Development of District wise Crash Prediction Model in Bangladesh

SOUMIK NAFIS SADEEK

MUSTOFA NAJMUS SAKIB SAJON

Department of Civil and Environmental Engineering (CEE)

Islamic University of Technology (IUT)

2015

Development of District wise Crash Prediction Model in Bangladesh

Soumik Nafis Sadeek

Student ID: 115408

Mustofa Najmus Sakib Sajon

Student ID: 115414

A THESIS SUBMITTED FOR THE DEGREE OF SCIENCE IN CIVIL ENGINEERING

Department of Civil & Environmental Engineering

Islamic University of Technology

2015

APPROVAL

The dissertation entitled "***Development of District wise Crash Prediction Model in Bangladesh*** ", by Soumik Nafis Sadeek and Mustofa Najmus Sakib Sajon has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil Engineering.

____

Supervisor
Dr. Shakil Mohammad Rifaat

Associate Professor
Department of Civil and Environmental Engineering
Islamic University of Technology (IUT)
Board Bazar, Gazipur, Bangladesh

DECLARATION

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Associate Professor **Dr. Shakil Mohammad Rifaat** and we have taken reasonable care to ensure that this work has not been submitted elsewhere for any purpose

Soumik Nafis Sadeek
Student ID: 115408
November, 2015

Mustofa Najmus Sakib Sajon
Student ID: 115414
November, 2015

ACKNOWLEDGEMENTS

The first round of thanks goes to my supervisor Dr. Shakil Mohammad Rifaat for his contrasting style of supervision. His guidance, suggestions and support regarding this research help me so much to improve the work and finish it on time. He made me easy to understand the very complex concept of statistics. His most valuable contribution was to make me think widely, largely and critically while developing a prediction model and to make transportation engineering interesting to me.

I would also like to thank assistant professor Dr. Moinul Hossain for his valuable comments and information from his experience in developing crash prediction models.

I would also thank S.M Sohel Mahmud, Accident Research Institute (ARI), BUET for providing us relevant crash data without which our research could not be possible.

Last of all, my parents, my brother and my one and only best friend deserve a big round of thanks for supporting me and to keep me calm and patience in the whole year long. Without their support this thesis could not have been possible to finish.

ABSTRACT

Bangladesh is an accident prone country. Every year a considerable number of road crashes occur in this country and these are categorized as fatal injury crash, grievous injury crash, simple injury crash and collision or no injury or property damage crash. Different independent factors are directly and indirectly associated with these crash occurrences. Thus, a crash prediction model is necessary to explore the adverse effects of various structural and non-structural elements that are linked with transportation systems on individual crashes in context of Bangladesh. Considering all districts of Bangladesh about 13 types of road infrastructures, all types of roads and highways, socio economic and demographic factors and weather conditions (rainfall, fog and temperature) have been taken as predictors to identify their significance on different crash occurrences. Negative binomial regression models have been developed for these 4 types of crashes with the available data.

From our study we have found that any types of concrete made infrastructure (RCC Bridge, Box culvert, RCC girder and PC girder) are vulnerable to the fatal and grievous injury crashes in the national, regional and zilla (district) roads. Highway infrastructures designed with composite materials i.e. Steel beam and RCC slab (SBRS), Truss with RCC slab (TRS), Baily with steel deck (BSD) are found less vulnerable to any types of the crash. Specially, SBRS and TRS are found safe for national highways and zilla roads.

National highways are found risk prone area for fatal and simple injury. Roads that are not surveyed yet have been found hazardous for grievous injury crash. On the contrary, zilla roads and village roads are found less vulnerable to fatal crash relative to national highway. Most of the roads in upazilla and union are of pavement type rather than earthen type. Flexible and rigid pavements are found increasing the fatal injury whereas brick pavements are found both positive and negative effect on grievous injury. Also, paved roads are found vulnerable to simple crash in the union roads in Bangladesh. Moreover, variations in the number of road structures and number of existing gap influence positively and negatively on different crashes.

In socio economic and demographic characteristics, number of female decreases the fatal crash where as sex ratio (M/F) tends to increase it. Also, the more the household size, the more the probability of fatal crash.

After considering weather conditions in Bangladesh, we have found that rainfall likely to decrease fatal crash and collision during the year of 2009-2013. Average minimum temperature is found negatively significant in 2009 and 2010 on grievous injury crash and collision but after that till 2013 it explored with positively significant. No significant effect of temperature is found on fatal and simple crash.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
ADB	Asian Development Bank
ANN	Artificial Neural Network
ARI	Accident Research Institute
ASCM	Aggregated Severe Crash Metric
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BRTA	Bangladesh Road Transport Authority
BSD	Baily with Steel Deck
BUET	Bangladesh University of Technology
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GLM	Generalized Linear Model
LGED	Local Government Engineering Department
ML	Maximum Likelihood
MLR	Multiple Linear Regression
NB	Negative Binomial
OLS	Ordinary Least Squares
PC	Pre-stressed Concrete
RCC	Reinforced Cement Concrete
RHD	Roads and Highway Department
SBRS	Steel Beam & RCC Slab
TAZ	Traffic Analysis Zone
TRS	Truss with RCC Slab
TSD	Truss with Steel Deck

NOTATIONS AND DEFINITION OF THE VARIABLES

E [.]	Expected value of the expression in the parenthesis
$\Gamma(.)$	Gamma Function
X	Explanatory Variables
X	Vector of explanatory variables
β	Parameter in estimation equation
β	Parameter vector in estimation equation
ε	Random error in the regression
σ^2	Variance
µ	Mean
∑	Summation
Π	Product
$\overline{\rho}^2$	Adjusted log likelihood Ratio Index
ρ^2	Pseudo R^2 / Log likelihood Ratio Index
χ^2	Chi-square test
LL ($\boldsymbol{\beta}_R$)	Log likelihood at Converges of the Restricted Model
LL ($\boldsymbol{\beta}_U$)	Log likelihood at the Converges of the Unrestricted Model
i, t, k	Index for observation

Chapter 1

INTRODUCTION

1.1 Introduction

Bangladesh is a developing country with a huge number of populations. So it needs to assure economic stabilization for the country and safety for each of the individuals living in this country. As we said earlier that it is a developing country; so since the independence of Bangladesh, the main development issue has been focused on building roads and road infrastructure to enhance the economic growth as well as to achieve economic freedom. In last 3 decades the main priority of the government has been on transportation sector and construction of roads and highways. ADB, IMF, World Bank all of these organizations have invested in this sector estimated US $40 billion. Government invested 90% of its allocation in transportation sector to construct roads and road infrastructure. (Source: www.assignment point .com /business/ economics/ Report on transportation-sector-development of Bangladesh)

Now Bangladesh has total road length is 21,302.08 km with a classification of national, regional and zilla road and also a considerable number of infrastructure (i.e bridges, culverts etc). *(RHD network, Bangladesh; Source : RHD website*)

Table 1.1: Length of Road classification and road infrastructure

Road classification	Road length(km)	Road infrastructure	Length(km)
National Highway	3,812.78	Bridges	4,507
Regional Highway	4,246.97	Culverts	13,751
Zilla Road	13,242.33		

With this vast road network there is an increasing number of transportation vehicles all over the country with various purposes. From the *BRTA report, 2012* there are 42,281 buses/ minibuses, 40,109 microbuses, 87,033 trucks, 1,20,180 cars, 7,19,231 motorcycles are being used on roads in all over the country (*BBS Statistical Year Book 2012*). All these are motorized vehicles though the transport demand is still predominantly met by non-motorized vehicles in Bangladesh. From the year 2007-2012 there is a 10-12% vehicles have been increased (*BRTA report 2012; adopted from BBS Year book 2012*) whereas the road length and road infrastructure construction have been increased approximately 0.12-0.62% on an average per year *(Based on RCS survey record of RHD Road Network database Report 2012; adopted from BBS year book 2012).* This is absolutely a slow process in compare.

Table 1.2: Increasing trend of vehicles and road length (2007-2012)

Year	Total Road length in km	Year	Total estimated number of vehicles
2008	20995	2007-2008	824948
2009	21020	2008-2009	929760
2010	21269	2009-2010	1038885
2011	21284	2010-2011	1159870
2012	21365	2011-2012	1280585

Data Source: Bangladesh Bureau of Statistics Year Book 2012

1.2 Background

In a small developing country like Bangladesh where the population density is 1033.5/km^2 *(Preliminary report on Population and Housing, 2011)* economic transportation would not possible at this trend of increasing of road length comparing to the number of vehicles. For this reason a considerable number of road crashes, accidents, loss of lives, property damages have been taken place all over the country in the last few years. If we look into the world status on traffic accidents and injury, according to the *Global Status Report on Road Safety 2013 published by World Health Organization*

(WHO) the total number of road traffic deaths remains unacceptably high at 1.24 per year. Only 7 percent of the world's population have adequate laws that address all five factors (speed, drink-driving, helmets, seat-belts and child restrains). According to this report traffic death rates per 1,00,000 Population by country income status, for low and middle income countries these are 18.3 and 20.1 respectively where

Bangladesh, as a developing country, is not detached with all of these problems. Rather, economic loss due to traffic accidents, fatalities, property damages are very acute in Bangladesh. There has been an alarming rise of road accidents in Bangladesh. According to *Accident Research Institute (ARI), BUET* every year the road accidents claim on average 12,000 lives annually and lead to about 35,000 injuries. From *World Bank statistics*, annual fatality rate from road accidents is found to be 85 per 10,000 vehicles.

