two-lane carriageway 2 * 7.5 m) :

$v_m = 95$ km /hr (when $Q_1 \leq 3000$ vehs / day / direction)

$v_m = 337 * (1/ Q^{0.1582})$ (when $Q_1 > 3000$ vehs / day / direction)

(2) Class 1 (Dual Two - lane carriageway 2 * 5.5 m) :

$v_1 = 72$ km /hr (when $Q_1 \leq 2000$ vehs / day / direction)

$v_1 = 147 * (1/ Q^{0.1582})$ (when $Q_1 > 2000$ vehs / day / direction)

(3) Class 2 (Single Two - lane Carriageway 7.0 m) :

$v_{2B} = 147 (1/ Q_2^{0.1622})$

(4) Class 3 (Single Two - lane Carriageway 6.0 m) :

$v_3 = 184 (1/ Q_2^{0.2184})$

(5) Class 4 (Single Two - lane Carriageway 5.0 m) :

$v_4 = 117 (1/ Q_2^{0.2184})$

(6) Class 5 (Single Two - lane Carriageway 3.0 m) :

$v_5 = 117 (1/ Q_2^{0.2184})$

where v_i is the mean speed of vehicles on road class I (km / hr) ;

Q_1 is the AADT flow in one - way (vehicles / day / direction) ;

Q_2 is the AADT flow in one - way (vehicles / day / direction) ;

These empirical speed/flow relationships were derived under the Chinese mixed traffic conditions in plain terrain. Traffic flows on the typical roads, except dual carriageways, consisted of some 70% of motor vehicles (including tractors) and 30% of non-motorised vehicles (e.g. bicycles) on the non-motor vehicle lanes. The motor vehicles consisted of some 20% of cars, 60% of light and medium goods vehicles (LGVs), and 20% of buses and heavy goods vehicles (HGVs) on the interurban and rural roads. The Chinese speed/flow relationship on rural Single carriageways in plain terrain, which represents that as flow increases the speed decreases. Due to the mixed traffic (the non-free-flowing) conditions and the higher percentages of LGVs and HGVs on roads, vehicle interactions are frequent and, hence, vehicle speeds and road capacities are expected to be lower than those in developed countries.

In order to test speeds/flow effects of highway appraisal in china that above models are typically represented for the light goods vehicles under the Chinese situation, vehicle speeds on the single and dual carriageways can be estimated. However, because empirical free speed models have not been studied in China, the speed for each type of vehicles on the straight, flat and smooth roads can not be estimated at this stage.

	VEHICLE MEAN SPEED (Km / Hr)	
TRAFFIC FLOW (Vehs/h/Direction) Q_c Capacity Flow	Single Carriageways	Dual Carriageways
	Light Vehicles	Light Vehicles
1	50.0	72.0
100	42.8	72.0
200	38.3	72.0
300	35.9	67.1
400	34.2	64.1
500	33.0	61.9
600	-	60.1
700	-	58.7
800	-	57.4
900	-	56.4
1000	-	55.4
1100	-	54.6
1200	-	53.9

Table 2.1 Estimates Of Empirical Speed / Flow Relationships On Typical Roads In Plain Terrain In China

2.6 ROADS OF BANGLADESH

As it has been intended to conduct the present study on the Bangladeshi highways, it would be appropriate to discuss about the road networks of Bangladesh. In this section, the classification and characteristics of the highways of Bangladesh have been discussed.

2.6.1 Road Classification

Bangladesh has two-tier administrative cum functional road classification (Bangladesh Transport Sector Study 1994). In the first stage road network has two classes : roads under the jurisdiction of roads and highways department, ministry of communications (RHD, MOCS) and the rest under local government. In the second stage classification while RHD network has three functional categories, local government network has five functional categories. RHD road comprises of :

a) National Highways connecting the nation capital with district (zila) headquarters, port cities and international highways;

b) Regional Highways connecting the different major region of the country and zila headquarters not connected by national highways; and

c) Feeder Roads (Type A) connecting sub-district (thana) headquarters to the arterial road network.

Local government roads consist of

i) Feeder Roads (Type B) connecting growth centres with thana headquarters or to the Arterial network.

ii) Rural Roads (Type 1) connecting union headquarters and local markets with centres or the Road system.

iii) Rural Roads (Type 2) connecting villages and farms with union headquarters and local markets;

iv) Rural Roads (Type 3) serving villages; and

v) Urban Local Roads: urban local roads are the responsibility of municipalities.

While feeder roads (type b) and rural roads fall in the jurisdiction of local government engineering department (L G E D). Considering the importance and monetary investment involved, the national highways should get the priority to be included first. Therefore, five national highways have been decided to be undertaken for the present research study.

2.6.2 Characteristics Of Roads In Bangladesh

Classification, definition and geometric standards of roads in Bangladesh are presented in the Table 2.2 below.

Category of roads	Crest width (m)	Pavement width (m)	Shoulder width on each side of road (m)	Definition
National highways				Highways connecting the national capital with divisional headquarters, old district Headquarters, port cities and international highways
A. Category a	12.2	6.7	2.75	
B. Category b	12.2	5.5	3.26	
Regional highways				Highways interconnecting district headquarters of the region and with national highways .
A. Category a	10.98	5.5	2.75	
B. Category b	10.98	3.66	7.66	
Feeder roads (type a)	7.33	3.66	1.83	Roads connecting uphill HQ with R&H road network .
Feeder roads (type b)	7.33	3.66	1.83	a. Roads connecting major rural market / development centres (growth centres) with upzilla HQ. b. Roads connecting growth centre with R&H network . c. Roads connecting one upzilla with other upzilla.
Urban roads	No fixed standard . Design standards vary according to traffic volume .			Roads within the territorial boundaries of cities/ towns and under municipal corporation or pourashavas
Rural roads				
A. Type - r1 (upzilla roads)	4.89	3.05	0.92	Roads connecting union headquarters and local marketwise with the upzilla headquarter or road system .
B. Type - r2 (union roads)	3.66	-	-	Roads connecting village and farms to local markets and union headquarters .
C. Type - r3 (village roads)	2.44	-	-	Roads within a village or between villages .

source: Bangladesh Transport Sector Study, Final Main Report, Planning Commission, Dhaka, Bangladesh, 1994.

Table 2.2 Classification of roads of Bangladesh

2.7 Comments

The literature review of this chapter highlighted the scope of the study of traffic arrival patterns and free speed of vehicles. No such study for Bangladeshi national highways has been made to investigate the above topics. It is therefore required to make a study on the traffic arrival pattern and free speed of vehicles on Bangladeshi national highway.

CHAPTER 3

DATA COLLECTION

3.1 INTRODUCTION

Parameters related to traffic flow are useful to the highway engineers in establishing geometric design criteria, selecting and implementing traffic control measures and evaluating the performance of highways. Traffic arrival patterns and their parameters are the basic input to any of mathematical modelling of highway traffic operations. Driver's free speed denoting his/her desired speed is a useful parameter considering the traffic safety and relevant control measures on the highway. Till now, no study has been made for investigating the above cited parameters for the national highways of Bangladesh. In Bangladesh, most of the national inter-city highways are two lane two way type with lane width varying from 2.9m-3.75m. Five national highways of Bangladesh namely Dhaka-Chittangong, Dhaka-Aricha, Dhaka-Mymensingh, Dhaka-Sylhet and Dhaka-Khulna, are selected for the present study.

3.2 REQUIRED DATA ITEMS

Required data items are as follows:

i) Headways between successive vehicles.

ii) Driver's free speed while he/she is not impeded by the front vehicles.

iii) Speed and flow data at different highway sites.

iv) Speed and density data at different highway sites.

v) Traffic and geometric characteristics of the highway sites.

3.3. METHODS OF DATA COLLECTION

The field data has been collected in three ways:

i) Qualitative Observation:

In order to observe the traffic operations in general, field observation of traffic flow has been made on the national highways of Bangladesh.

ii) Manual measurement:

Physical dimension of the selected sites such as shoulder width and pavement width have been measured.

iii) Video Recording:

In order to estimate the vehicular time headway data, free speed data and average speed, flow and density data, video recordings of the traffic flow have been made.

3.4 VIDEO PHOTOGRAPHY AS TRAFFIC DATA SOURCE

In order to be able to analyse the traffic operation, a comprehensive and permanent recording of the traffic operation is necessary. Video recording is a widely used and cost-effective means of traffic data collection which can provide a comprehensive and permanent record of traffic movements (Hossain, 1996). One can obtain many sets of required information regarding the traffic operation from the same recorded film. Also, recorded video tapes can readily be used to observe the same traffic scenario repeatedly as many times as required during analysis. It was, therefore, decided to use video cameras as a main method of recording highway traffic data.

In video filming process the main instrument of data recording is the video camera. For this, video camera should be placed on a high place to cover a large area of selected section, of the highway and the camera axis should be parallel with the road alignment.

3.5 DESIRED SITE CHARACTERISTICS

Considering the scope of the study and the limitations of video filming, the selected site of highway sections should possess following characteristics.

i) The site should be suitable for video data collection.

ii) The site should be chosen free from intersection effect by offsetting a further distance from intersection and market place.

iii) The site should include the wide variations in traffic conditions in the study area i.e. with/without non-motorised vehicle.

iv) The site should include vehicle and traffic situation typical of the study area.

v) The site should be free from the disturbances caused by road side access of traffic.

vi) The section should be free from obstruction.

vii) The site should be reasonably flat to eliminate the effect of gradient which is out of the scope of the present research study.

viii) There should be minimum disturbances from pedestrian, parked vehicles and transit/para-transit stops to exclude the effect from these which is again out of the scope of present study.

3.6 PRELIMINARY SURVEY

The preliminary survey has been aimed at identifying sites which satisfy most of the above set criteria. The preliminary survey has also provided the following useful information for the successful implementation of final survey.

i) The appropriate time for data collection considering the return journey for data collection, time of day, sunlight condition and traffic flow conditions. It has been observed that the time period of 11.00 A.M to 3.00 P.M satisfies most of the considerations cited above.

ii) The proper position for the camera stand considering the visibility of 250-300 meter to be filmed. It has been found that with the maximum zooming facility the available video camera can record a distance of around 250m clearly.

iii) The number of surveyors required in the field to install ranging rods with placards & flags and to record travel time.

iv) For the successful implementation of data collection project training and practical trips have to be given to the surveyors.

v) The possible the problems which may occur during the final survey work.

3.7 PROBLEMS IDENTIFIED DURING PRELIMINARY SURVEY

During preliminary survey, the following problems have been identified:

i) In order to make traffic data measurement, initially, ranging rods have been installed at 50 metre intervals for a distance of 250 metre. But on T.V screen, these ranging rods cannot be clearly seen. To overcome this problem, placards and flags have been fixed at the upper end of the ranging rod.

ii) Installation of ranging rod has also been a problem. Because, in most cases road side soil was not providing enough grip to hold the ranging rod standstill. In order to overcome this problem ranging rod stands have been used to strengthen the installation of ranging rods.

iii) Another problem identified during preliminary survey is the availability of a suitable high place from where video recording can be made. In order to be able to see around 300 m on T.V screen, video recording has to be done from a high place. No one or two storied building beside the highway has been found at potential sites. Therefore it has been decided to mount the camera stand on a high wooden table which itself has again been mounted on the pick-up van parked beside the road.

iv) Parking the pickup van on shoulder has also been a problem, because, the unused shoulder is not vary wide to accommodate the pickup van. While, parking the vehicle on the pavement may influence the traffic operations. These has been considered while selecting the final sites.

v) In order to hold the light camera stand at standstill from the disturbances of wind and vibration of running vehicles, a skilled person has always been kept available to maintain the proper alignment of camera.

vi) It has been observed that most of the highway sections have been well planted with trees on both sides. These plantations have created obstructions to sights and sunlight on many occasions. This has been considered while selecting the site and camera station.

vii) Light weight placards and flags have been observed to change their positions frequently by wind. Therefore, it has been decided to reinforce the placards and flags to make them as stable as possible against wind effect. Also two persons have always been available to ensure their proper orientations.

viii) Availability and direction of sunlight are important for proper video filming. These considerations have been made while selecting highway section, camera station and time of video recording.

3.8 DESCRIPTION OF THE SELECTED SITES

Five highway sections have been selected on five national highways for the purpose of data collection. The characteristics of the sections are as follows:

a) At Savar on Dhaka-Aricha highway: A fairly flat and straight section on Dhaka-Aricha highway has been selected. At Savar area which is 36 km away from central Dhaka. The pavement width at this section has been found to be 7.5 m wide and also in good condition having no potholes and major cracks. The section also has a shoulder of 2.0 m at both side.

b) At Modonpur on Dhaka-Chittagong highway: This fairly straight and flat section has been selected at Modonpur on Dhaka-Chittagong highway about twenty five km away from central Dhaka. The pavement width at this section has been found to be 7 m and in good condition. At both sides of the section, 3.1 m of shoulder has been found.

c) At National park on Dhaka-Mymensingh highway: This flat and fairly straight section has been selected in National Park area on Dhaka-Mymensingh highway. The pavement width (6 m) here has been found to be narrower than the above sites. But the pavement has been found to be in similarly good condition as above sections. At both sides of the section 1.4 m of shoulder has been observed.

d) At Bultha on Dhaka-Sylhet highway : This section has been selected at Bultha on Dhaka-Sylhet highway which is 33 km away from central Dhaka. This is a flat and fairly straight section having 6.8 m of pavement width and 1.6 m of shoulder at both sides. Although pavement surface appears to be little older than the above sections, but there is no potholes or large cracks on the pavement.

e) At Keranigong on Dhaka-Khulna highway: This section has been selected in Keranigong area which is about 14 km away from central Dhaka. The pavement width has been found to be 5.8 m here which is the narrowest among the five sections. However, at both sides of the road 1.6 m wide shoulder has been observed.