If we look into the data (1998-2013) collected from *Accident Research Institute (ARI), BUET (ARI annual report 2013)* there are fluctuations in the number of casualties by casualty injury (i.e Fatal, Grievous, Simple). From 1998 to 2000 the injury increased by 15.7%. Maximum injury was occurred in the year 2007 about 7074 in number *(ARI report 2012)* Moreover, if we look into the data following from 2008-2013, Injuries are very acute every year.

Table 1.3: An overview of casualties (2008-2013)

Year	Fatal	Grievous	Simple	Total
2008	3570	1752	664	5986
2009	2703	1438	308	4449
2010	2443	1271	435	4149
2011	2072	1071	377	3520
2012	1953	850	492	3295
2013	1781	632	296	2709

Data Source: Accident Research Institute Report 2012, Table 3

According to *the Accident Research Institute (ARI) report, 2012* the fatality rate of road accidents in Bangladesh is very high with about deaths per 10,000 vehicles per year whereas in USA it is 2, 1.4 in UK and 3.3 in New Zealand for 1000 people. In India, the motor vehicle are 12/1000 people and fatalities rate 25/10,000 vehicles.

In the following figure, we can see different types of collision that causes fatal injury, grievous injury, simple injury and property damage in Bangladesh from the year 2009-2013. Maximum crashes occur with the hit to the pedestrians.

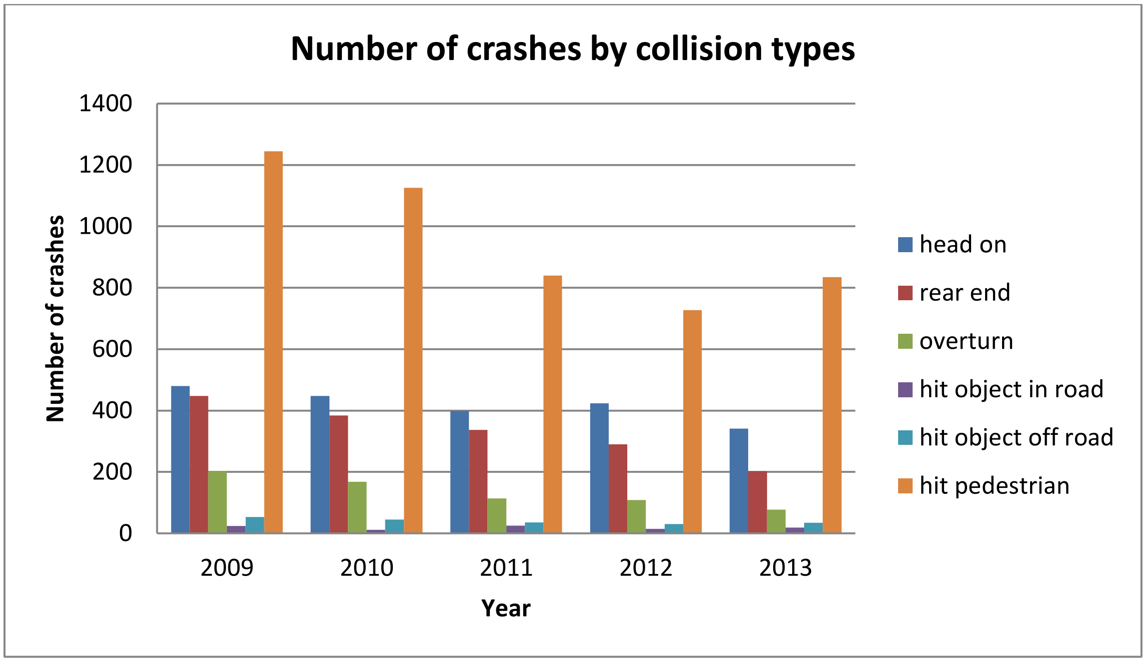

Figure 1.1: Number of crashes by collision types

(Data Source: Accident Research Institute)

Declination of road fatalities in the developed countries are considered to be decreased because they have developed research on road safety and accident prediction models as well as they have tended to promote good safety practices. In Bangladesh, increasing population, urbanization, motorization, lack of investment in road safety, violation of traffic laws, unplanned roads are some of the major causes of road accidents.

1.3 Accidents and Economic Loss

As a result of traffic accidents not only severe injury, loss of peoples' life occurs but also this creates a burden not only socially but also economically. Lots of resources are damaged and a considerable number of expenditure occurs at a time of an accident. It is a large waste of countries scarce resources. From the data of preliminary report on *Economic Census 2013*, we can see that the largest portion of economic establishments engaged in Transportation services are located in Dhaka (26 percent) and the smallest proportion are located for Barisal (1 percent).

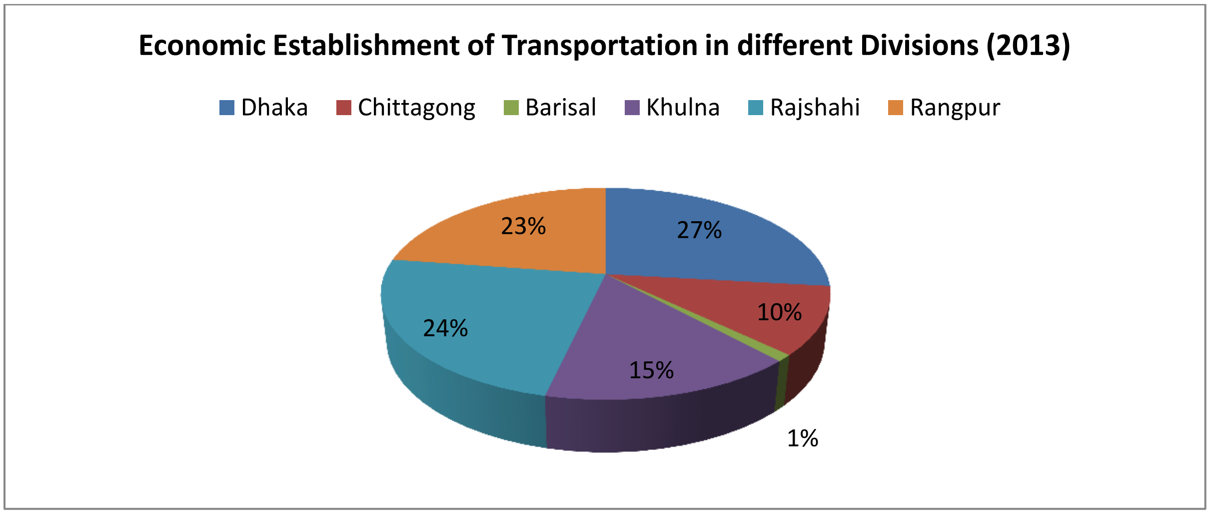

Figure 1.2 Economic establishment of Transportation engaged in different Division
(Source: Economic Census Report 2013, Bangladesh)

From *Economic census report 2013*, in the year of 2011-2012, expenditure of the Government in developing Transport sector was BDT 52,646 million. But road accident causes a great economic loss. The preliminary estimation revealed that total annual cost of road accidents and injuries in Bangladesh varied between 1.8 to 2.2 percent of its GDP

(*ARI report 2012*) which could be around Taka 75,000 million to Taka 90,000 million respectively. The total cost is distributed as lost out put 57.4 percent, pain, grief and suffering cost 34.1 percent, vehicle damage cost is 4.8 percent, medical and other cost is 3.7 percent. *(Rifaat et al, 2014)*

Terrible losses of lives and injuries with consequent property damages resulting from road traffic accidents have now emerged as serious issues in Bangladesh which affect the community personally, socially and economically. World Health Organization (WHO) estimates that the economic costs of road crashes is US$ 518 billion globally per year; for developing countries the economic loss is about US$ 100 billion*(Haque et al, 2009*).
From the LGED annual report 2013-14, for 1,192 km upazilla roads, 1,578 km union roads, 3,779 km rural roads and for road maintenance of 2,408 km the cost about 659.77 crore, 735.56 crore, 1152 crore and 205.76 crore BDT have been spent respectively. And for road infrastructures construction, in 2013-14 with the expense of 1096 crore BDT, 32,707 meter Bridges and culverts have been constructed, reconstructed and maintained.

1.4 Weather and Accidents

In Bangladesh a considerable number of accidents occur every year due to bad weather condition. Specially, in the coastal region due to heavy rainfall and turbulent wind speed several accidents occur every year. From the following figure, we can observe that most of crash occurs due to rainfall and fog. Wind does not affect too much on the crash occurrence in Bangladesh except coastal zones like Barisal, Cox’s Bazar etc.

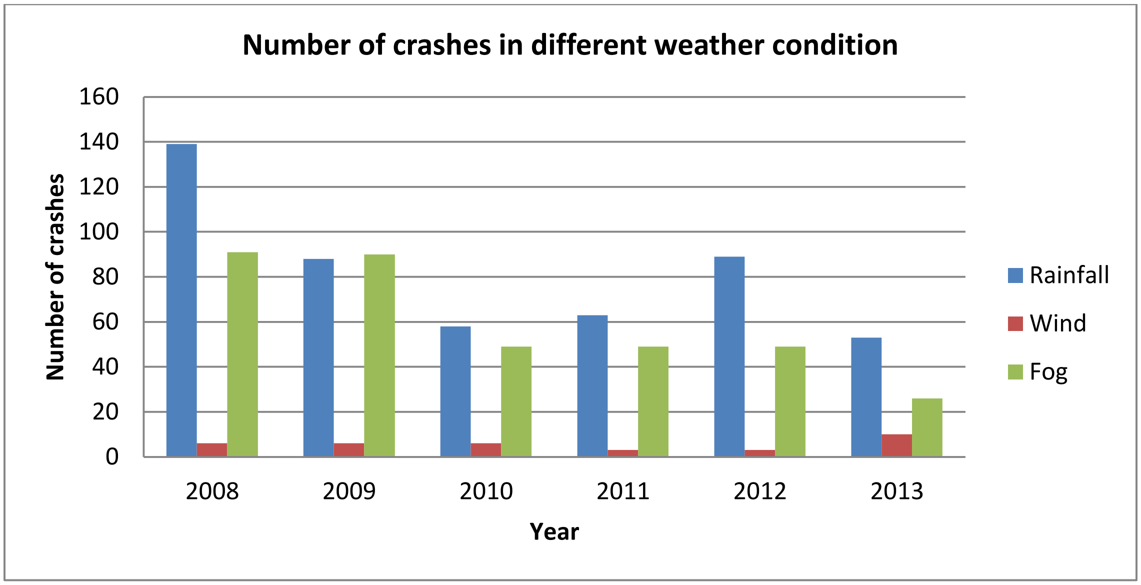

Figure 1.3 Number of crash occurrence due to bad weather condition

Data Source : Accident research Institute, Bangladesh (ARI report 2013, Table 12)

1.5 Crash Prediction Model

It is necessary to understand the depth of causes how the accident occurs to increase road safety in highways. To reduce accidents and severity of injuries in developed countries development of accident prediction model is practiced. Through accident prediction model we can make some relationship between accidents and the factors for which accident occurs. In our study we will develop relationship of district wise accidents of Bangladesh with Road infrastructure, Weather conditions and Socio-economic Demography of Bangladesh. In Bangladesh, roads are the main key factor contributing hugely on accident occurrence. To develop accident prediction models we need huge data which is sometimes very difficult to get or most of the time data is not available. In our study, we have collected data of district wise road infrastructure classifications and their measured length, road side objects and their in between gaps from Roads and Highway Department of Bangladesh (RHDB) and Local Government Engineering Department (LGED), several weather conditions i.e district wise rainfall, fog, temperature, humidity and wind from Bangladesh Meteorological Department (BMD) and socio economic demographic statistical data from Bangladesh Bureau of Statistics year book – 2012.

1.6 Research Objectives

This dissertation contributes to develop a district wise accident prediction model in Bangladesh by integrating all 64 district wise road infrastructure and their length, the existing weather condition of all the districts and relate with prediction of an accident and lastly, effect of socio-economic demography on this crashes.

The specific objectives of this research are as follows

a) How the increasing or decreasing number of road infrastructures effect on accidents
b) How the severity and risk involves in different locations (districts) in Bangladesh.
c) To understand different socio-economic groups response and their role in road accidents.
d) To understand the effect of increasing or decreasing road length on the crash frequency
e) To understand how different weather condition of different districts effect on crashes.
f) To make a relationship between district wise road accidents and fatality rate from the past years statistics and a prediction of future consequences.
g) To identify the severe accident occurring locations.
h) To understand the effect of paved road in different district on the road accidents.

1.7 Structure of the Thesis

The thesis is organized into chapters. Each chapter will provide an overview and will follow with number of subsections.

Chapter 1: Introduction

This chapter presents all the context of the research and set objectives.

Chapter 2: Literature Review

This chapter reviews various factors that effect on accidents and reviews previous accident prediction models. Important information and findings also documented the this chapter

Chapter 3: Data and methodology

This chapter sets the convenient method that will be followed for the prediction model with statistical analysis by dint of collected data and comparing them with relevant studies. Also justify the methodologies.

Chapter 4: Crash Frequency Analysis

This chapter deals with correlation between independent and dependent variable, develop accident prediction model and description as well as evaluation of significant variables.

Chapter 5: Conclusions

The final chapter of the dissertation draws conclusions on the research findings, contribution to the existing knowledge, limitations of the study and finally ends with future research directions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Transportation is a major indicator that represents the development of a country. A good transportation system comprises with physical condition of a road, traffic safety of the road, the economic condition and importance of the road, good legislation and traffic laws on the road, road infrastructures and distinct functions of the roads in different weather conditions and the socio economic aspects of a road. A good forecasting about future traffic demand and by obeying it a good road construction is always economic. Bad planning and policy, inappropriate design, using deteriorating road construction materials, lack of futuristic vision, improper road safety research, unconscious act of human behavior (i.e. over speeding, improper passing are the key issues that occurs a road accident. In order to reduce the severity of accidents as well as injury we need to find a scientific way that can help in planning a safe highway for communication. And now-a-days, predicting accidents on roads and highways by developing some models is the most advanced and well established solution. Certainly, for this purpose we need specific data of various factors that links with accidents

The main purpose of our research is to develop an crash prediction model, means to make a relationship with crash frequency per road length (Dependent variable) with some factors that directly effect on the accident (Independent variables) i.e. road infrastructure and length, weather conditions and socio economic demography. For this purpose we had gone through several literature reviews where we found several developed models regarding crash prediction where several factors have been considered. And in this chapter we will discuss all of our studies and make an approach to relate them with our own research.

In regarding our study, we have reviewed the following factors that are related with the causes of crash. This study will guide us with some facts for our own research late on.

2.2 Crash Severity Factor

In this research, the main objective is to find out major effects of different road infrastructures, socio-economic and demography and weather conditions on different types of crashes. In 2007 *Kopelias et al*., investigated the geometrical, operational and weather effects on crash number and severity. An important outcome of this analysis is that fixed and temporal roadway characteristic and presence of rain or wet pavements may explain 5% to 10% of the crashes. They had come for a conclusion that about 80% of all crashes involved drivers inattention, lending support to the findings that road way and environmental factors and relatively minor causes of crashes. *Scneider and Sarolainen, 2011* identified the factors that associated with injury level of motorcyclists involved in crashes. Their study showed that impact of relevant crash factors varied by crash type and location and also mentioned that injuries were more likely when high speed or alcohol was involved. In 2014, *Rey et al.,* presented a new method to rank the severity of an impact with road side hazard based on observable crash data and also at the same year, *Wang and Stamatiadis*, 2014 proposed a new surrogates measures – Aggregated Severe Crash Metric (ASCM), which is based on study of conflict and traffic simulations to allow relative comparisons and safety evaluations between intersection designs in relation to crash severity.

Anowar et al., 2014, studied the factor influencing on intersection crash severity in Bangladesh. They showed that crash severity increases when the intersection are located in rural areas. This study also suggested conducting a safety review and improvement of intersection geometry, public education campaigns.

2.3 Road infrastructure and street pattern factor

Wang et al., (2013) studied that the analysis of road network designs can improve the road safety design. At the level of Traffic Analysis Zone (TAZ), this study suggests that there is a relationship between road structures and safety. Various changes in road infrastructure and geometric design can be linked with the changes in fatalities and reported accidents. It was highlighted by *Noland and Oh, (2004)* that

- Increase in road width can increase traffic accidents.
- Increase in lane number can increase traffic accidents and fatalities
- Increased in outside shoulder width decrease the accidents
- Inclusion of demography does not significantly change these results
- No statistical association with changes in safety is found for median widths, inside Shoulder widths, horizontal and vertical curvature.

Several street patterns have different effect on traffic collisions. Popular road patterns such as warped parallel, loops and lollipops, lollipops on a stick, and mixed shapes are associated with fewer crashes than traditional gridiron pattern (*Rifaat et al., 2009*)

In *2004, Fahaut* studied about the effect of local environment and infrastructures on road unsafety. This study showed that lack of education and enforcement can play a substantial role in the co-occurrence of road crashes. The same results were also found by the study of *Benoit (2004)* that suggests infrastructure improvement. *Albalate et al., (2013)* studied about infrastructure spending versus regulation. It was found that impact of infrastructure spending is overestimated without the inclusion of regulatory variable.

Road infrastructures are always damaged and impaired. Increase runoffs, nutrient loading are one of the reasons. They need to be replaced or retrofitted as soon as possible. *Raje et al.,(2013)* examined the rainfall runoff loadings on infrastructure design. They demonstrated that the cost of redesign was comparable to conventional construction costs and also design options cost less per nutrient load treated than did conventional management practices.

In context of Bangladesh, *Haque (2006)* analyzed that the total reported accidents of nearly 39% occurred in national highways. Regional feeder highways and feeder roads have accounted for about 12% and 15% of accidents respectively. In another study, *Rab (2006*) found that about 60% fatal accidents in Bangladesh occur on national and regional highways and of the remaining 15% occur on the feeder roads, 7% on the rural roads and

19% on the city roads. The fatality rates are 48% pedestrians, 37% passengers and 15% are drivers.

2.4 Road Safety factor

In this factor the main focus is on the road users, the existing road structure (i.e Paved or unpaved), traffic and road characteristics. In a study of evaluating traffic safety based on micro level behavioral data indicates that the relationship between the road users and changing process during their collision course or leaving it *(Laureshyn et al., 2010*)

In a study from *Wang et al., (2013)* it is mentioned over more than 1.2 million people die worldwide as a result of road traffic crashes and 50 million are injured per annum. It is very important to understand the factors affecting on the crash occurrence in road safety research. Specific focus is given on traffic and road related factors mainly for accidents on major roads. Several factors most notably: speed, congestion, and road horizontal curvature were found to have mixed effects on road safety and need further examinations. This study also showed future research directions on the effect of factors are also developed most notably improving the quality of data, exploring the factors in developing counties and rural areas, and employing advanced statistical models, effect of speed and congestion on road accidents, whether curvature improves road safety, and the use of more sophisticated statistical models so as to better understand the effect of factors on road accident.