All the relevant information of the selected highway sections along with the date of data collection has been presented Table 3.1.

Name of highways	Date	Location	Pavement width	Shoulder width
Dhaka-Mymensingh	11-11-97	National park	6m	1.4m
Dhaka-Khulna	9-11-97	Karanigong	5.8m	1.6m
Dhaka-Sylhet	13-11-97	Boltha	6.8m	1.6m
Dhaka-Chittagong	18-11-97	Modonpur	7m	3.1m
Dhaka-Aricha	19-11-97	Savar cantonment	7.5m	2.0m

Table 3.1 Description of data collection sites

3.9 PREPARATION FOR DATA COLLECTION

For successful data collection in the field necessary arrangements have been undertaken with due considerations to the problems identified during the preliminary survey. A check list of required things has been prepared to check necessary items each day before starting for the field for data collection.

In order to get the distance mark on the recorded videofilm, placards containing numeric number 1 to 10 have been prepared from hard paper board. Numbers on placards have been written with bright marker paint. Ropes have been collected for hanging the 30inch by 24inch placards from the ranging rod. To make the placards more identifiable, colourful flags have also been decided to be used along with the placards. To make the flags stable enough, metal wires have been passed through them.

Twenty ranging rods, twelve folding chairs, tripod stand with clamp, two odometers, measuring tapes, two stop watches and eight safety vest are borrowed from the survey store and traffic engineering laboratory of BUET. Spray paint and anamel paint along with brush have been collected to mark the pavements whenever necessary. A pickup van has been hired for transport purpose of the whole survey team along with the instruments and necessary applinaces.

3.10 DATA COLLECTION PROCEDURE

Before starting for data collection, all the instruments and items necessary for data collection have been loaded on pick up van one by one according to the checklist. Special attention has been given to the video camera checking whether the battery is fully charged and whether the video cassettes are blank. Then journey to data collection is started.

At first, the pick up van has been parked on the roadside at a point suitable for cammera station at the selected site. Then the camera along with its tripod stand has been mounted on the wooden table which is again mounted on the pick up van(see Fig. 3.1). In the next step, camera axis and sight have been adjusted for video recording. After that ranging rods have been installed along with the placards and flags at 50m intervals. At the starting point which is near to the camera the placard bearing the serial zero(0) has been hung from the ranging rod. Then placards serial no. 1,2,3 etc. have been hung from the ranging rod at the successive 50m interval(see Fig. 3.2).

After checking all the necessary functions of video camera, video recording has been started at this point. As the 8m.m video cassette can record only for 90 minutes, new blank cassette has been inserted when 90 minutes recording has been completed. Also battery charged indicator has been checked at a regular interval. With the diminishing battery charge sign on the old battery has been replaced by charged battery. About three hours of video filming has been made at each site. However, including the preliminary survey, a total of 25 hours of video recording has been made.

There is little deviation in the filming process at the field from the standard as cited earlier. That is, there is an angle of camera axis created with the alignment of highway. This is because, camera station has to be taken on the side of the road so that there is no interruption to traffic movement due to the parked vehicle. However, considerations have been given to this aspect during data collection. It could be avoided by using telescopic tower installing video camera at vintage point.

3.11 DATA EXTRACTION

As mentioned earlier, the video recording has been made on 8mm video cassette. Recorded film has then been transferred to standard VHS cassettes. After the transferred, a time base showing 1/10th of second has been superimposed on the video film. Because the timer of the video camera is in second which is not adequate for accurate calculation of speed and headway data.

Data extraction from the video cassette is a difficult and time consuming task. Data items have been collected watching the video playback at the laboratory. Speed, density, flow, headway data have been the main points of interest for this research project. Data items such as free speed, time headway, flow volume, density and vehicle compositions have been estimated for the five selected highways.

3.11.1 Traffic Headway

Time headway is the time between the arrival of successive vehicle at a specified point. It is the reciprocal of volume. Time headway data used for this study has been collected from the video playback. The superimpose timebase on video film has been very useful in this regard.

3.11.2 Free Speed

In this study, driver's are considered to be free or unimpeded when the front vehicle is 80m away from him/her. At studio, free speed has been measured from video playback. Free speed is calculated using the travel time required by a vehicle to pass through the 50m section. The superimpose timebase(accurate up to $1/10^{th}$ of second) has been utilised for this purpose.

3.11.3 Traffic Volume and Average Speed

Traffic volume is defined as the number of vehicles that pass a point along a highways per unit of time. Average speed mentioned here is the average of time mean speed of vehicles over a 50m section of highway.

Both speed and volume data have been collected from video playback. As the total videofilming for a site is about three hours, traffic volume per fifteen minutes intervals have been estimated during this study. However, these speed and volume data has been used only to illustrate the speed-flow condition during the data collection period

3.11.4 Traffic Density and Average Speed

Traffic density also refereed to as traffic concentration, is defined as the average no. of vehicles occupying a unit length of road way at a given instant. In this study traffic density has been measured as vehicles per quarter km as approximately quarter of a km can be clearly seen on the video playback. This density and speed data have been collected from video playback. However, these density and speed data have been used only to illustrate the speed-density condition at site during data collection.

The average speed mentioned here is the average of space mean speed of vehicles (distance travelled divided by average travel time of vehicle) taken over a 50m section of highway.

The collected data items have been presented in appendix A.

Fig. 3.1 Arrangement of setting the camera on pickup van

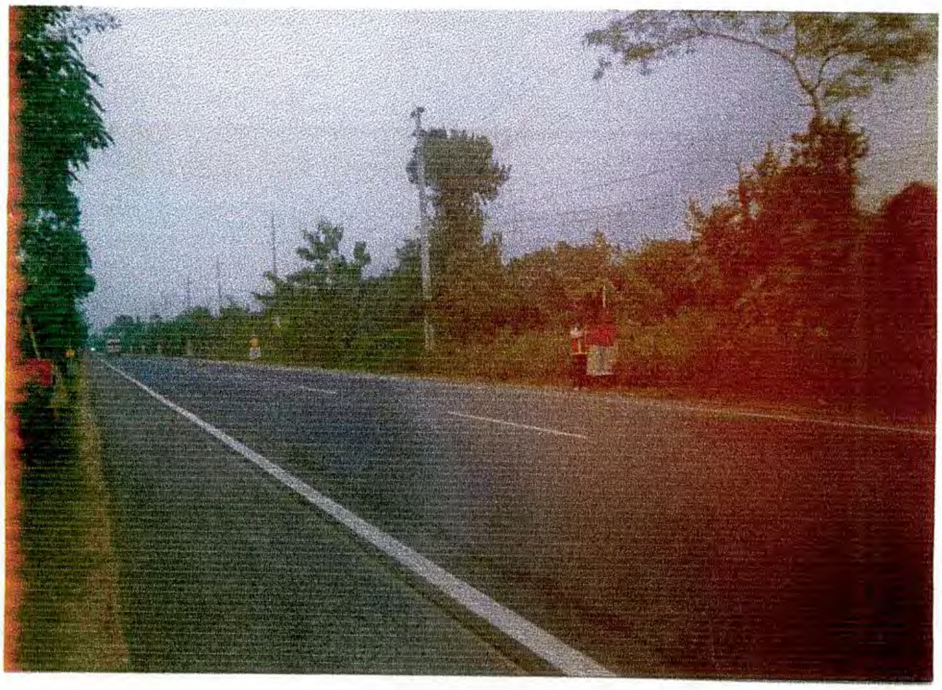


Fig. 3.2 Roadside arrangements during video filming

CHAPTER 4

DATA ANALYSIS AND INTERPRETATION OF RESULTS

4.1 GENERAL

In this chapter, both qualitative and quantitative analysis and interpretation of collected highway traffic data have been made. In the quantitative analysis, a general observation and analysis of highway traffic stream have been made. While quantitative observation includes the analysis of traffic arrival pattern data and free speed data along with the presentation of relevant speed-flow, speed-density situation. Data have been collected from five selected road sections of five major highways of Bangladesh. In order to achieve the objectives of this study, data have been collected from different highway sections. Field survey has been conducted for a period of three weeks during the month of November 97. Efforts have been given to determine relevant statistics of vehicle arrival pattern, free speed data and to analyse relationship between speed-flow and speed-density during the period of data collection. It has been tried to estimate most of the parameters microscopically i.e. at every vehicle level, rather than macroscopically i.e. at average level of traffic stream characteristics.

4.2 STATISTICAL ANALYSIS

Detailed statistical analysis of the data has been undertaken in order to estimate typical values of the measured traffic parameters, and to investigate their variability by searching for mathematical distributions. The statistical packages such as STATGRAPH version 7.0 and SPSS 6.1 for WINDOWS have been used for general statistical analysis and relevant graphical output respectively. The most common methods for testing goodness of fit are the Chi-square test and Kolmogrov-smirnov test(Bullen and Mei 1993). The chi-square test of goodness-of-fit has been used throughout this study to test the goodness of fit of distribution function to the observed data. However, the Chi-square test is sensitive to the grouping arrangements of the data. Therefore, the Kolmogorov-Smirnov test has also been used as a tool for checking the goodness-of-fit, especially, when Chi-square test appears to be not suitable for the respective data set.

The Chi-square test gives an overall measure of the difference between observed and predicted frequencies. It provides a comparison of estimated Chi-square values with the tabulated values for the Chi-square distribution, and thus, enabled the estimation of the degree of acceptance of a hypothesis. The Kolmogorov-Smirnov (K-S) test measures how much the estimated empirical cumulative distribution function differs from that of the assumed distribution. The K-S statistics compares the empirical distribution model derived from observed data with the theoretical one using the maximum absolute differences between the two. Tolle(1969)(Bullen and Mei 1993) did his analysis with the Kolmogrov-smirnov test because he found that the Chi-square test is not a very forgiving analysis and may be thrown off by only a few "bad" points. In reality, obtainment of actual "good" chi-square fits from data which are influenced by so many unpredictable variables is not fully expected.

An overall 5% level of significance has been taken as the basis of accepting the statistical significance. However, in order to be able to make relatively wider basis of acceptance 1% level of significance has also been checked if the situation demands so. The analysis tables and graphical outputs regarding the estimation of the parameters have been presented in this chapter.

4.3 QUALITATIVE ANALYSIS

It has been observed that the traffic stream on the five selected highways comprises of both motorised and nonmotorised vehicles. Although the proportion of nonmotorised vehicles appears to be much lower than that of motorised portion. Also the pedestrian activities has been found to be very low on the selected highway sections.

On the highway sections with paved shoulder, nonmotorised vehicle normally ply on the paved portion of the shoulder. But if there is no paved shoulder portion nonmotorised vehicles normally share the same pavement width with the motorised vehicles. For this reason, on the highway section without paved shoulder it has been observed that motorised vehicles have to undertake overtaking manoeuvres frequently to overtake the impeding nonmotorised vehicles. It has also been observed that in the following situation drivers maintain close headways and with any opportunity of overtaking he/she avails that readily.

Generally, it has been found that nine types of vehicles i.e., bus, truck, minibus, minitruck, Autorickshaw, passenger car, pickup van, motorcycle and nonmotorised vehicles. It has also been observed that a significant portion of the motorised traffic comprises of commercial buses and trucks. Loaded trucks and short route local buses have been observed to maintain relatively lower speed. Among the five highways Dhaka-Aricha highway appears to cater highest proportion of short route local buses(mostly Dhaka-Aricha and Dhaka-Manikgonj route).

4.4 QUANTITATIVE ANALYSIS

Quantitative analysis regarding traffic composition, vehicle arrival pattern, free speed and speed-flow-density conditions at different highway sites have been presented in this section.

4.4.1 Traffic Composition

At the first stage of quantitative analysis, the average proportion of different vehicle types in the traffic mix have been investigated. The typical traffic compositions found in different highways have been presented in the Table 4.1. From the Table 4.1, it can be observed that the proportion of nonmotorised vehicles varies in the range of 5.93% to 17.75% with the lowest and highest percentage being in the Dhaka-Khulna and Dhaka-Mymensingh highway respectively. The proportion of buses has been found to be maximum on the Dhaka-Chittagong highway. While the proportion of trucks has been found to be maximum on Dhaka-Aricha highway. Another interesting observation from the Table 4.1 is that the proportion of autorickshaw alone is approximately sixty percent indicating high use of this motorised transit for local movement on this highway.