Planning and management of road safety is very important. *Linderman (2007),* studied the design of roads and road environment in Switzerland where it was shown that today's design of roads include a wide variety of safety and new planning and design principles have experienced lower speeds and greater recognition of the traffic activity on the sides. Road safety can be boosted for all road users. This article actually described the way in which the philosophy of planning has changed. *Gomes (2013),* mentioned that planning and management of urban road networks is very important. With detailed and accurate information on the factor affect accident occurrences. So it is necessary to allow explicit inclusion of road safety aspects in planning and road management.

2.5 Road Crash Factor

Hoque et al., (2003) found that in Bangladesh the principal contribution factors of accidents are adverse roadside environment, poor detailed design of junctions and road sections, excessive speeding, overloading, dangerous overtaking, reckless driving, carelessness of road users, failure to obey mandatory traffic regulations, variety of vehicle characteristics and defects in vehicles.

A study from this year, *Lee et al., (2015)* studied the effectiveness of changing lane width in reducing crashes on road way segments. From Generalized non-linear model they found that the crash rate highest for 12' lane and lower for lane width less than or greater than 12'.

In 2013, in 6 European countries the difference between single vehicle and multi vehicle crashes was investigated in a collection of fatal crashes. The most important variables to differentiate between single and multivehicle crashes were traffic flow, the presence of a junction and the presence of a physical division between carriageways. Some highlights are

1) Driver characteristics were not significant after correcting for road conditions.
2) Time variables were not significant after correcting for road conditions

Crashes of impaired drivers with more passengers were more likely to be single vehicle crashes than those of other drivers. (*Martensen & Duporit , 2013*)
In a study of combined frequency severity approach for the analysis of rear end crashes on urban arterials by *Das & Mohammad in 2011* it was found that higher Average Daily Traffic (ADT) is more likely to result in more crashes and absence of on-street parking may result in diminished severity of injuries resulting from crashes as they may provide "soft" crash barrier in contrast to fixed road side objects.

In Netherland, *(Petegam et al., 2014*) a crash prediction model was developed for road design risk factor for runoff road crashes. Crash prediction model estimates the relative safety of rural roads with a speed limit 80km/hr. A small set of estimated effects of traffic volume and road characteristics on runoff road crashes. A strong curvature was found to increase the risk on run off road crash by factor 3

From the study of *Holridge et el., 2005*, they studied the crash severity impacts of fixed road side. This study analyzed the performance of roadside objects by developing multivariate statistical models of injury severity in fixed objects crashes using discrete outcome theory. The result showed Leading ends of the guardrails and bridge rails along with wooden poles increase the probability of fatal injury. The face of guardrails is associated with a reduction in the probability of evident injury

In Dhaka city, children less than 15 years of age should take into greater consideration as they are victims of more than 16% of fatalities *(Alam et al., 2006)*. From the last 10 years of data most accidents occurred in the year of 2007 and number is 3949 (ARI report 2012). *Hoque* found that, pedestrians alone are involved in more than 47% of road accidents and 49% of all fatalities in Bangladesh. In Bangladesh one of the main causes of accident is aggressive speed. Speed Differentials and excessive speed pose a safety hazards. In Bangladesh, district wise study of different factors affecting individual crashes is not studied rigorously in the past. *Rifaat et al., (2014),* studied the effect of road infrastructures, socio economic and demography factors considering district level data. However, they have considered only all crashes ignoring the severity level of different crashes. Moreover, the factors related to weather condition have not yet been explored in that particular study.

2.6 Socio-economic and Demographic Factor

As we stated earlier economic growth is greatly reduced for accident crashes in Bangladesh. In *2005, Kopits & Cropper* examined the relationship between traffic fatality and per capita income and uses it to forecast traffic fatalities by geographic regions. Traffic failure projection fatalities suggest that the global road death toll will grow up by approximately 66% over next 20 years. It reflects divergent rates of change in different parts of the world: a decline in fatalities in high income countries of approximately 28% versus an increase in fatalities of almost 92% in China and 147% in India. Road death is projected approximately 2 per 10000 persons in developing countries by 2020 while it will fall 1 per 10000 in high income countries.

Traynor, (2008) also estimated the correlation between per capita income and fatalities per VMT. They showed a non-linear correlation. Moreover, population density, severe alcohol abuse, presence of interstate highways all correlates significantly with fatality rates. Also *Benoit, (2004)* found that the demographic changes in age cohorts, increase seat belt use, reduced alcohol consumption and increases in medical technology reduce the effect of fatalities.

From the study *of Rifaat et al., (2014)* we can observe socio economic and demographical effect on crashes in Bangladesh. They observed that increase in household population results increasing accident number and also male population decreases the crash number and female population shows vice versa. But this situation may change with the change of economic condition.

2.7 Weather Factor and Accident

Weather is an important factor effecting on accidents. In 2014 a review of the effect of traffic and weather characteristics on road safety was studied. This study identifies the gaps and discusses the needs for further research. Traffic flow seems to have a linear relationship with accident rates, even though some studies suggest linear relationship with accidents.

In 2010, Camacho et al. analyzed weather effect on free flow speed. This results showed that rain and snow both caused a reduction in speed and in 2011, *Asamer and Zuylen* investigated that saturation flow rate is significantly influenced by various weather conditions.

From the research of *Hayat et al., 2013* highlights the link between weather conditions and road accident risk at an aggregate level for France, the Netherlands and Athens region and on a monthly basis. Both averages and extreme weather effects on monthly number of accidents were estimated for France, the Netherlands and the Athens region for years of more than 20.

Thefilatos & Yannism, (2014) showed that precipitation increases the crash frequency but not very consistent. But this study did not find any straight forward impact of visibility, wind and temperature on road safety.

Basyouny et al., (2014) investigated the weather states on crash severity by full Bayesian multivariate safety models. For crash type, adverse weather conditions were associated with the increase of 9% to 73.7% for all crash types, with the highest increase for run off the road crashes. Sudden weather changes of major snow or rain were statistically significant and positively related with all crash types.

Anowar et al., (2014) investigated that fair weather, rainy, foggy and windy conditions were associated with increased intersection crash severity in Bangladesh.

2.8 Crash Models

Thakali et al., (2009) described that there are four conventional methods for crash model. Each type of model selection depends on the researcher own interest, real life situations and the research problems. The models are

* Descriptive model

* Risk model

* Accident consequence model

* Predictive/analytical method.

The predictive and analytical method is used to identify the relationship between the independent variables that causes the accidents and dependent variable. The formulation of accident prediction model has been adopted by many researchers (*Fridstrom et al., 1995; Greibe, 2003; Eisenberg, 2004; Caliendo et at., 2007).*

The popular accident prediction models developed in different parts of the world are mainly by four different approaches: multivariate analysis, Empirical Bayes, fuzzy logic and Artificial Neural Network (ANN) method (*Caliendo et al., 2007*). Mostly used method is multivariate analysis. Empirical Bayes theory needs a huge data whereas fuzzy logic and ANN is time consuming and complicated.

Chung, (2005) discovered that Generalized Linear Models is widely used, is that elements effecting accident are categorized data. Moreover, because accidents are discrete essentially, expressions of difference about accident reaction is most efficient in expressed data system by categorize style. And this method makes it possible to test significance of categorized data as fixed quantity.

The unsatisfactory property of linear regression models has led to the investigation of Poisson model. Poisson or Negative Binomial (NB) regression models, instead, are better suited for defining the random, discrete, and nonnegative nature of crash occurrence (*Milton & Mannering, 1998)*

In this study, two main factors used in the development of accident prediction model are based on Traffic data and geometric data. The selection of highway section for the accident prediction model development in this study was based on the section with most completed data or with a large number of AADT counting stations so that the most reliable model can be developed. But the problem with AADT data is its coverage issue *(Thakali et al., 2009*)

Chapter 3
Data and Methodology

3.1 Introduction

In this chapter, discussion about data collection and methodology adopted for the crash frequency analysis has been introduced. The sources of data used for this study are described first and then the mathematical formulation of the selected statistical models is discussed. The key steps in the methodology are followed by the theoretical framework of several crash occurrence models, such as Multiple Linear Regression (MLR), Poisson Regression Model and Negative Binomial Regression (NB) model, used in this study. The development of these models will assist us to understand how these models can be used to fulfill the objectives of the study; i.e. effects of various road infrastructures, various categories of road lengths, socio-economic and demographic factors and weather factors on different crash occurrence. However, these models need to be calibrated with a reliable and representative dataset. The overall workflow of the methodology is given in figure 3.1

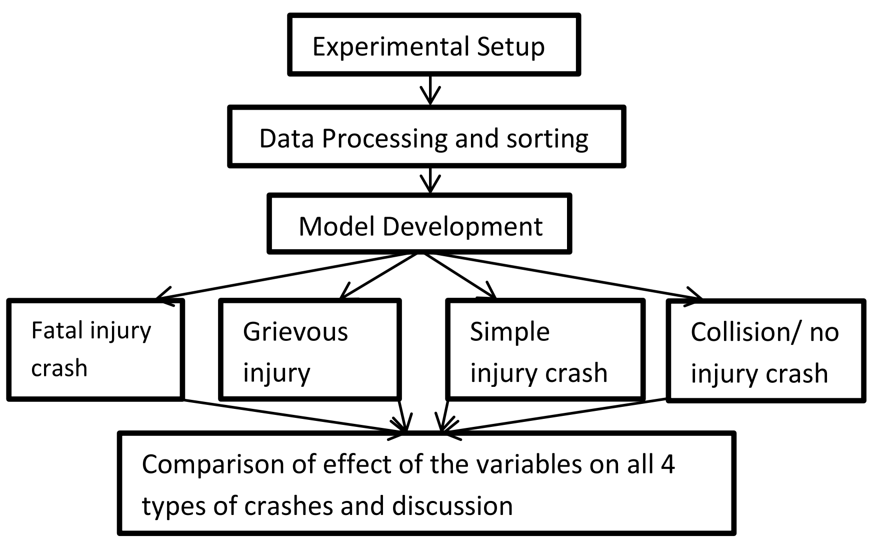

Figure 3.1: Flowchart of the Methodology

3.2 Data Collection

We have collected several dataset of road infrastructures and road lengths, socio-economic and demographic factors and weather factors from different data sources. Procedure is discussed below

3.2.1 Different types of Road Infrastructures

From the online official database of Roads and Highways Department (RHD) of Bangladesh, we have collected 13 types of road infrastructures constructed in Bangladesh. These are box culvert, slab culvert, RCC girder bridge, pc girder bridge, RCC bridge, arch masonry, truss with steel deck, truss with RCC slab, truss with timber deck, baily with steel deck, baily with timber deck, steel beam and RCC slab and pc box. RHD does not survey pipe culvert. Also, lengths of national highways, regional highways, zilla roads, roads that are not surveyed have been collected.

3.2.2 Different types of highways and roads length

From Local Government Engineering Department (LGED), Bangladesh, we have collected length of earthen roads, highways constructed with flexible and rigid pavements, existing gap number and span and lastly, number of structures and span. From LGED online database, we have collected and sorted all these datasets.

3.2.3 Socio-economic and demographic factors

From the statistical year book-2012 of Bangladesh Bureau of Statistics (BBS), we have collected the data of general household, institutional household, other types of household, number of male and female, male-female ratio and literacy rate

3.2.4 Weather factors

Bangladesh Meteorological Department (BMD) provided us with rainfall, fog and average temperature (maximum and minimum) data from the year 2009 to 2013.

3.2.5 District wise number of crash occurrence data

Fatal, grievous, simple and collision are the four types of crashes occurred every year in Bangladesh. From Accident Research Institute (ARI), we have collected this individual crash data from the year 2009 to 2013 respectively to relate with predictors.

3.3 Statistical Models for Crash Frequency Analysis

Statistical modeling is used to develop crash prediction models. It relates several crash occurrences as response variable with various factors like road infrastructures, its geometrical characteristics, various socio economic and demographic effects. We can actually use these models to estimate road safety andto identify the hazardous locations.

The principal objective of a statistical model is to identify a probabilistic system in the form of

$$y = f(x)$$

Where, the dependent variable y is a function of a set of independent variables x. The regression analysis of the above mentioned form examines:

- Whether the observed patterns in the data are consistent with theoretical prediction
- The relationship of a quantitative variable with one or more qualitative or quantitative independent variables.

In many accident frequency studies, the dependent variable y represents total number of annual traffic crashes as a count result and independent variables x represent the associated roadway infrastructures, geometries, traffic and regulatory controls and other relevant characteristics. The theoretical effect of x on y is called systematic effect *(Winkelmann, 1997).* Traffic planners and researchers are mainly interested with the systematic variations as it can be affected by changes in geometry and other road features. The other component, called random variation disturbs the identification of the systematic variation. It is the coexistence of the systematic and random effects that is addressed by statistical regression models.

This section gives a detail description of the statistical models which will be used for crash frequency analysis, their mathematical formation, assumptions and limitations of various models. These models include Multiple Linear Regression model (MLR), Poisson regression and Negative binomial regression models. A detail description of model evaluation that includes various tests and goodness of fit will then be discussed. Finally, a method to find the elasticity of independent variables will be described.

3.3.1 Multiple Linear Regression Model

The most widely used regression model to analyze crash frequency data is the multiple linear regression model *(Hakim, 1984)* which is given by

$$y = \boldsymbol{X\beta} + \varepsilon$$

Where, y is the number of crashes

$\boldsymbol{X}$ is a vector of explanatory variables

$\boldsymbol{\beta}$ is a vector of parameters to be estimated

ε is the error term

The assumptions of the ordinary least square (OLS) model are :

a) Expectations of the error term is zero
b) Homoscedasticity: variance of the errors is the same regardless of the value of $\boldsymbol{x}$
c) Normality : the error term is normally distributed
d) Independence : the observations are free form autocorrelation

If the assumptions are valid, then the OLS estimator is the best linear unbiased estimator However, since accident data are usually random, discrete, nonnegative, and count data, there are lots of undesirable properties in MLR such as assumption of normality and common variance and also the possibility of negative outcomes that results misinterpretation of count data *(Jovanis and Chang, 1986)*. To overcome the problems associated with MLR models, *Jovanis and Chang (1986)* proposed that the Poisson regression should be used instead for developing crash frequencies.

3.3.2 The Poisson Regression Model

The relationship between highway geometric factors and accidents and all of them came to the conclusion that Poisson regression model is superior to MLR to describe discrete, random, nonnegative data *(Joshua and Garber, 1990; Miaou et al., 1992; Miaou and Lum, 1993)*

The basic assumptions of Poisson distribution are:

a) Probability of more than one event occurring in a short period of time is zero
b) Probability of one count in a subinterval is the same for all subintervals and proportional to the length of the subinterval and
c) Count in each subinterval is independent of other subintervals.

If event n occurs according to a Poisson process with parameter μ, then the Poisson distribution can be written as:

$$\Pr(n_{it} \mid \mu_{it}) = \frac{e^{-it} \mu^{n_{it}}}{n_{it}!}$$

Where, $\Pr(n_{it})$ is the probability of n crashes occurring on roadway section i in time t

μ_{it} is the expected number of crashes on roadway section i in time t

The Poisson distribution has the limitation that the variance and mean should be approximately equal i.e.

$$Var(n_{it}) = E(n_{it}) = \mu_{it}$$

In the case of accident frequencies, the variance is generally much larger than the mean (over dispersion) at which point the Poisson model becomes inappropriate.

3.3.3 Negative Binomial Model

It has been observed that accident frequency data tend to be over dispersed i.e. the variance is significantly greater than the mean (*Shankar et al., 1995; Poch and Mannering, 1996)*. Consequently, the choice of Poisson distribution model can lead to erroneous coefficient estimate and wrong inference. To overcome this problem, negative binomial distribution, which includes a gamma-distributed error term in the parent Poisson model, was developed. This relaxes the Poisson's mean variance equality constraint and takes the unobserved heterogeneity into account.

The negative binomial model is derived by rewriting equation as:

$$\ln \mu_{it} = \boldsymbol{\beta}\mathbf{X_{it}} + \varepsilon_{it}$$

Where, $e^{\varepsilon_{it}}$ is a gamma-distributed error term with a mean one and variance k.

The resulting probability distribution under the negative binomial assumption is:

$$Pr(n_{it}|\mu_{it}, k) = \frac{\Gamma(n_{it} + 1/k)}{\Gamma(1/k)} \frac{1}{n_{it}} \left(\frac{k\mu_{it}}{1 + k\mu_{it}}\right)^{n_{it}} \left(\frac{1}{1 + k\mu_{it}}\right)^{1/k}$$

In which k≥0 is often referred to as over-dispersion parameter. If k reduces to zero, then the NB model reduces to the Poisson regression model. In this way, the Poisson regression model is nested within the NB and a t-test for k = 0 can be used to evaluate the significant presence of over-dispersion in the data.

In the negative binomial model, it is assumed that unconditional mean μ_{it} is independently distributed over time. For this specification, the mean and variance will respectively be:

$$E(n_{it} \mid \mu_{it}, k) = \mu_{it}$$

$$Var(n_{it} \mid \mu_{it}, k) = \mu_{it}(1 + k\mu_{it})$$

The mean variance relationship of the distribution is given by

$$Var(n_{it} \mid \mu_{it}, k) = E(n_{it})[(1 + kE(n_{it})]$$

Estimation of μ_{it} can be obtained through standard maximum likelihood as mentioned in the previous section and is given by

$$L(\mu_{it}) = \prod_{i=1}^{N}\prod_{t=1}^{T} \frac{\Gamma(n_{it}+1/k)}{\Gamma(1/k)} \frac{1}{n_{it}} \left(\frac{k\mu_{it}}{1+k\mu_{it}}\right)^{n_{it}} \left(\frac{1}{1+k\mu_{it}}\right)^{1/k}$$

This function is maximized to obtain coefficient estimates for **β** and k. Several researchers have employed this negative binomial (NB) distribution and they have proved that NB model is better than Poisson model to analyze crash data *(Miaou, 1994; Kulmala, 1995; Shankar et al., 1995; Poch and Mannering, 1996; Abdel-Aty and Radwan,2000)*

3.3.4 Model Evaluation

Statistical models will be evaluated to select the best model from the competitive set of models. The evaluation will be done by

1) Likelihood Ratio Test
2) Log-likelihood Ratio Test (ρ)

Likelihood ratio test is a common test used to assess two competing models. It provides evidence in support of one model, usually a full or complete model, over another competing model that is restricted by having a reduced number of model parameters.

The models are also tested for an overall goodness of fit with the help of log likelihood ratio index. Finally, the elasticity values are calculated for the final model to find the relative effects of different independent variables. These are described in detail in the following.