Name Of the Highways	Flow range vph	%B	%Tr	%Mb	%Mt	%Ar	%Pc	%P.v	%M.c	%Nmt
Dhaka-Aricha	520-640	20.49	20.65	13.25	2.16	5.70	17.72	3.54	6.47	10.02
Dhaka-Chittagong	512-708	25.50	12.29	7.37	1.42	20.96	19.54	1.55	1.29	10.09
Dhaka-Mymensing h	260-332	22.92	13.26	7.89	2.47	11.91	14.16	3.15	6.52	17.75
Dhaka-Sylhet	212-360	16.80	20.21	18.90	2.36	3.15	20.47	3.15	1.58	13.39
Dhaka-Khulna	212-360	6.44	5.16	11.08	1.03	59.02	5.41	0.52	5.41	5.93

Note: B=Bus, Tr=Truck, Mb=Minibus, Mt=Minitruck, Ar=Autorickshaw, Pc=Passenger-car, P.v=Pickupvan, Mc=Motor cycle, Nmt=Nonmotorised

Table 4.1 Traffic composition found in different highways

4.4.2 Analysis Of Traffic Arrival Pattern

The quantitative measurement of traffic arrival interval has been taken by estimating the successive headways between vehicles. To analyse the time headway distribution of a traffic stream, some knowledge about the drivers who make up the traffic stream is needed. Individual drivers will have their own unique desired headways and driving habits. Thus each driver will have a time headway distribution with a unique mean and standard deviation that may vary under different traffic conditions. The traffic stream is made up of individual time headway's of different drivers with these different distributions. The measured headway distribution of a traffic stream is therefore the combination of the individual time headway distributions. The characteristics of combined distribution is rather complicated considering the extreme case when the traffic volume is very high and all drivers have to drive at the car following headway. The mean of each individual time headway may still be different but they will converge toward a single value because of the close spacing. Traffic arrival pattern has been analysed by using the statistical software noted above.

All the traffic arrival pattern data have been grouped according to the source highway. A general statistical analysis of each group has been made and the mean, standard deviation are shown in table 4.4. Frequency histogram of each group of traffic arrival pattern have been plotted to get their general distribution pattern. The frequency histograms are shown in Fig. 4.1 to Fig. 4.5. It can be observed from the frequency histograms (Fig. 4.1 to Fig. 4.5) that vehicular headway distributions have resemble to negative exponential and lognormal pattern which need to be function fitting. Therefore, distribution functions of negative exponential and lognormal have been investigated with a view to fit a proper distribution function to the vehicle arrival pattern.

The statistical analysis results of distribution function fitting are given in Table 4.2 to Table 4.3. The goodness-of-fit test of negative exponential and lognormal distribution functions to the vehicular headway interval data are discussed below.

i) Negative exponential distribution : The goodness-of-fit test with exponential distribution function reveals that the traffic arrival patterns on Dhaka-Aricha, Dhaka-Mymensingh and Dhaka-Khulna highways follow this distribution function (Table 4.2) according to both Chi-square and K-S test at 5% level of significance. However, at 1% level of significance the headway data of Dhaka-Sylhet and Dhaka-Chittagong show good fit to the exponential distribution pattern from both the tests.

ii) Log-normal distribution : The Chi-square goodness-of-fit test with lognormal distribution function reveals that the traffic arrival pattern on none of the five highways follow this distribution at 5% level of significance. However, the K-S goodness-of-fit test supports that the traffic arrival pattern on all but Dhaka-Mymensingh highway follow lognormal distribution at 5% level of significance(Table 4.3).

The distribution of traffic arrival pattern along with their parameters are presented in Table 4.4 for the five highways.

Data set		Dhaka - Aricha	Dhaka - Chittagong	Dhaka - Mymensingh	Dhaka - Sylhet	Dhaka - Khulna
Chi-square test	Chi-square value	12.689	20.141	5.529	18.83	9.54
	Critical Chi-square value at 5% LOS (10 d.o.f)	18.31	18.31	18.31	18.31	18.31
Test result		accepted	not accepted*	accepted	not accepted*	accepted
Kolmogorov-Smirnov test	K-S value	0.063	0.083	0.077	0.112	0.035
	Critical K-S value at 5% LOS	0.073	0.073	0.092	0.098	0.104
Test result		accepted	not accepted*	accepted	not accepted*	accepted

Note: LOS = Level of significance, d.o.f = degree of freedom, * = accepted at 1% LOS

Table 4.2 Results of goodness-of-fit test of Exponential distribution to vehicle arrival pattern of highways.

Data set		Dhaka - Aricha	Dhaka - Chittagong	Dhaka - Mymensingh	Dhaka - Sylhet	Dhaka - Khulna
Chi-square test	Chi-square value	25.427	17.326	22.993	26.217	19.777
	Critical Chi-square value at 5% LOS (9 d.o.f)	16.92	16.92	16.92	16.92	16.92
Test result		not accepted	not accepted	not accepted	not accepted	not accepted
Kolmogorov -Smirnov test	K-S value	0.061	0.055	0.1	0.09	0.077
	Critical K-S value at 5% LOS	0.073	0.073	0.092	0.098	0.104
Test result		accepted	accepted	not accepted	accepted	accepted

Note: LOS = Level of significance, d.o.f = degree of freedom,

Table 4.3 Results of goodness-of-fit test of Lognormal distribution to vehicle arrival pattern of highways

Name of the Highway	Distribution Type	Minimum (sec)	Mean (sec)	Standard deviation (sec)	Maximum (sec)
Dhaka-Aricha	Exponential**	0.3	11.879	(12.18)	73.4
	Lognormal*	0.3	1.937	1.106	73.4
Dhaka-Chittagong	Lognormal*	0.1	1.873	1.225	76.6
Dhaka-Mymensingh	Exponential**	0.1	23.478	(24.46)	132.9
Dhaka-Sylhet	Lognormal*	0.7	2.462	1.281	107.8
Dhaka-Khulna	Exponential**	0.6	29.621	(28.93)	194.5
	Lognormal*	0.6	2.858	1.167	194.5

Note: *= supported by K-S test and **= supported by both K-S and Chi-square test

Table 4.4 Results of the analysis of traffic arrival pattern with distribution and their parameters

4.4.3 Free Speed Distribution Pattern

Free speed considered in this study is basically drivers desired speed when driver is not influenced by the front vehicle. For this study, a vehicle is considered as free when the vehicle ahead of it is more than 80m away. In order to determine the free speed distribution pattern, the free speed data of five commonly available vehicles are collected on one of the selected highway section (Dhaka-Aricha highway). The commonly available vehicles types are bus, minibus, truck, passenger-car and non-motorised vehicles. The frequency histogram of the free speed data of the vehicles are presented in Fig.4.6 to Fig. 4.10. From these figures, it can be observed that the frequency histograms of vehicles free speed data show the trend of normal distribution pattern.

The goodness-of-fit tests with normal distribution function have been conducted to test the fit to the free speed data of different vehicles. The relevant Chi-square and K-S statistics(both test values and critical values at 5% level of significance) are presented in Table 4.5. From the Table 4.5 it can be observed that the free speed data of all the five vehicles follow the normal distribution pattern. And the same is supported by both Chi-square and K-S test. All the relevant parameters of normal distribution function for different vehicles are presented Table 4.6.

Similar free speed analysis can also be made on other four highway sections. But due to time limitations of the present research study the same has not been performed.

Data set		Bus	Passenger-car	Truck	Minibus	Non-motorised
Chi-square test	Chi-square value	4.853	3.791	1.901	2.30	3.579
	Critical Chi-square value at 5% LOS	7.81 (3 d.o.f)	9.49 (4 d.o.f)	5.99 (2 d.o.f)	5.99 (2 d.o.f)	5.99 (2 d.o.f)
Test results		accepted	accepted	accepted	accepted	accepted
Kolmogorov -Smirnov test	K-S value	0.121	0.11	0.118	0.127	0.12
	Critical K-S value at 5% LOS	0.217	0.198	0.22	0.22	0.22
Test results		accepted	accepted	accepted	accepted	accepted

Note: LOS = Level of significance, d.o.f = degree of freedom

Table 4.5 Results of goodness-of-fit test of normal distribution to free speed of vehicles on Dhaka-Aricha highway

Data set	Bus	Minibus	Truck	Passenger-car	Non-motorised
No. of observations	39	38	38	47	38
Mean (kmph)	70.3	62	56.4	72.3	13.1
Standard deviation (kmph)	9.9	7.1	8.58	12.45	1.29
Minimum (kmph)	52.94	52.53	41.26	54.06	9.7
Maximum (kmph)	92.02	81.82	80.88	104.33	15.45

Table 4.6 Parameters of normal distribution functions for free speed data of Dhaka-Aricha highway

4.4.4 Relationship Of Free Speed With Pavement And Shoulder Width

Generally, drivers using the national highway are experienced and regular based. Because, the undisciplined driving condition on the same does not welcome the occasional and new drivers. Based on this ideas, drivers age and experienced factors have been taken as uniform for developing free speed model. Again, free speed data has been collected on flat and straight road section with almost similarly good surface condition. Therefore, horizontal curvature, pavement surface condition and longitudinal gradient factors have been assumed to be uniform for the data side. However pavement width and shoulder width (including both paved and unpaved shoulder) have been found to be different at different sites.

A linear free speed model of the following form has been regressed with the free speed data of different highway sites.

$$v = a_1 w_1 + a_2 w_2 \qquad \cdots\cdots\cdots\cdots(4.1)$$

Where,

v =Free Speed (km/hr)

a_1 = Coefficient

w_1 = Pavement width (metre)

a_2 = Coefficient

w_2 = Shoulder width (metre)

Regression analysis has been made using the Statgraphics software for four commonly found motorised vehicles. Values of coefficient a_1, a_2 and coefficient of determination(R^2) for four vehicle types are presented in Table 4.7 The high coefficient of determination(R^2) values in the Table 4.7 suggest high correlation of free speed with the values of pavement and shoulder width. While the positive values of a_1 and a_2 denotes the increase of free speed for per metre increase of pavement and shoulder width respectively. It can be observed that the values of coefficient a_1 varies in the range of 7.25 to 10.29 with no abrupt change in the values. But one of the values (for bus) of coefficient a_2 has been resulted as -1.24 suggesting a negative correlation is due to the presence of quite a few local buses with low desired speed on Dhaka-Aricha highway. Obviously the free speed of this local buses are dictated by their vehicle condition. However, values of a_2 for other three vehicle varies in the range of 0.76 to 5.65. From the Table 4.7, it can be observed that the free speed of bus and car are mostly benefited from the increase of pavement width. While the free speed of minibus and car are mostly benefited from the increase of shoulder width.

Data set	Bus	Minibus	Truck	Car
Co-efficient "a_1"	10.29014	7.257506	7.92808	9.355068
Standard error for "a_1"	1.132343	0.757692	1.126762	0.970261
Co-efficient "a_2"	-1.236583	5.645872	0.763086	4.444578
Standard error for "a_2"	3.996653	2.448641	4.06094	3.176301
Coefficient of determination (R^2)	0.968	0.9772	0.9665	0.9678

Table 4.7 Coefficients of linear regression analysis

4.4.5 Speed-Flow Condition At Sites

While investigating the traffic arrival pattern, it is useful to study the speed-flow condition for the same time period. Vehicular traffic flow in 15 minutes intervals and average vehicle speeds(time mean speed weighted for motorised and nonmotorised group) have been estimated for different highway sites. Considering the similarity in geometry the five highways have been grouped in three categories. In Fig. C.1 in appendix C the speed-flow condition of category one comprising Dhaka-Aricha and Dhaka-Chittagong has been presented. The speed-flow condition of category two comprising Dhaka-Sylhet and Dhaka-Mymensing highway has been presented in Fig. C.2 in appendix C. While as third category, the speed-flow condition of Dhaka-Khulna has been presented in Fig. C.3 in appendix C.

4.4.6 Speed-Density Condition At Sites

Speed data considered for this portion of study is the space mean speed(weighted) averaged over a relatively short section of roadway(50m in this case). The space mean speed in this case has been estimated by dividing the section length with the average time taken by different vehicles for passing the section. The section length of 50 metre has been taken considering the visibility condition on video playback. And, density data has been prepared on the basis of vehicle density over a 250m stretch of highway.

From the consideration described in the above sections the speed-density condition of five highways have been presented in three groups. For the first group comprising Dhaka-Aricha And Dhaka-Chittagong highway has been presented in Fig. C.4 in appendix C. For second group comprising Dhaka-Sylhet and Dhaka-Mymensingh highway has been presented in Fig. C.5 in appendix C. For the third group comprising only Dhaka-Khulna highway has been presented in Fig. C.6 in appendix C.