3.3.4.1 Likelihood Ratio Test

The likelihood ratio test statistic is

$$X^2 = -2[LL(\boldsymbol{\beta}_R) - LL(\boldsymbol{\beta}_U)]$$

where, $LL(\boldsymbol{\beta}_R)$ is the log likelihood at converges of the 'restricted' model

$LL(\boldsymbol{\beta}_U)$ is the log likelihood at converges of the unrestricted model

The test static is χ^2 distributed with the degrees of freedom equal to the difference in to the numbers of parameters in the restricted and unrestricted model.

3.3.4.2 Log-likelihood ratio index

To measure the overall goodness of the models, the log likelihood ratio index will be calculated. The R^2 as a goodness of fit measures for OLS estimator has been used by traffic safety engineers and researchers for many years. However, since count data models are non-linear, there is no R^2. Instead, the common practice is to use a 'pseudo' R^2 statistic, which is often known as log-likelihood ratio index (Ben-Akiva and Lerman, 1985) which is given by

$$\rho^2 = 1 - \frac{L(\boldsymbol{\beta})}{L(0)}$$

Where, $L(\boldsymbol{\beta})$ is the log likelihood value of the fitted model

$L(0)$ is log likelihood value of the model only with constant term.

Everything else being equal, a specification with a higher maximum value of log likelihood function is considered to be better. The lowest value of log likelihood function corresponds to the model with constant term only and is considered as worse case. The value of ρ^2 is between 0 and 1, the better models approaching the latter. Like the R^2

statistics, it has the undesirable characteristic that for same data set, it will increase whenever new variables are added to the model. To overcome this disadvantage Ben-Akiva and Lerman (1985) incorporated a correction for the number of covariates, p, to give the adjusted log likelihood ratio index as in the following equation

$$\bar{\rho}^2 = 1 - \frac{\mathrm{L}(\boldsymbol{\beta}) - \mathrm{p}}{L(0)}$$

3.3.5 Elasticity of the Variables

In order to check the relative significance of independent variables from the final model, the elasticity of the variables was calculated. Elasticity is defined as the percent change in dependent variable due to one percent change in the independent variable. The elasticity of crash frequency μ_{it} with respect to x_{itk} is defined as:

$$E_{x_{itk}}^{\mu_{it}} = \frac{\partial \mu_{it}}{\mu_{it}} \times \frac{x_{itk}}{\partial x_{itk}}$$

where, x_{itk} is the kth independent variable for section i in year t.

Using this equation, the sensitivity of crash occurrence to any variable can be obtained. With the increase in elasticity value the sensitivity of crash occurrence to a change in the specific variable also increases. The elasticity in Equation is only appropriate for continuous variables. It is not valid for non-continuous variables such as indicators variables that take on values of 0 or 1. For an indicator variable, pseudo-elasticity is computed to estimate an approximate elasticity of the variables. The pseudo-elasticity gives the incremental change in frequency caused by a discrete (0-1) change in the indicator variables. The pseudo-elasticity for indicator variable is computed as

$$E_{x_{itk}}^{\mu_{it}} = \frac{e^{\beta} - 1}{e^{\beta}}$$

Chapter Four

Crash Frequency Analysis

4.1 Introduction

In this chapter, discussion will be limited to describe several crash occurrence models with all independent variables or predictors that have significant effect on these crashes. In Bangladesh, four types of crashes occur every year according to Accident Research Institute (ARI) report (1998-2013). They have classified these crashes based on their severity i.e. Fatal injury crash, Grievous injury crash, Simple injury crash and Collision or no damage or property damage crash. In our study, these crashes have been taken as dependent or response variable. Then, district wise road infrastructure (type wise) length, several type road lengths, socio-economic and demographic factors and various weather factors have been taken as independent variables. And therefore, a model has been run for every individual crashes to see the effect of included independent variables on the response variable.

4.2 Dependent and Independent Variables

From the ARI report (1998-2013), four different crashes i.e. Fatal crash, Grievous crash, Simple crash and Collision are taken as dependent variables. For our model, crash data is taken from the year 2009-2013. From the year 2009 to 2013, total 8,578 fatal, 1,692 grievous, 286 simple and 326 collision type crashes occurred in the overall Bangladesh. Fatal crash indicates death occurrence, grievous crash means serious injury occurrence, simple crash is slight injury occurred and lastly, collision points to accident occurs but no injury found.

In Bangladesh, according to the Roads and Highway Department, Bangladesh, there are 13 types of infrastructure constructed in Bangladesh till now. Names and numbers of these structures are given in the following table:

Table 4.1: Type wise Road infrastructures and their numbers

Name of the Road Infrastructures	Number (overall count in Bangladesh)
Box Culvert	9441
Slab Culvert	3991
RCC Girder Bridge	2387
PC Girder Bridge	405
RCC Bridge	244
Arch Masonry	318
Truss with Steel Deck	204
Truss with RCC Slab	30
Truss with Timber Deck	6
Baily with Steel Deck	973
Baily with Timber Deck	23
Steel Beam and RCC Slab	230
PC Box	5

Courtesy: Roads and Highway Department, Bangladesh Database (www.rhd.gov.bd/BridgeDatabase/Default.asp)

Roads and Highway Department, Bangladesh arranges these road infrastructures national wise, regional wise and zilla wise. Conditions of these road structures are stated below:

Table 4.2: Conditions of the road infrastructures

	Condition			
Road Classification	**A**	**B**	**C**	**D**
National Highway	2932	661	644	108

Regional Highway	2264	661	969	224
Zilla Road	8337	1611	2317	764

A = No Damage, B = Minor Damage, C = Major Elemental Damage, D = Major Structural Damage

Courtesy: Roads and Highway Department, Bangladesh Database (www.rhd.gov.bd/BridgeDatabase/bridgebyconditions.asp)

From Road and Highways Department, Bangladesh, the total length of district wise national, regional, Zilla road, Upazilla road & Union road with paved & unpaved length for each of the classification were acquired.

Length of the Flexible pavement, rigid pavement, brick pavement, earthen road length data were found from the Local Government Engineering Department (LGED). All of these data were divided in Upazila road, Union road, Village road A and Village road B. A table is given below comparing Earthen and pavement roads

Table 4.3: Earthen and Pavement Roads

Road Type	Earthen (km)	Pavement (km)
Upazila Road	6585.81	29797.33
Union Road	19981.70	22478.31
Village Road A	100645.49	8736.13
Village Road B	86117.94	22291.41

Courtesy: Local Government Engineering Department (LGED), (www.lged.gov.bd/ViewRoad2.aspx)

District wise Socio-economic and demographic factors have been taken from Bangladesh Bureau of Statistics (BBS) Year Book, 2012. The variables included are General Households, Institutional Households, Other type of Households, Number of Male and Female , Both sex, Size of the households, Sex ratio (M/F) and Literacy rate (7 years +).

Weather factor is also considered as every year a considerable number of crashes occur due to adverse weather condition. A statistics regarding this is shown in Chapter 1, Table 1.4. Bangladesh Meteorological Department (BMD) provided the data of Fog, Rainfall, Maximum temperature and Minimum temperature, Wind intensity and its direction. In our study, Fog, Rainfall, maximum temperature and Minimum temperature are taken as a predictor. Data is taken in the year range of 2009 – 2013.

4.3 Study area

The study area covers the entire Bangladesh. All the 64 districts have been considered. All the road bridges, culverts, road lengths, socio economic demographic factors, weather conditions i.e. rainfall, fog and temperature have been taken as a unit of district wise. All the data that we have extracted and sorted covered all the districts. Figure 4.1 shows the entire Bangladesh road network.

Figure 4.1: Road Network of Bangladesh

4.4 Development of Crash Occurrence Model

As we stated earlier, four types of crashes have been considered so four crash models will be developed individually. Total 104 independent variables are taken as a predictor of these models among which district wise road infrastructures and type wise road lengths comprise 75 variables, nine socio-economic and demographic variables and 20 weather variables have been considered.

4.4.1 Fatal Crash Occurrence Model

Reported road crash data from 2009-2013 are used in this study. During this period total 10,882 crashes occurred of which 8578 crashes were fatal. During this period about 78.8% crashes were classified as fatal, 15.6% were as serious or grievous, 2.6% as slight injury or simple crash and 3% as collision or no injury.

Total 104 independent variables are defined for further investigation. During the model calibration, first importance is importance to road infrastructures then socioeconomic and demographic factor and lastly weather factor. Some factors and variables were excluded because they were found statistically insignificant. These include literacy rate, institutional households, fog problems, rigid pavement road length etc. At last 23 variables are found in the final model and these are shown in table 4.4 together with their mean and standard deviation. All most all of these variables are continuous in nature.

Results from the calibrated model are shown in table 4.5. Based on P-value of t-test, 23 variables are found significant i.e. p value < 0.1.That means confidence interval is 90% and significance level is 10%. From the study of *Kockelman and Kweon (2002)*, low statistically significant variables can be retained in the model, if they have important effects on the crash severity.