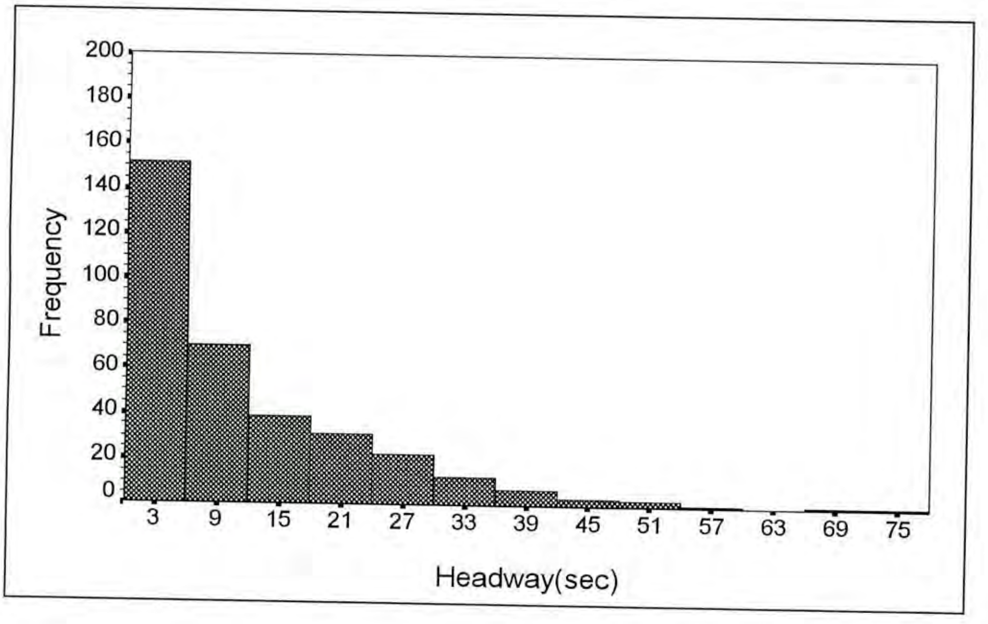


Fig. 4.1 Frequency histogram of headway data of Dhaka-Aricha highway

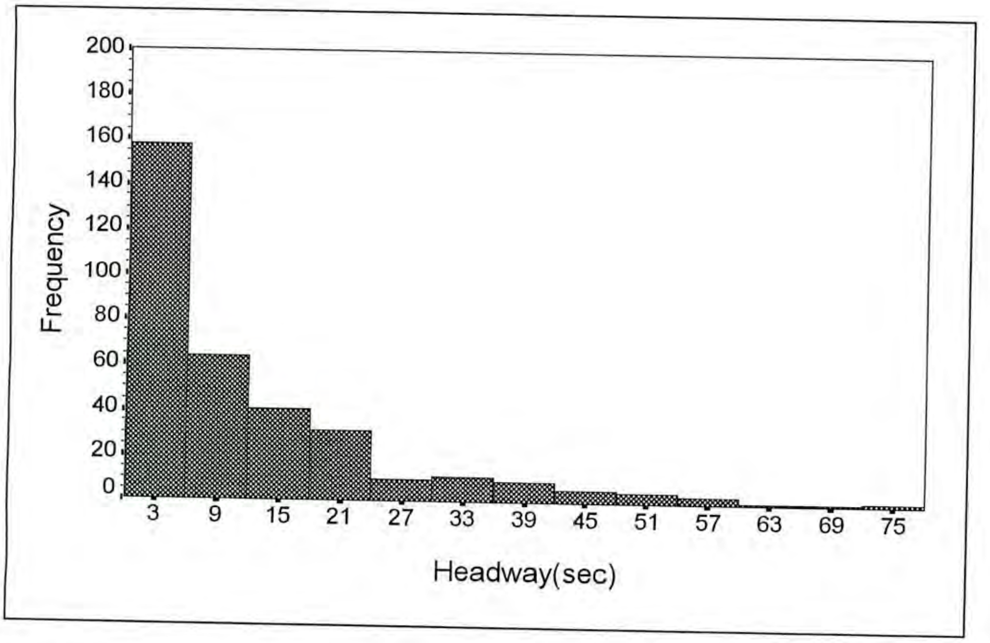


Fig. 4.2 Frequency histogram of headway data of Dhaka-Chittagong highway

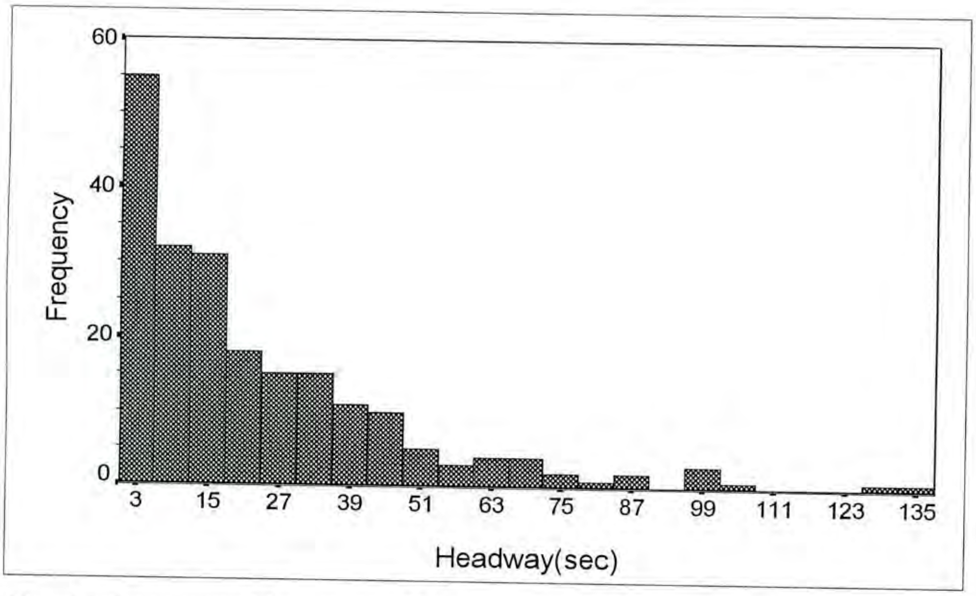


Fig. 4.3 Frequency histogram of headway data of Dhaka-Mymensingh highway

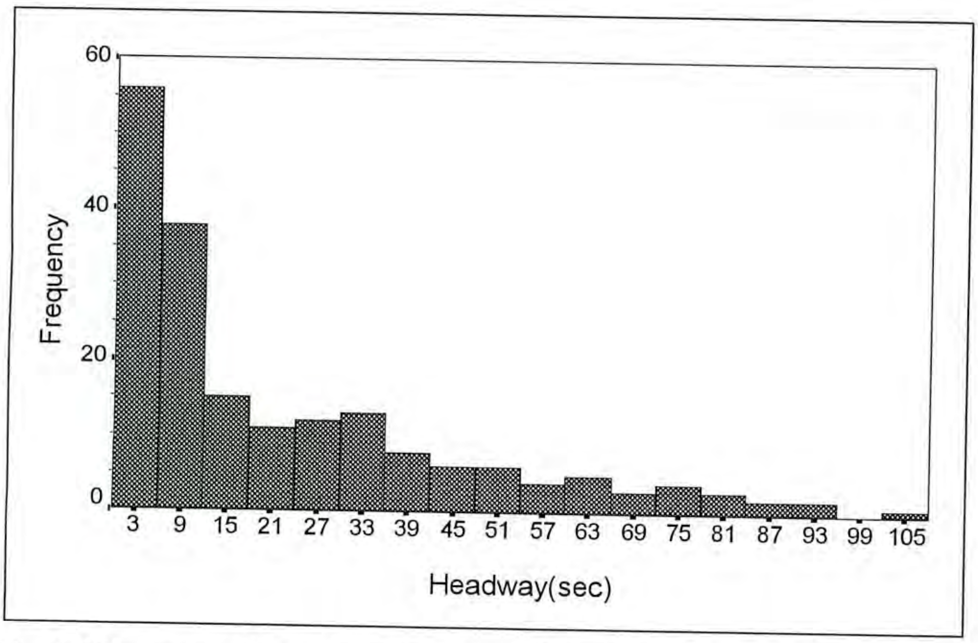


Fig. 4.4 Frequency histogram of headway data of Dhaka-Sylhet highway

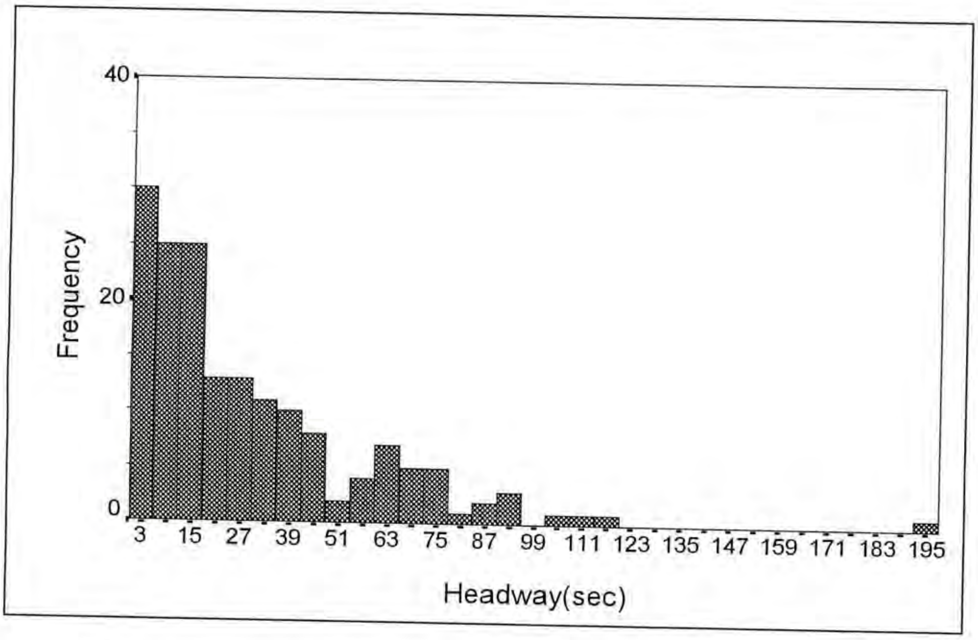


Fig. 4.5 Frequency histogram of headway data of Dhaka- Khulna highway

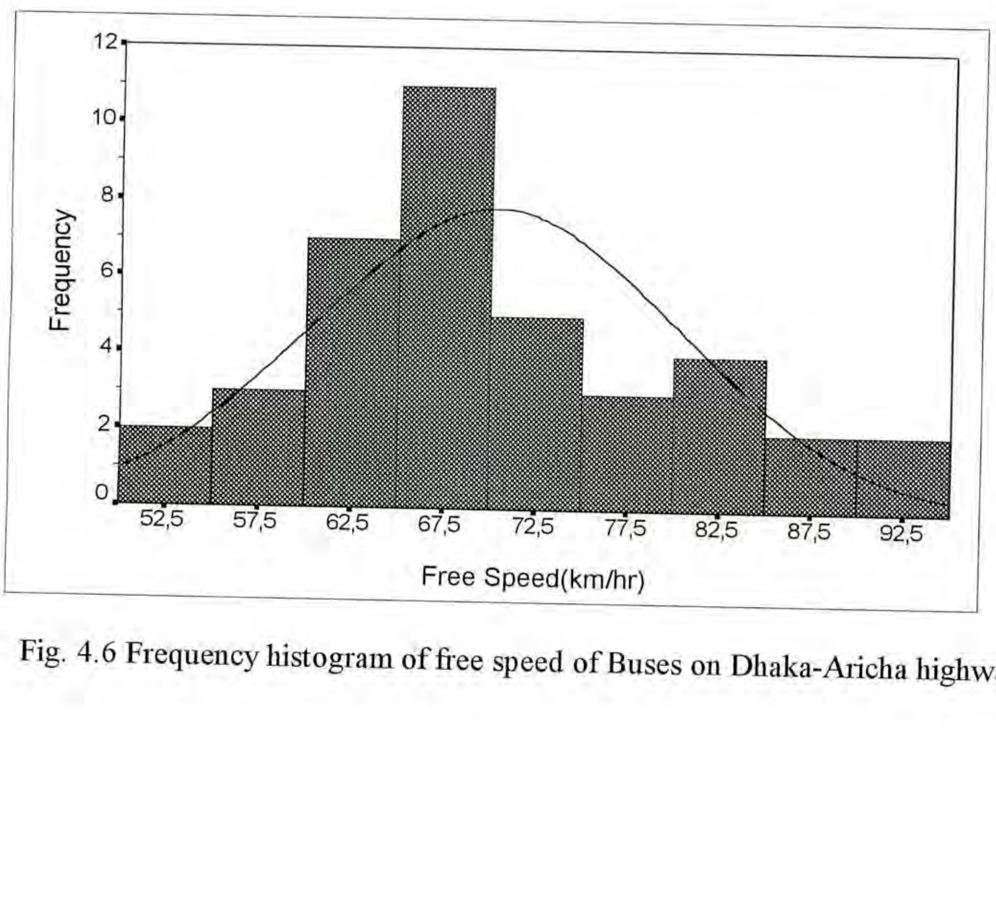


Fig. 4.6 Frequency histogram of free speed of Buses on Dhaka-Aricha highway

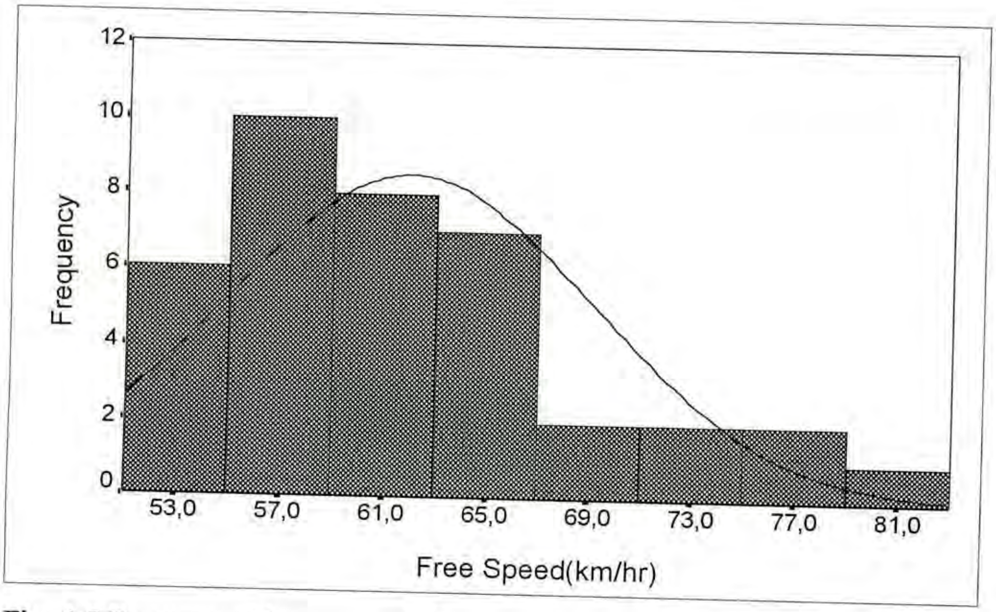


Fig. 4.7 Frequency histogram of free speed of Minibuses on Dhaka-Aricha highway

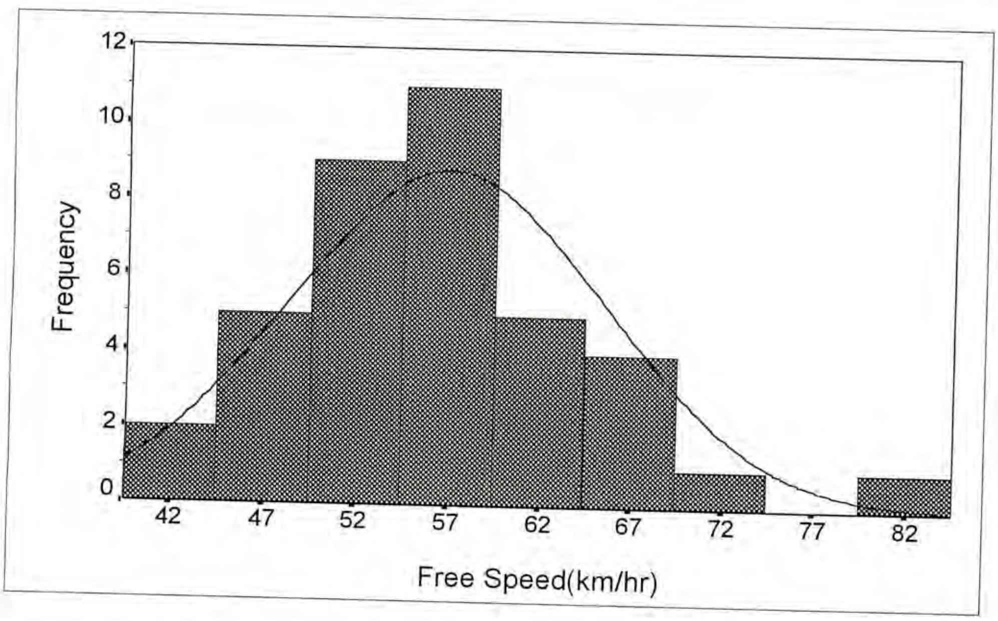


Fig. 4.8 Frequency histogram of free speed of Trucks on Dhaka-Aricha highway

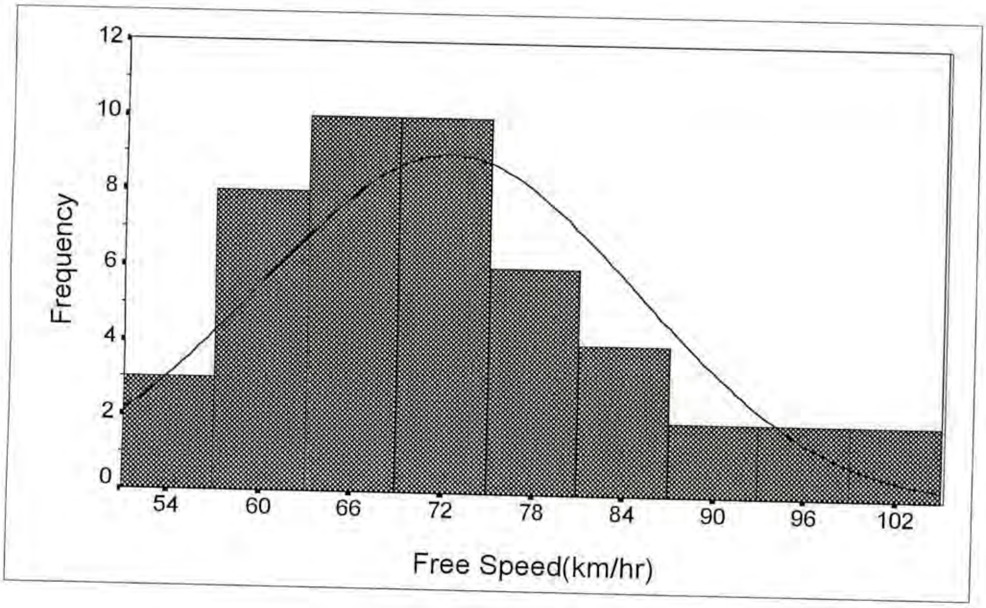


Fig. 4.9 Frequency histogram of free speed of Passenger-cars on Dhaka-Aricha highway

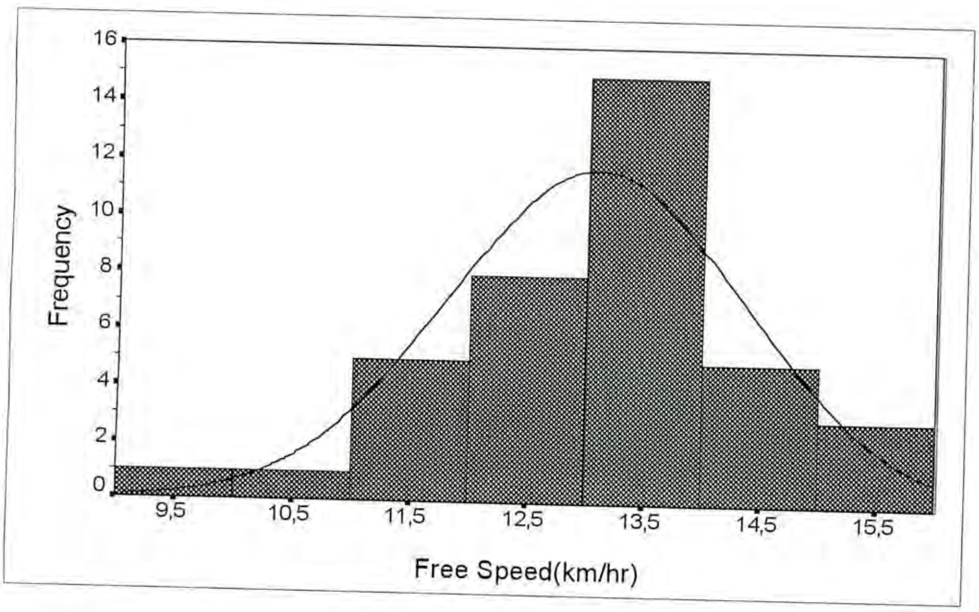


Fig. 4.10 Frequency histogram of free speed of Nonmotorised vehicles on Dhaka-Aricha highway

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter presents the conclusions and recommendations of the research study for estimation of parameters related to traffic flow on the selected national highways of Bangladesh. In particular, conclusions on different traffic arrival headway patterns and free speed characteristics of vehicles have been summarised. Recommendations and guide lines for relevant future study have also been presented.

5.2 CONCLUSIONS

5.2.1 Traffic Arrival pattern

Analysis of traffic arrival pattern using the vehicular time headway data reveals that the pattern follows more than one distribution models for two highways. Generally, it has been found that the vehicles maintain close headways when they are in following situation. For Dhaka-Aricha highway, the goodness-of-fit test suggests that the arrival headway pattern follows exponential distribution supported by both Chi-square and K-S tests. However, K-S test suggests that the same headway data also fits to the lognormal distribution. For the headway data of Dhaka-Chittagong highway, the lognormal distribution gives good fit as suggested by K-S test only. Analysis of the headway data of Dhaka-Mymensingh highway reveals that the traffic arrival pattern can be expressed by exponential distribution as suggested by both Chi-square and K-S test. From Chi-square test, no good fit has been found for the headway data of Dhaka-Sylhet highway. But K-S test suggests that the traffic arrival pattern on this highway can be given by lognormal distribution. It has also been observed that exponential distribution gives good fit to the headway data of Dhaka-Khulna highway as suggested by both Chi-square and K-S test. However, only K-S test suggests that the same data group also follows lognormal pattern.

5.2.2 Free Speed Characteristics

Analysis of free speed data of vehicles on a typical section of Dhaka-Aricha highway reveals that free speed of the commonly available vehicles (bus, truck, car, minibus and nonomotorised vehicles) follow normal distribution models. While the mean free speed of motorised vehicles ranges from 56.4 kmph for truck drivers to 72.3 kmph for passenger car drivers, the same for non-motorised vehicles is 13.1 kmph. It is also observed that drivers' free speed depends on the pavement width and shoulder width of the two-lane two-way highways. From regression analysis, a linear relationship of free speed with pavement and shoulder width has been developed. The analysis reveals that drivers' free speed increases with the increase in pavement width. In a pavement width range of 5.8 metre to 7.5 metre, free speed of motorised vehicles' drivers increases in a range of 7.25 to 10.29 kmph for each metre of pavement widening. Similar relationship of free speed with the shoulder width has also been found except for the case of bus. For the cases of trucks, minibuses and passenger-cars, it has been observed that in a shoulder width range of 1.4m to 3.1m, free speed increases in a range of 0.76 to 5.65 kmph for each metre of shoulder widening at both sides. However, inclusion of some slow speed local buses in the data group has been resulted negative correlation of bus's free speed with the shoulder width.

5.2.3 Speed-Flow And Speed-Density Condition

For the limited period of traffic data collection, the speed-flow and the speed-density condition have been investigated. However, considering the limited period and traffic flow range, it is not worthy to go for investigating the overall speed-flow-density relationship.

5.2.4 Limitations Of The Study

Present study is limited to the flat, horizontal and disturbance free sections on five selected national highways. As we did not have any purpose built high platform and also there was no roadside suitable building to be used as platform, the camera axis could not be fixed vertically. It is anticipated that this will result some amount of parallax error during data measurement. We have collected data from video recording with $1/10^{th}$ of superimpose clock which was not high precision in counting travel time required by a vehicle to pass through the 50m section. National highways comprises only eleven percent of total highway network. More than two third (71%) of the national highways even have pavement width below the prescribed specification limits viz. 5.5 m (Bangladesh Transport Sector Study, 1994). But the pavement width of the five highway sections in this study are in the range of 5.8m to 7.5m.

5.3 RECOMMENDATION FOR FUTURE STUDY

Based on the experience gathered from the present study the following recommendations for future study in this field can be suggested:

i)The same study can be performed with 1/100 seconds time base on the recorded video film.

ii) The large amount of speed-flow data is needed to get a good correlation between speed and flow.

iii) The large amount of speed-density data is needed to get a good correlation between speed and density.

iv) Video data collection from a further high station is suggested to minimise the relevant parallax error.

v) The same study can be performed on the national highways with pavement width narrower than 5.5m.

REFERENCES

ADAMS, W.F. , Road Traffic considered as random time series, Journal of Inst. of Civil Engrs., Vol. 4, 1936-37, pp.121-130.

ASHTON, W. D. (1966), The theory of road traffic flow. Methuen & Co. Ltd., London.

BANGLDESH TRANSPORT SECTOR STUDY, Final Main Report, Planning Commission, Dhaka, Bangladesh, 1994

BRANSTON, D. (1976) Models of single lane time headway distribution. *Transportation Science*, Vol. 10, No. 2, pp. 125-148.

BULLEN, A.G.R. AND MEI, M. (1993) Lognormal distribution for high traffic flows, *Transportation Research Record,* vol. 1398. pp 125-128.

GREENBERG, I. (1966), The lognormal distribution of headway times, Proc. Australian Road Research Board, Vol. 2, No. 7, pp. 14-20.

GREENSHIELD(1975), Transportation Research Board Special Report 165

GRIFFITHS, J. D. and HUNT, J. G. (1991) Vehicle headways in urban areas. *Traffic Engineering & Control, Oct'91*, pp 458-462.

HOSSAIN M (1996) "Modelling traffic operations in urban networks in developing countries" Ph.D thesis, Dept of Civil and Environmental Engineering, University of Southempton, UK.

MANNERING F.L AND KILARESKI (1993), "Principles of highway engineering and traffic analysis" John willey & Sons Inc.

MILLER, A. J. (1961) A queuing model for road traffic flow, *J. Royal Stats. Soc.* Vol. 23, Series B, No. 1, pp. 64-75.

PIPES, L.A. (1967) Car-following models and the fundamental diagram of road traffic. *Transportation Research*, Vol. 1, pp.21-29.

SCHULL A., (1955) The probability theory applied to distribution of vehicles on two-lane highways. *In Poisson and traffic*, pp. 59-75, (Eno Foundation)

TANNER, J. C. (1961) Delays on a two lane road. *J. Royal Stats. Soc.* Vol. 23, Series B, No. 1, pp. 38-63.

TAYLOR, M.A.P and YOUNG, W. (1984) The Distribution of speeds and gaps in traffic systems. *In-Traffic Flow Theory*, Dept. of Civil Engr., Monash University, pp. 55-70.