Table 4.4: Explanatory variables used in Fatal crash occurrence model

Explanatory variables	Mean	Standard Deviation
Road Infrastructures length in meter (By type)		
National Highway		
Box culvert	225.70	257.56
RCC	24.60	78.87
Steel beam & RCC slab	55.03	133.07
Regional Highway		
PC girder	241.45	478.29
RCC girder	312.12	356.954
Steel beam & RCC slab	18.48	76.07
Zilla Road		
Arch masonry	5.86	10.86
PC Box	4.91	39.25
PC girder	368.16	603.26
Truss with RCC slab	22.76	108.59
Road length in kilometer		
National Highway	55.92	51.02
Zilla Road	209.724	104.926
Length of village road B	1774.18	966.87
Union road length (Surface type wise)		
Flexible Pavement	300.02	172.18
Rigid Pavement	12.11	32.20
Structure number		
Union	1013	656
Existing gap		
Upazilla	55.92	86.37
Village road A	438.31	391.39
Village road B	547.77	541.39

Socio-economic and Demographic Factors		
General Household	486990	367809
Female	1654866	4648487
Sex-ratio	112.84	112.00
Weather		
Rainfall (mm)	2016.33	590.01

Table 4.5 Parameter estimation of Fatal Crash occurrence model

Number of Observation	41	**LR χ^2 (23)**	125.41	**Log likelihood at convergence**	-163.14454
Dispersion	mean	**Prob> χ^2**	0.000	**Log likelihood at constant**	-225.89847
Log likelihood	-163.14454	**Pseudo R^2**	0.2778		

Variables	**Estimated Co-efficient (β)**	**Standard error**	**t-statistics**	**P- value**
Road Infrastructures length in meter (By type)				
National Highway				
Box culvert	0.0005754	0.000094	6.12	0.000
RCC bridge	0.0008818	0.0002193	4.02	0.000
Steel beam & RCC slab	-0.0009573	0.0002603	-3.68	0.000
Regional Highway				
PC girder	0.0002861	0.0000509	5.63	0.000

RCC girder	0.0002666	0.0000942	2.83	0.005
Steel beam & RCC slab	0.000594	0.0002711	2.19	0.028
Zilla Road				
Arch masonry	0.0056296	0.00258	2.18	0.029
PC Box	-0.0022462	0.0006645	-3.38	0.001
PC girder	0.0002063	0.0000424	4.87	0.000
Truss with RCC slab	-0.0009196	0.0002492	-3.69	0.000
Road length in km				
National Highway	0.0059087	0.0006611	8.94	0.000
Zilla Road	-0.0014489	0.0003793	-3.82	0.000
Length of village road B	-0.0000845	0.0000404	-2.09	0.037
Union road length (Surface type wise),km				
Flexible pavement	0.0006201	0.0002148	2.89	0.004
Rigid pavement	0.0056234	0.0008138	5.68	0.000
Structure number				
Union	0.0001951	0.0000627	3.11	0.002
Existing gap number				
Upazilla	-0.0018832	0.0003748	-5.02	0.000
Village road A	-0.0007064	0.0001645	-4.29	0.000
Village road B	0.0008954	0.0001128	7.94	0.000
Socioeconomic and demographic characteristics				
General Household	1.53e-07	6.83e-08	2.25	0.025
Female	-2.49e-08	7.27e-09	-3.43	0.001
Sex ratio (M/F)	0.0005374	0.0001845	2.91	0.004
Weather				
Rainfall	-0.0001285	0.0000555	-2.32	0.021

4.4.1.1 Model Evaluation:

We have used STATA statistical software to evaluate our model. For fatal crash, it is meanly dispersed. Log-likelihood is -163.14454. It is used in the LR chi square test of whether all variables' regression coefficients are simultaneously zero or not. LR is the test statistic that all regression coefficient are simultaneously equal to zero. It is calculated as negative two times of the difference of the likelihood for the null model and fitted model from the iteration log of the STATA software we actually can find it. In our model it is -2[-163.14454-(-225.89847)] = -125.51. Pseudo R^2 is used to evaluate the overall model goodness-of-fit. In our model it 0.2778 which means model is 27.78% fit. It can be calculated as 1- (-163.14454/-225.89847) = 0.2778.

4.4.1.2 Interpretation of significant variables

Negative binomial regression coefficients are used to interpret the results of our model. It can be done as follows: one unit change in the predictor variable, the difference in the logs of expected count of the response variable is expected to change by the respective regression coefficient given the other predictor variables in the model are held constant.

4.4.1.2.1 Road infrastructural variables

From the table 4.5, it is found that in the Box culvert (β=0.0005754, p=0.000) and RCC (β=0.0008818, p value = 0.000) type infrastructure in the National Highway, both have positive impact on the fatal crash. That means, if length of these two infrastructures increase, probably fatal crash will increase by 0.0005754 and 0.000818 unit respectively. Between these two, RCC Bridge is 35% more vulnerable than Box culvert. Fatal crash may occur because of damage of the structure or it may need retrofitting. Cross section of the bridges is very important. If carriageway and shoulder kept narrow, it is dangerous on national highway where high speed often occurs.

On the other hand, Steel beam and RCC slab (SBRS) (β= -0.0009573, p=0.000) made infrastructure has opposite impact i.e. if length of SBRS made structure is increased then fatal crash possibly decrease. This may occur perhaps the strength of SBRS made structure is more enough than RCC bridge or Box culvert. Its strength deterioration due to creep or shrinkage may be low and importantly lane width probably more enough to pass heavy vehicles. From the study of *Noland & Oh (2004)* and *Lee et al., (2015)* it was reported that with the increase of the lane width crash occurrence increases. But in Bangladesh, there is no concrete highway manual, no speed limit signs and also drivers do not follow rules specially bus and truck drivers. If lane width increases they might feel free to drive specially in the national highway.

In the regional highway if PC girder (β=0.0002861, p=0.000) and RCC girder made structure (β=0.0002666, p=0.005) increase, fatal crash possibly increase. If footways are not provided on this type of structures with parapets, relative volume of pedestrians and not motorized vehicles are not predicted properly then hit pedestrian type crashes probably occur. PC girder is at high risk than RCC girder bridge. Interestingly, SBRS (β=0.000594, p=0.028) made structure has positive impact on fatal crash that means, fatal crash may increase if the length of the SBRS made structure increases. It is complete opposite scenario that of national highway for SBRS. Perhaps, while planning for traffic systems, regional highway is given less importance than national highway.

In context to zilla road, with the increase of Arch masonry (β=0.0056296, p=0.029) and PC girder (β=0.0002063, p=0.000), crash occurrence likely to be increased. Here, the fatal crash occurrence drops by about 28% for zilla road than regional highway for PC girder. This indicates to the safety improvement in the zilla road rather than regional.

On the other hand, Truss with RCC Slab (TRS) (β= -0.0009196, p=0.000) and PC box (β= -0.0022462, p=0.0010) type structures have negative impact on fatal crash. With the increase of these structures' length, fatal crash may decrease. This indicates that the roadside condition may be satisfactory, drivers are more conscious while driving in the zilla roads.

In the national highway (β=0.0059087, p=0.000), fatal crash likely to be increased. This result remains consistent with the study of Haque (2006) and Rab (2006). They also studied that most of the crash occur in the national highways. Because, drivers may not more attentive and conscious with their safety while driving in the national highway. Also, as it is in national highway so drivers feel free to speed up their vehicle or their unnecessary overtaking may probably increase the crash occurrence. Sometimes, it is found open air markets beside the national highway. So, pedestrians may also at risk of fatal crash caused by heavy high speed bus or trucks. This may also occur if there is no speed breakers provided in the upstream side and downstream side of highway at the place of open air market. Moreover, in the national highway, there are many paved sections where probability of crash occurrence is very high. So, fatal crash severity increases in the national highway. To reduce it, message signs may be provided in the highways. On the contrary, in the zilla road (β= -0.0014489, p=0.000) and village road (β= -0.0000845, p=0.037), fatal injury crash possibly decrease. Zilla roads and village roads may be given less importance compare to national highways. So, drivers give more attention and more conscious while driving in these roads. Also, road side signs, poles, bridge abutment, trees may not interfere with sight distance on curves .

With the increase of flexible (β=0.0006201, p=0.004) and rigid (β=0.0056234, p=0.000) pavement, crash occurrence probably increase. If proper maintenance and reconstruction of the road is not introduced regularly, if good quality materials and also traffic forecasting that means number of equivalent standard axle (ESA) is not planned properly then deterioration of the respective pavements will gradually increase and thus, fatal crash occurrence possibly increase. Carpeting, overlaying, complete reconstruction may not be maintained and expected life expectancy may not be properly calculated. Union based roads are not designed with great care in Bangladesh. So, this may be one of the reasons to possible increase of the fatal crash.

With the increase of number of structures in the union zone (β= 0.0001951, p=0.002) and increase of existing gap number (β=0.00089574, p=0.000) in the village road B, fatal crash occurrence may increase. And, with the increase of existing gap number of the structures in the upazilla road and village road A, crash occurrence likely to be decreased by 0.0018832 and 0.0007064 respectively. From the study of *Rifaat et al., 2014*, the same result was found that existing gaps decrease the traffic volume by providing alternative transportation route and mode such as ferries and by minimizing traffic exposure these gaps may reduce the road crashes.

4.4.1.2.2 Socioeconomic and Demographic Characteristics

With the increase of the general households (β=1.53e-07, p=0.025), fatal crash occurrence may increase. The same result was found from the study of *Rifaat et al., (2014.)* With the increase of number of female (β=-2.49e-08, p=0.001), fatal crash occurrence tends to be decreased as female are likely to be more conscious to the surrounding environment while driving than male. With the increase of sex ratio (M/F) (β=0.0005374, p=0.004), crash occurrence tends to be increased. Actually, male has more risk taking behavior compare to the female.

4.4.1.2.3 Weather Factor

With increase of rainfall (β= -0.0001285, p=0.021), Fatal crash occurrence likely to be decreased by 0.0001285 factor. It occurs probably due to driver becomes so conscious about their driving when it is raining. They may be conscious while driving and deprived of increasing running speed.