TOLLE, J. E. (1971), The lognormal headway distribution model, *Traffic Engineering and Control,* Vol. 13, No. 1, pp 22-24.

TOLLE, J. E. (1976), Vehicular headways distribution: testing and results. Transportation Research Board, TRR 567, pp. 56-64.

WRIGHT P.H. AND PAQUETTE R. J. (1979), "HIghway Engineering", 5th edition, John wiley and sons.

XISHI SHI(1995), "Highway Approval in developing countries- A method for determining the cost effectiveness of Highway schemes" Ph.D thesis, Dept of Civil and Environmental Engineering, University of Southempton, UK.

APPENDIX A
DATA TABLES

A.1 HEADWAY DATA

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
0.3	0.1	0.1	0.7	0.6
0.6	0.2	0.6	0.9	1
0.7	0.2	0.7	0.9	1
0.7	0.4	0.7	1	1.1
0.7	0.5	0.9	1.1	1.3
0.8	0.5	0.9	1.1	1.3
0.8	0.6	0.9	1.2	1.5
0.9	0.6	1	1.4	1.8
0.9	0.7	1	1.4	1.8
0.9	0.8	1.1	1.4	1.8
0.9	0.8	1.1	1.4	1.8
0.9	0.8	1.1	1.6	2.1
0.9	0.8	1.1	1.7	2.2
1	0.9	1.2	1.7	2.2
1	0.9	1.2	1.7	3.3
1	0.9	1.3	1.7	3.3
1.1	0.9	1.4	1.8	3.3
1.1	0.9	1.4	1.9	3.4
1.1	1	1.6	1.9	3.5
1.2	1	1.6	2	3.6
1.2	1	1.7	2	3.7
1.2	1.1	1.8	2.2	3.8
1.2	1.1	1.9	2.2	3.9
1.3	1.1	1.9	2.3	4
1.3	1.1	1.9	2.3	4.1
1.4	1.1	2	2.3	4.2
1.4	1.2	2	2.3	4.3
1.4	1.2	2	2.4	4.6
1.4	1.2	2.2	2.4	4.9
1.4	1.2	2.2	2.5	5.2
1.4	1.2	2.2	2.5	7
1.4	1.2	2.3	2.6	7.2
1.4	1.3	2.4	2.7	7.6
1.4	1.3	2.4	2.9	7.7
1.6	1.3	2.4	2.9	7.8
1.6	1.4	2.4	2.9	7.8
1.6	1.4	2.6	3	7.8
1.6	1.4	2.8	3	8.3
1.6	1.4	2.9	3.1	8.7
1.6	1.4	2.9	3.1	9.1

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
1.7	1.4	3	3.1	9.2
1.7	1.4	3.1	3.1	9.3
1.8	1.5	3.1	3.2	9.8
1.8	1.5	3.3	3.3	9.9
1.8	1.5	3.7	3.4	10.1
1.8	1.5	3.8	3.5	10.3
1.9	1.5	3.9	3.7	10.8
1.9	1.6	4.2	3.8	10.8
1.9	1.6	4.4	3.9	11.1
1.9	1.6	4.6	4	11.1
1.9	1.6	4.9	4.2	11.3
1.9	1.6	5	4.3	11.3
2	1.6	5.2	4.5	11.4
2	1.7	5.5	4.5	11.5
2	1.7	5.9	4.5	11.6
2	1.7	6	5.4	13
2	1.8	6.1	6.1	13.1
2.1	1.8	6.1	6.1	13.6
2.1	1.8	6.5	6.2	13.7
2.1	1.8	6.8	6.4	13.8
2.1	1.8	6.8	6.8	13.8
2.1	1.8	6.8	7	14
2.2	1.8	6.9	7.1	14.2
2.2	1.9	7.1	7.2	14.4
2.3	1.9	7.2	7.2	14.4
2.4	1.9	7.2	7.4	14.6
2.4	1.9	7.4	7.5	14.6
2.4	1.9	7.4	7.5	14.7
2.4	2	7.6	7.6	14.9
2.4	2	7.6	7.6	15.4
2.5	2	7.8	7.8	15.6
2.5	2	7.9	7.8	15.7
2.6	2	8	8	16.2
2.6	2	8.7	8	16.4
2.7	2.1	8.7	8.1	16.5
2.7	2.1	8.8	8.3	16.7
2.8	2.1	9.2	8.6	17
2.8	2.2	9.5	8.6	17.6
2.8	2.2	9.5	8.8	17.6
2.8	2.2	9.7	8.8	17.6
2.9	2.2	9.9	9.2	18.1
2.9	2.2	10.1	9.5	18.4
2.9	2.3	10.6	9.7	18.5
2.9	2.3	10.9	10	18.8
3	2.3	10.9	10.2	20.6
3	2.3	11.1	10.6	21.3
3	2.3	11.2	10.7	21.5
3.1	2.5	12	10.8	21.6
3.1	2.5	12.1	10.8	21.8

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
3.1	2.5	12.5	10.9	22
3.1	2.6	12.5	10.9	22.7
3.1	2.6	12.7	10.9	22.8
3.2	2.6	12.7	11.4	23.1
3.2	2.7	13.2	11.5	24.2
3.2	2.8	13.2	12.2	24.3
3.3	2.8	13.4	12.6	24.3
3.3	2.8	13.5	12.8	24.7
3.3	2.9	14	13.3	25.9
3.3	3	14.6	13.3	26
3.4	3.1	15	13.7	26
3.4	3.1	15.4	15	26
3.5	3.2	15.5	15.3	26.4
3.5	3.2	15.6	15.7	26.6
3.5	3.2	15.7	15.9	28
3.6	3.3	15.8	16.2	29
3.6	3.3	16.3	16.4	29.3
3.6	3.3	16.3	16.8	30.2
3.7	3.4	16.3	17.3	30.3
3.7	3.4	16.3	17.6	31.5
3.7	3.4	16.3	18.1	31.7
3.8	3.4	16.5	20.4	33.9
3.8	3.5	16.5	20.8	34.2
3.9	3.5	16.7	20.9	34.8
3.9	3.6	17.5	21.1	34.9
4	3.7	17.6	22.4	35.2
4	3.8	17.7	22.6	35.6
4	3.8	17.7	23	35.7
4	3.9	17.8	23.2	36.5
4.1	3.9	18.2	23.7	36.8
4.1	4	18.6	23.7	37.1
4.1	4	19.1	24.2	37.5
4.3	4	19.4	24.3	38.2
4.3	4.3	19.6	24.4	39.1
4.3	4.3	19.7	24.6	39.8
4.3	4.3	19.9	25.9	40.6
4.3	4.3	20.5	26.6	40.6
4.4	4.5	20.6	27.4	41.8
4.5	4.5	20.9	28	42
4.5	4.7	21	28.2	42.2
4.6	4.9	21.2	29	43.1
4.7	4.9	21.5	29.2	43.4
4.9	4.9	21.7	29.4	43.4
4.9	4.9	22	30.9	43.5
4.9	4.9	22.3	30.9	45.6
4.9	5	22.7	31.3	45.8
5	5.1	23.2	31.8	49.3
5	5.1	24.1	32	50.4
5.1	5.1	25	32.4	54.9

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
5.1	5.1	25	33.4	54.9
5.2	5.1	25.3	33.6	56.4
5.3	5.1	25.9	34.6	58.7
5.4	5.3	26.1	34.7	60.2
5.4	5.3	26.1	34.8	63.1
5.5	5.3	26.8	35.2	63.2
5.5	5.4	26.8	35.8	63.3
5.5	5.4	26.9	36.3	63.5
5.5	5.4	27.1	37	64.1
5.6	5.6	27.4	37.5	64.8
5.6	5.6	28	38	69.2
5.7	5.6	28.5	40	69.3
5.7	5.6	28.9	40.4	70.9
5.8	5.6	30	41.5	70.9
6.1	5.7	30.5	41.5	71.9
6.1	5.8	31.1	42.4	72.7
6.1	5.8	32.4	43	74.9
6.1	5.8	32.5	44.4	75.5
6.3	5.8	32.5	44.8	75.6
6.3	5.9	32.6	46.2	76.5
6.4	6.1	32.6	47.1	82.7
6.4	6.2	33.1	50.6	84.8
6.4	6.2	33.2	50.6	87.9
6.5	6.2	33.4	50.7	90.5
6.5	6.3	34.3	50.9	93.7
6.6	6.4	34.5	50.9	94.1
6.6	6.5	34.9	51.8	103.8
6.6	6.5	35.2	57.4	113.3
6.7	6.6	36.8	57.4	117.8
6.8	6.7	37.1	57.4	194.5
6.9	6.7	39.2	59	
6.9	6.7	39.4	60	
7.1	6.9	39.9	60.2	
7.3	7.1	40	60.8	
7.4	7.2	40.1	61.2	
7.5	7.3	40.5	65.7	
7.6	7.3	40.5	66.1	
7.6	7.6	41	68.9	
7.7	7.6	41.6	71.3	
7.7	7.6	42.4	73.9	
7.7	7.6	42.9	75.8	
7.8	7.6	43.4	76	
7.8	7.8	43.7	77.3	
7.9	7.8	45	78.7	
7.9	7.9	46	80.6	
8	7.9	46.9	81.4	
8.1	7.9	47.3	84.3	
8.1	8	47.7	85.6	
8.3	8.2	47.8	90.7	

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
8.3	8.3	48.1	92.6	
8.6	8.5	48.9	107.8	
8.6	8.5	51.2		
8.7	8.5	52.3		
9.1	8.5	53.4		
9.1	8.7	55.3		
9.2	8.8	55.3		
9.2	8.8	59		
9.4	8.9	61.4		
9.4	8.9	62		
9.5	9.1	62.4		
9.6	9.1	64.9		
9.6	9.3	66.7		
10	9.3	67.4		
10.1	9.3	68		
10.2	9.3	69.3		
10.3	9.6	72.9		
10.3	9.6	73.1		
10.3	9.9	83.5		
10.3	10.1	84.4		
10.4	10.1	87.6		
10.4	10.3	96.1		
10.6	10.4	99.8		
10.7	10.5	100.8		
10.8	10.5	104.7		
10.8	10.5	126.7		
10.9	10.5	132.9		
11.2	10.7			
11.2	10.9			
11.4	11.3			
11.4	11.4			
11.6	11.5			
11.6	11.6			
11.6	11.8			
11.7	11.9			
12	12			
12.3	12			
12.4	12.1			
12.5	12.2			
12.6	12.6			
13.1	12.8			
13.2	12.9			
13.4	12.9			
13.7	13			
13.7	13.4			
13.7	13.4			
13.8	13.4			
13.8	13.5			
14	13.5			

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
14	13.6			
14.2	13.7			
14.2	13.7			
14.3	13.7			
14.3	13.8			
14.5	14.1			
14.5	14.2			
14.5	14.3			
14.6	14.7			
14.9	14.8			
15.2	14.9			
16.1	15.2			
16.2	15.4			
16.2	15.4			
16.2	15.7			
16.4	15.7			
16.4	15.8			
16.6	16.3			
16.7	16.4			
17	16.5			
17.1	16.7			
17.3	16.7			
17.3	17.1			
17.9	17.2			
17.9	17.5			
18	17.6			
18	17.8			
18.2	18			
18.4	18.1			
18.5	18.2			
18.6	18.2			
18.8	18.4			
18.8	18.9			
18.9	19			
19.7	19.6			
19.7	20.1			
20.1	20.1			
20.2	20.3			
20.7	20.6			
20.7	20.6			
20.9	20.8			
21	21.1			
21	21.8			
21.1	21.8			
21.6	22			
22.1	22.1			
22.1	22.3			
22.2	23			

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
22.3	23.2			
22.5	23.3			
22.8	23.3			
23.1	23.5			
23.1	23.5			
23.4	23.6			
23.4	23.8			
23.9	23.8			
24	23.8			
24.7	23.9			
25.4	24.1			
25.7	25			
26	25.2			
26.2	25.2			
26.3	27.1			
26.7	27.3			
27	27.6			
27.2	28.2			
27.3	29.1			
27.3	29.9			
27.4	30.3			
27.6	31.2			
27.7	32.1			
27.8	32.3			
28.2	32.9			
28.8	33.3			
29.1	33.8			
29.4	34			
29.7	34.1			
29.9	35			
30.6	35.4			
31	36			
31.5	36			
31.9	36.9			
32.3	37.4			
32.9	38.3			
33.2	38.4			
33.6	38.7			
33.9	39.2			
34.1	41.3			
34.5	42.4			
34.7	44			
35.1	45			
36.4	45.5			
36.9	46.7			
37.1	47.2			
37.4	49.8			
38.4	51.3			
38.6	52.1			

Dhaka-Aricha (sec)	Dhaka-Chittagong (sec)	Dhaka-Mymensingh (sec)	Dhaka-Sylhet (sec)	Dhaka-Khulna (sec)
39.9	52.2			
42.2	52.4			
44.3	54			
46.1	54.3			
46.3	54.7			
49	56.3			
52.6	60			
53.5	66.9			
58.2	72			
69.8	76.6			
73.4				

A.2 FREE SPEED DATA

Bus Kmph	Minibus Kmph	Truck Kmph	Passenger car Kmph	Nonmotorised Kmph
52,94	52,53	41,26	54,06	9,7
54,55	52,94	43,68	54,23	10,57
56,88	53,39	44,88	54,6	11,14
58,07	53,53	46,4	57,67	11,19
59,56	54,55	46,8	58,71	11,48
60,22	54,55	46,8	59,56	11,53
60,22	55,15	47,2	59,56	11,94
60,44	55,71	49,64	60	12,2
62,07	55,73	49,93	60,89	12,35
62,52	56,13	49,94	60,89	12,7
62,52	58,07	50,87	61,83	12,73
64,29	58,08	52,5	63,24	12,73
65,52	58,29	52,5	63,98	12,78
66,67	58,33	52,5	63,98	12,93
66,88	58,92	52,84	64,74	12,99
67,68	58,92	53,36	65,52	13,01
67,97	59,56	55,15	66,32	13,03
67,97	60	55,15	67,13	13,04
68,09	60,67	56,48	67,41	13,05
69,11	60,68	57,07	68,54	13,08
69,23	60,89	57,07	68,76	13,09
69,23	61,12	57,07	69,11	13,1
69,56	62,07	57,07	69,41	13,17
71,84	62,17	58,29	69,7	13,2
72	63,98	58,92	70,6	13,35
74,07	64,29	58,92	70,91	13,43
74,74	64,29	58,92	71,84	13,75
74,79	65,52	59,56	71,84	13,75
76,29	65,52	59,79	72,8	13,85
77,57	65,52	60,22	74,79	13,85
78,29	66,67	63,24	74,79	14,45
80,29	69,23	63,24	76,19	14,45
81,82	70,91	67,13	76,9	14,48
81,82	71,21	67,97	77,96	14,48
82,19	73,78	68,76	78	14,48
85,71	75	68,82	80,29	15,28
87,95	75,91	73,78	80,69	15,45
90	81,82	80,68	81,9	15,45
92,02			81,9	
			81,9	

Bus Kmph	Minibus Kmph	Truck Kmph	Passenger car Kmph	Nonmotorised Kmph
			84,43	
			89,02	84,43
			92,02	
			95,23	
			96,92	
			103,02	
			104,33	

A.3 FREE SPEED AND WIDTH DATA

bus kmph	pavw metre	sholdw metre	minibus kmph	pavw metre	sholdw metre	truck kmph	pavw metre	sholdw metre	p.car kmph	pavw metre	sholdw metre
92.02	7.5	2	58.92	7.5	2	67.13	7.5	2	67.1	7.5	2
87.95	7.5	2	58.08	7.5	2	80.68	7.5	2	66.3	7.5	2
82.19	7.5	2	65.52	7.5	2	57.07	7.5	2	74.8	7.5	2
74.07	7.5	2	59.56	7.5	2	49.93	7.5	2	60.9	7.5	2
69.11	7.5	2	75.91	7.5	2	55.15	7.5	2	76.2	7.5	2
58.09	7.5	2	53.53	7.5	2	58.92	7.5	2	60	7.5	2
57.68	7.5	2	73.78	7.5	2	49.64	7.5	2	96.9	7.5	2
60.22	7.5	2	55.71	7.5	2	68.76	7.5	2	54.6	7.5	2
60.44	7.5	2	65.52	7.5	2	59.56	7.5	2	59.6	7.5	2
59.56	7.5	2	81.08	7	3.1	57.07	7.5	2	64	7.5	2
74.74	7.5	2	82.57	7	3.1	73.78	7.5	2	84.4	7.5	2
74.79	7.5	2	67.42	6	1.4	43.68	7.5	2	70.9	7.5	2
74.79	7.5	2	49.72	6	1.4	47.2	7.5	2	69.1	7.5	2
60.22	7.5	2	46.63	6.8	1.6	58.44	7	3.1	76.9	7.5	2
59.56	7.5	2	67.16	6.8	1.6	56.07	7	3.1	64	7.5	2
62.52	7.5	2	84.51	6.8	1.6	61.43	7	3.1	69.7	7.5	2
67.97	7.5	2	71.15	6.8	1.6	59.41	7	3.1	71.8	7.5	2
56.88	7.5	2	46.03	5.8	1.6	49.72	6	1.4	61.8	7.5	2
62.52	7.5	2	41.47	5.8	1.6	47.75	6	1.4	60.9	7.5	2
67.97	7.5	2	58.29	7.5	2	41	6	1.4	54.2	7.5	2
56.88	7.5	2	52.53	7.5	2	46.51	6	1.4	78	7.5	2
62.52	7.5	2	62.17	7.5	2	54.88	6	1.4	54.1	7.5	2
80.29	7.5	2	55.15	7.5	2	47.75	6.8	1.6	59.6	7.5	2
65.45	7	3.1	63.98	7.5	2	41	6.8	1.6	78	7.5	2
73.77	7	3.1	60.89	7.5	2	46.51	6.8	1.6	68.5	7.5	2
80	7	3.1	58.92	7.5	2	54.88	6.8	1.6	74.8	7.5	2
72	7	3.1	71.21	7.5	2	47.75	6.8	1.6	70.6	7.5	2
74.69	7	3.1	65.52	7.5	2	49.59	6.8	1.6	89	7.5	2
70.31	7	3.1	61.12	7.5	2	48	6.8	1.6	104	7.5	2
66.18	6	1.4	60.67	7.5	2	46.88	6.8	1.6	103	7.5	2
67.92	6	1.4	55.73	7.5	2	58.06	6.8	1.6	92	7.5	2
53.89	6	1.4	60.68	7.5	2	62.5	6.8	1.6	81.9	7.5	2
81.08	6	1.4	53.39	7.5	2	51.87	6.8	1.6	81.9	7.5	2
74.07	6	1.4	56.13	7.5	2	64.52	6.8	1.6	81.5	7	3.1
77.92	6	1.4	70.91	7.5	2	80.72	6.8	1.6	78.3	7	3.1
67.16	6	1.4	58.33	7.5	2	66.91	6.8	1.6	75	7	3.1
64.75	6	1.4	56.07	7	3.1	85.71	6.8	1.6	84.9	7	3.1
74.07	6	1.4	72.89	7	3.1				90	7	3.1
75	6	1.4	75.63	7	3.1				74.7	7	3.1
78.26	6	1.4	68.5	7	3.1				76.6	7	3.1
64.75	6	1.4	63.15	7	3.1				80	7	3.1
64.75	6	1.4	65.45	7	3.1				77.9	7	3.1
65.45	6	1.4	75	7	3.1				72	7	3.1
91.37	6	1.4	66.18	7	3.1				94.7	7	3.1

bus kmph	pavw metre	sholdw metre	minibus kmph	pavw metre	sholdw metre	truck kmph	pavw metre	sholdw metre	p.car kmph	pavw metre	sholdw metre
86.12	6	1.4	65.45	7	3.1				101	7	3.1
52.33	6.8	1.6	69.28	7	3.1				90	7	3.1
58.06	6.8	1.6	55.51	6	1.4				67.2	7	3.1
70.31	6.8	1.6	72.87	6	1.4				57.5	6	1.4
73.17	6.8	1.6	75.63	6.8	1.6				62.7	6	1.4
68.7	6.8	1.6	74.7	6.8	1.6				78.3	6	1.4
60.61	6.8	1.6	72.83	6.8	1.6				87.4	6	1.4
41.76	5.8	1.6	45.92	5.8	1.6				82.6	6	1.4
60	5.8	1.6	50.56	5.8	1.6				61.2	6	1.4
69.23	5.8	1.6	48.03	5.8	1.6				60.6	6	1.4
			60.05	5.8	1.6				90.9	6	1.4
									96.8	6.8	1.6
									76.9	6.8	1.6
									87	6.8	1.6
									82.2	6.8	1.6
									80.7	6.8	1.6
									82.2	6.8	1.6
									78.9	6.8	1.6
									73.5	6.8	1.6
									75.6	6.8	1.6
									94.2	6.8	1.6
									63.4	5.8	1.6

A.4 FLOW-SPEED

A.4.1 Dhaka-Aricha and Dhaka-Chittagong

Data set	Flow (veh/quarter hr)	Weighted average speed (kmph)
Dhaka-aricha	149	57,02
	160	47,27
	126	51,62
	135	52,08
	130	58,79
Dhaka-Chittagong	149	55
	128	56,38
	147	58,52
	172	57,12
	177	54,72

A.4.2 Dhaka-Mymensingh and Dhaka-Sylhet

Data set	Flow (veh/quarter hr)	Weighted average speed (kmph)
Dhaka-Mymensingh	82	48,74
	69	42,83
	73	47,1
	65	42,98
	83	43,09
	73	42,3
Dhaka-Sylhet	66	52,95
	71	54,75
	66	53,75
	66	55,38
	74	53,19

A.4.3 Dhaka-Khulna

Flow (veh/quarter hr)	Weighted average speed (kmph)
90	43,56
53	47,35
61	49,41
76	50,07
64	50,73
77	47,09
56	46,59
63	48,91
76	51,66
64	46,65

A.5 SPEED-DENSITY

A.5.1 Dhaka-Aricha and Dhaka-Chittagong

Data set	Density (veh/quarter km)	Weighted average speed (kmph)
Dhaka-aricha	11	35,88
	2	55,51
	7	51,12
	9	53,55
	4	49,57
	3	51,31
Dhaka-Chittagong	6	42,47
	2	76,8
	11	49,77
	8	51,13
	13	56,43

A.5.2 Dhaka-Mymensingh and Dhaka-Sylhet

Data set	Density (veh/quarter km)	Weighted average speed (kmph)
Dhaka-Mymensingh	7	40,95
	7	29,92
	5	39,67
	5	45,86
	2	45,9
	3	38,66
	6	48,47
	11	40,17
Dhaka-Sylhet	2	52,1
	12	42,65
	2	67,56
	8	55,74
	3	50,31
	6	38,72
	11	41,49
	10	42,51

A.5.3 Dhaka-Khulna

density (veh/quarter km)	Weighted average speed (kmph)
14	37,25
5	35,8
7	44,28
2	46,29
3	33,18
2	38,97
5	50,05
9	43,25
4	44,54
11	39,14

APPENDIX B
ANALYSIS TABLES

B.1 EXPONENTIAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-ARICHA HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	4.333	126	105.14	4.138
4.333	8.500	62	70.68	1.0657
8.500	12.667	39	49.75	2.3228
12.667	16.833	28	35.03	1.41049
16.833	21.000	24	24.67	0.0184
21.000	25.167	15	17.37	0.324
25.167	29.333	17	12.23	1.859
29.333	33.500	10	8.61	0.2231
33.500	41.833	13	10.33	0.6885
41.833	50.167	5	5.13	0.00303
50.167	66.833	3	3.8	0.1685
above	66.833	2	1.24	0.4677

Chisquare = 12.6892 with 10 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0633372
Estimated KOLMOGOROV statistic DMINUS = 0.0526415
Estimated overall statistic DN = 0.0633372

B.2 LOGNORMAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-ARICHA HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	4.333	126	115.3	.993698
4.333	8.500	62	81.7	4.736801
8.500	12.667	39	46.1	1.088339
12.667	16.833	28	28.1	.000308
16.833	21.000	24	18.3	1.789791
21.000	25.167	15	12.5	.498951
25.167	29.333	17	8.9	7.402547
29.333	33.500	10	6.5	1.860820
33.500	41.833	13	8.7	2.168406
41.833	50.167	5	5.3	.014764
50.167	66.833	3	5.7	1.288623
above 66.833		2	7.0	3.584508

Chisquare = 25.4276 with 9 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0401802
Estimated KOLMOGOROV statistic DMINUS = 0.0618274
Estimated overall statistic DN = 0.0618274

B.3 EXPONENTIAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-CHITTAGONG HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	4.459	126	103.99	4.6582
4.459	8.818	69	71.1	0.062
8.818	13.177	36	50.09	3.9665
13.177	17.536	30	35.089	0.738
17.536	21.895	19	24.65	1.294
21.895	26.255	18	17.32	0.02668
26.255	30.614	7	12.16	2.19276
30.614	34.973	8	8.54	0.03447
34.973	43.691	12	10.213	0.31069
43.691	52.409	10	5.043	4.8719
52.409	65.486	5	3.21	0.99788
above	65.486	3	1.7	0.9888

Chisquare = 20.14196 with10 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0836516
Estimated KOLMOGOROV statistic DMINUS = 0.0365128
Estimated overall statistic DN = 0.0836516

B.4 LOGNORMAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-CHITTAGONG HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	4.459	126	129.9	.11702172
4.459	8.818	69	75.1	.49804849
8.818	13.177	36	41.1	.62161081
13.177	17.536	30	25.1	.96274346
17.536	21.895	19	16.5	.36500710
21.895	26.255	18	11.5	3.65110101
26.255	30.614	7	8.3	.21751184
30.614	34.973	8	6.2	.49350701
34.973	43.691	12	8.5	1.39773562
43.691	52.409	10	5.4	3.88771415
52.409	65.486	5	5.0	.00000520
above 65.486		3	10.2	5.11430507

Chisquare = 17.3263 with 9 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0556918
Estimated KOLMOGOROV statistic DMINUS = 0.0485321
Estimated overall statistic DN = 0.0556918

B.5 EXPONENTIAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-MYMENSINGH HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	6.459	58	51.469	0.8286
6.459	12.818	35	38.56	0.3289
12.818	19.177	28	29.413	0.0679
19.177	25.536	19	22.43	0.5259
25.536	31.895	14	17.11	0.5654
31.895	38.255	14	13.04	0.0733
38.255	44.614	13	9.94	0.9394
44.614	50.973	8	7.59	0.0219
50.973	63.691	9	10.207	0.14286
63.691	82.768	7	7.898	0.102187
82.768	108.205	7	4.167	1.92486
above	108.205	2	2.13	0.007934

Chisquare = 5.529 with 10 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0772443
Estimated KOLMOGOROV statistic DMINUS = 0.0287917
Estimated overall statistic DN = 0.0772443

B.6 LOGNORMAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-MYMENSINGH HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	6.459	58	66.9	1.18602
6.459	12.818	35	42.8	1.41103
12.818	19.177	28	25.5	.23603
19.177	25.536	19	16.8	.29897
25.536	31.895	14	11.7	.43787
31.895	38.255	14	8.6	3.38866
38.255	44.614	13	6.5	6.41984
44.614	50.973	8	5.1	1.66668
50.973	63.691	9	7.3	.37558
63.691	82.768	7	6.9	.00278
82.768	108.205	7	5.3	.58057
above 108.205		2	10.6	6.98991

Chisquare = 22.9939 with 9 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0605543
Estimated KOLMOGOROV statistic DMINUS = 0.1004
Estimated overall statistic DN = 0.1004

B.7 EXPONENTIAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-SYLHET HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	6.504	60	46.730	3.768
6.504	12.308	35	31.85	0.3115
12.308	18.113	15	24.724	3.8244
18.113	23.917	10	19.185	4.3974
23.917	29.721	12	14.89	0.3377
29.721	35.525	12	11.556	0.01705
35.525	41.329	7	8.969	0.43226
41.329	52.938	14	12.3645	0.21633
52.938	64.546	8	7.45	0.0406
64.546	81.958	11	6.007	4.15016
81.958	116.783	5	4.12	0.18796
above	116.783	0	1.15	1.15

Chisquare = 18.83 with 10 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.112388
Estimated KOLMOGOROV statistic DMINUS = 0.0493061
Estimated overall statistic DN = 0.112388

B.8 LOGNORMAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-SYLHET HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	6.504	60	61.0	.0153
6.504	12.308	35	36.4	.0509
12.308	18.113	15	22.3	2.3687
18.113	23.917	10	14.8	1.5464
23.917	29.721	12	10.4	.2434
29.721	35.525	12	7.7	2.4716
35.525	41.329	7	5.8	.2428
41.329	52.938	14	8.1	4.2254
52.938	64.546	8	5.3	1.3491
64.546	81.958	11	5.1	6.8076
81.958	116.783	5	5.3	.0193
above	116.783	0	6.9	6.8773

Chisquare = 26.2177 with 9 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0728418
Estimated KOLMOGOROV statistic DMINUS = 0.0900442
Estimated overall statistic DN = 0.0900442

B.9 EXPONENTIAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-KHULNA HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	7.769	34	38.8	0.583826
7.769	14.938	35	27.8	1.875711
14.938	22.106	21	21.8	0.030054
22.106	29.275	15	17.1	.262884
29.275	36.444	12	13.4	.154531
36.444	43.613	16	10.6	2.812838
43.613	50.781	4	8.3	2.215272
50.781	65.119	11	11.6	0.0310344
65.119	79.456	10	7.2	1.131952
79.456	100.963	6	5.9	0.000793
100.963	143.975	3	4.3	0.371627
above	143.975	1	1.3	0.06977

Chisquare = 9.54029 with 10 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0301037
Estimated KOLMOGOROV statistic DMINUS = 0.0359529
Estimated overall statistic DN = 0.0359529

B.10 LOGNORMAL DISTRIBUTION FOR HEADWAY DATA OF DHAKA-KHULNA HIGHWAY

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	7.769	34	41.0	1.20785
7.769	14.938	35	34.1	0.02453
14.938	22.106	21	22.4	0.08476
22.106	29.275	15	15.3	0.00463
29.275	36.444	12	10.9	0.11746
36.444	43.613	16	8.0	7.94624
43.613	50.781	4	6.1	0.71455
50.781	65.119	11	8.5	0.75490
65.119	79.456	10	5.5	3.74089
79.456	100.963	6	5.2	0.13608
100.963	143.975	3	5.2	0.93704
above	143.975	1	5.9	4.10879

Chisquare = 19.7777 with 9 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0776305
Estimated KOLMOGOROV statistic DMINUS = 0.0620538
Estimated overall statistic DN = 0.0776305

B.11 FREE SPEED ANALYSIS FOR BUSES

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below		60.000	5	5.8	.102
	60.000	65.000	7	5.7	.288
	65.000	70.000	11	7.5	1.669
	70.000	75.000	5	7.6	.890
	75.000	80.000	3	6.0	1.518
above	80.000		8	6.4	.387

Chisquare = 4.85327 with 3 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.121487
Estimated KOLMOGOROV statistic DMINUS = 0.0562993
Estimated overall statistic DN = 0.121487

B.12 FREE SPEED ANALYSIS FOR CARS

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	57.000	3	5.1	.8946
57.000	63.000	8	5.5	1.0867
63.000	69.000	10	7.9	.5612
69.000	75.000	10	8.9	.1232
75.000	81.000	6	8.1	.5342
81.000	87.000	4	5.8	.5607
above	87.000	6	5.6	.0311

Chisquare = 3.79177 with 4 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.110495
Estimated KOLMOGOROV statistic DMINUS = 0.0713888
Estimated overall statistic DN = 0.110495

B.13 FREE SPEED ANALYSIS FOR TRUCKS

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	49.000	7	7.3	.0161
49.000	54.000	9	7.4	.3375
54.000	59.000	11	8.7	.6026
59.000	64.000	5	7.4	.7520
above 64.000		6	7.2	.1935

Chisquare = 1.90154 with 2 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.118915
Estimated KOLMOGOROV statistic DMINUS = 0.0516335
Estimated overall statistic DN = 0.118915

B.14 FREE SPEED ANALYSIS FOR MINIBUSES

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	55.000	6	6.2	.00482
55.000	59.000	10	6.6	1.71715
59.000	63.000	8	8.3	.01462
63.000	67.000	7	7.7	.06760
above 67.000		7	9.1	.49644

Chisquare = 2.30064 with 2 d.f.

Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.127726
Estimated KOLMOGOROV statistic DMINUS = 0.0913704
Estimated overall statistic DN = 0.127726

B.15 FREE SPEED ANALYSIS FOR NONMOTORISED VEHICLES

Chisquare Test

Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below	12.000	7	7.7	.06094
12.000	13.000	8	10.3	.52399
13.000	14.000	15	10.8	1.63333
14.000	15.000	5	7.3	.724645
above 15.000		3	1.9	.6368

Chisquare = 3.5797 with 2 d.f.

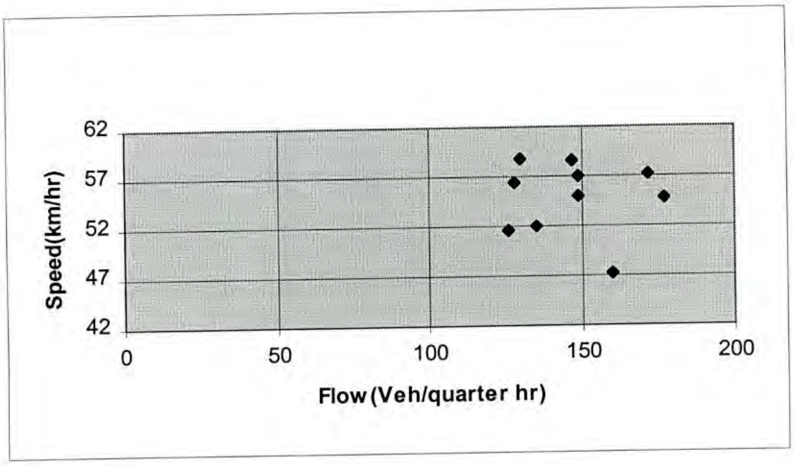
Kolmogorov-Smirnov Test

Estimated KOLMOGOROV statistic DPLUS = 0.0700532
Estimated KOLMOGOROV statistic DMINUS = 0.120518
Estimated overall statistic DN = 0.120518

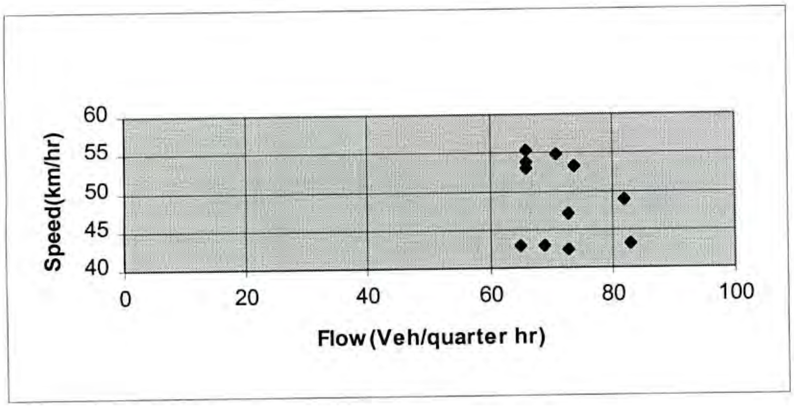
APPENDIX C

SPEED-FLOW-DENSITY OBSERVATION

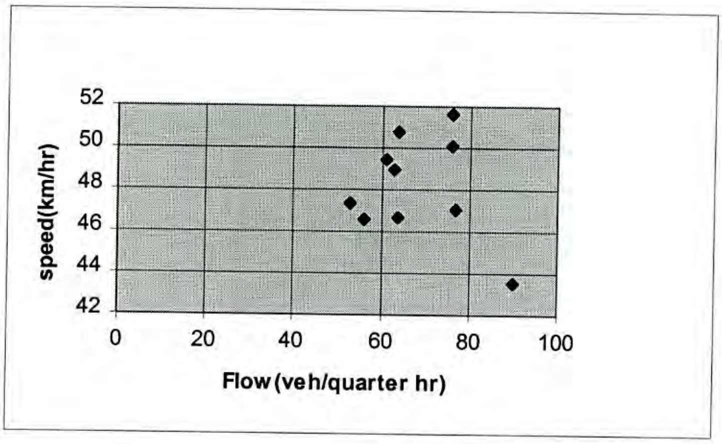
C.1 SPEED-FLOW CONDITION AT DHAKA-ARICHA AND DHAKA CHITTAGONG HIGHWAYS



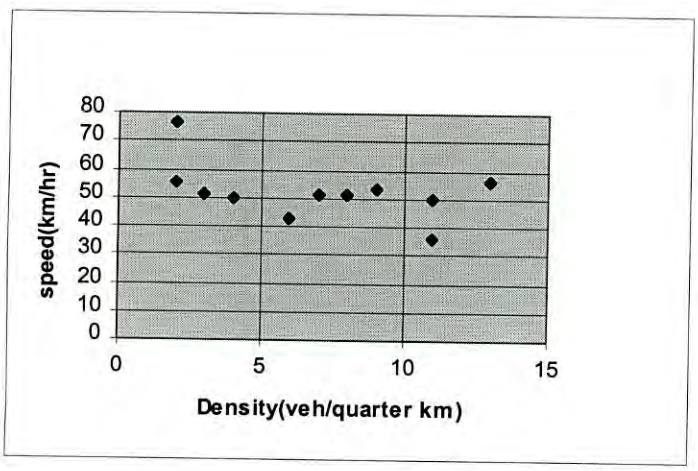
C.2 SPEED-FLOW CONDITION AT DHAKA-MYMENSINGH & DHAKA-SYLHET HIGHWAYS



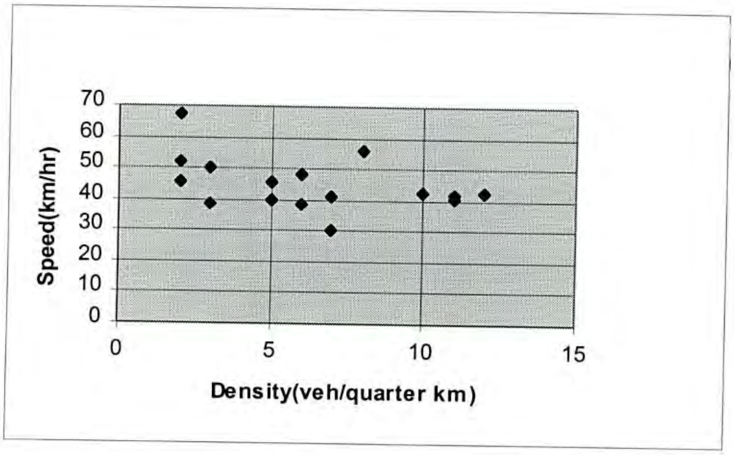
C.3 SPEED-FLOW CONDITION AT DHAKA-KHULNA HIGHWAY



C.4 SPEED-DENSITY CONDITION AT DHAKA-ARICHA AND DHAKA-CHITTAGONG HIGHWAYS



C.5 SPEED-DENSITY CONDITION AT DHAKA-MYMENSINGH AND DHAKA-SYLHET HIGHWAYS



C.6 SPEED-DENSITY CONDITION AT DHAKA-KHULNA HIGHWAY