4.4.2 Grievous Crash Model

Grievous crash indicates serious injury crashes. During the period of 2009-2013, 15.6% crashes were Grievous type crash in Bangladesh. Grievous injury crash is actually serious injury type crash.

Table 4.6: Explanatory variable used in Grievous crash occurrence model

Explanatory variables	Mean	Standard Deviation
Road Infrastructures length		
National Highway		
Box culvert (m)	225.7	257.6
RCC bridge (m)	24.6	78.9
PC girder bridge (m)	546.8	1009.6
Regional Highway		
RCC girder bridge (m)	312.12	357
Zilla Road		
Steel beam & RCC slab (m)	49.3	119.8
Highway length		
Not surveyed (km)	22.71	31.33
Upazilla		
Pavement brick (km)	22.67	27.35
Union		
Pavement brick (km)	49.8	68.9
Structure span		
Village road A (m)	5776.08	3783.94
Socio economic & Demographic characteristics		
Other Household	4336	17577
Weather		
Average minimum temperature (°C)		
Year 2009	21.63	1.32
Year 2012	21.4	1.35

Table 4.7: Parameter estimation of Grievous crash occurrence model

Number of Observation	60	**LR χ^2 (12)**	45.58	**Log likelihood at convergence**	-200.30412
Dispersion	mean	**Prob> χ^2**	0.000	**Log likelihood at constants**	-223.09391
Log likelihood	-200.30412	**Pseudo R^2**	0.1022		

Explanatory variables	**Estimated Co-efficient (β)**	**Standard error**	**t-statistics**	**P-value**
Road Infrastructures length				
National Highway				
Box culvert (m)	0.0010808	0.000266	4.06	0.000
RCC bridge (m)	0.0011064	0.0006498	1.70	0.089
PC girder bridge (m)	-0.0001542	0.0000749	-2.06	0.040
Regional Highway				
RCC girder bridge (m)	0.0003659	0.0001632	2.24	0.025
Zilla Road				
Steel beam & RCC slab (m)	-0.0014561	0.0007263	-2.00	0.045
Highway length				
Not surveyed (km)	0.0037407	0.0022981	1.63	0.104
Upazilla				
Pavement brick (km)	0.004075	0.002397	1.70	0.089
Union				
Pavement brick (km)	-0.0025885	0.0011066	-2.34	0.019
Structure span				
Village road A (m)	0.000611	0.0000184	3.31	0.001

Socio economic & Demographic characteristics				
Other Household	-0.0000109	4.41e-06	-2.48	0.013
Weather				
Average minimum temperature (°C)				
Year 2009	-.7897977	.3639024	-2.17	0.030
Year 2012	.8821347	.3520592	2.51	0.012

4.4.2.1 Model Evaluation

To know the effect of the different independent variables on the Grievous crash occurred every year in Bangladesh, we ran a model in STATA software. For grievous crash, it is meanly dispersed. Log-likelihood is -200.30412. It is used in the LR chi square test of whether all variables' regression coefficients are simultaneously zero or not. *LR* is the test statistic that all regression coefficient are simultaneously equal to zero. It is calculated as negative two times of the difference of the likelihood for the null model and fitted model from the iteration log of the STATA software we actually can find it. In our model it is -2[-200.3014-(-223.09391)] = -45.58. Pseudo R^2 is used to evaluate the overall model goodness-of-fit. In our model it 0.1022 which means model is 10.23% of fitness. It can be calculated as 1- (-200.30412/-223.09391) = 0.1022.

4.4.2.2 Interpretation of Significant Variables

Negative binomial regression coefficients are used to interpret the results of our model. It can be done as follows: one unit change in the predictor variable, the difference in the logs of expected count of the response variable is expected to change by the respective regression coefficient given the other predictor variables in the model are held constant.

4.4.2.2.1 Road Infrastructure Factors

From the table 4.7, we have found only 9 infrastructural variables to be statistically significant in this model. Box culvert (β=0.0010808, p=0.000) is found adverse impact on the grievous crash. If its length increases than grievous crash may increase by 0.0010808 units. The same result was also found for the fatal crash also. But it is found more likely to occur grievous crash than fatal crash. Sometimes absence of solid medians, high speed of buses, pedestrian movements, infrastructure capacity tends to increase the serious injury crash. With the increase of the RCC bridge (β=0.0011064, p=0.089) length by one unit, crash occurrence likely to be increased. It is same for the fatal crash also. But it is more vulnerable for grievous crash. With the time being concrete strength reduces. Shrinkage, creep, fatigue loads reduces the concrete strength. Absence of any special features like bridge approach increased the probability of severe crash outcome, a result that was *Rifaat and Tay (2009)* because the presence of special road features might alert the drivers and induce them to reduce their speed and drive more carefully.

For PC girder bridge (β= -0.0001542, p=0.040), if its length increases, crash occurrence probably decreases. PC girder type bridges may work well on the national highways rather than regional and zilla roads as crash occurrence likely to be increased there.
In the regional zone, with the increase of the length of the RCC girder bridge (β=0.0003659, p=0.025), serious or grievous crash may be increased. Sometimes, driver cannot detect an unexpected conditions or it is difficult to perceive information source or condition in a regional roadway environment. In the zilla roads, Steel beam and RCC slab (SBRS) (β= -0.0014561, p=0.045) type infrastructures may be good in strength compared to the others as because with the increase of SBRS, probability of crash occurrence decreases.

From the data of Roads and Highway Department, Bangladesh, we have found that total 1453.71 km roads still are not properly surveyed in Bangladesh. No survey means no information about that road section. So, no information regarding a road system increases the probability of crash occurrence. In our study, not surveyed roads (β=0.0037407, p=0.10) are found positively significant. That means, if the amount of 'not surveyed road' increases, grievous crash occurrence also increases by a factor of 0.0037407.

Roads pavement made of bricks in the upazilla road are found positively significant i.e. β-0.004075, p=0.089; on the contrary in the union road, brick pavement type roads are found to be negatively significant with the value β= -0.0025885, p=0.019. That means, if more road pavements are made with brick at the upazilla sectors in Bangladesh then grievous crash occurrence would possibly increase, on the other hand, in the union sector crash occurrence will probably decrease. Bricks can be easily broken under traffic loads and also due to adverse weather condition. To interpret this result more effectively we need AADT data to identify in which area traffic load is more. It may help to interpret this situation. If structural span (β=0.000611, p=0.001) increases in the village roads, serious injury may occur. In the villages structural span may not be constructed properly or maintained properly so crash probably occur.

4.4.2.2.2 Socio-economic and Demographic Factors (Grievous crash)

Increase of the other household rather than general and institutional households (β= -0.0000109, p=0.013) may possibly decrease the crash occurrences where as general household number tends to increase the fatal crash. It indicates to that the other households that industrial areas are well traffic controlled and also drivers tend to obey the rules to avoid any type of crash. But *Rifaat et al, 2014* revealed that when general household size increases, crash occurrence likely to be decreased.

4.4.2.2.3 Weather Factors (Grievous crash)

If the minimum average temperature p=0.030 increases, the probability of crash occurrence decreases by -.7897977 unit in the model. This result is found for the year of 2009. But, in the year 2012, with the increase of average minimum temperature (β=

0.8821347, p=0.012), the model shows that crash occurrence increases. Comparing with the year 2009, in 2012 percentage of crash occurrence probably increases. Minimum temperature also indicates to the winter season. May be the during 2012, it might be foggy weather compare to 2009. So, crash occurrence increases. Also, drivers' comfortness in winter, vehicle speed, vehicle lighting system in the foggy weather directly effect on the crash occurrence.

4.4.3 Simple Crash Model

In the year duration from 2009 to 2013, only 2.6% crashes belong to simple or slight injury crash. In the model we have considered all five years crash to explore the effect of different variables.

Table 4.8: Explanatory variable used in Simple crash occurrence model

Explanatory variables	Mean	Standard Deviation
Road Infrastructures Length (m)		
National Highway		
RCC Bridge	24.59460317	78.8747086
Regional Highway		
Baily with Steel Deck	149.453125	272.254813
Zilla Road		
PC Girder Bridge	368.1573	3.7204
RCC Girder Bridge	908.4254688	643.3081319
Truss with RCC slab	22.7615625	108.5934297
Truss with steel deck	313.5459375	362.3697423
Road Length(km)		
National Highway	55.92203125	51.02040063
Union Road(km)		
Paved Road	12.10804878	32.19504568
Upazilla Road(km)		
Structure span	6274.946875	3444.355919

≤4000	0.265625	0.445156919
Weather		
Rainfall (mm)		
Year 2011	2161.28125	580.3734285
2013	2057.171875	696.5669684

Table 4.9: Parameter Estimation of Simple Crash Model

Number of Observation	41	**LR χ^2 (11)**	70.51	**Log likelihood at convergence**	-71.904972
Dispersion	mean	**Prob> χ^2**	0.000	**Log likelihood at constants**	-107.15767
Log likelihood	-71.904972	**Pseudo R^2**	0.3290		

Explanatory variables	Estimated Co-efficient (β)	Standard error	t-statistics	P- value
Road Infrastructures length(m)				
National Highway				
RCC Bridge National (m)	0.0041094	0.0008448	4.86	0.000
Regional Highway				
Baily with steel deck(m)	-0.0016141	0.000497	-3.25	0.001
Zilla road				
PC Girder Bridge(m)	0.0004727	0.0001786	2.65	0.008
RCC Girder Bridge(m)	-0.000584	0.0002357	-2.48	0.013
Truss with RCC slab(m)	-0.003945	0.0019535	-2.02	0.043
Truss with steel deck(m)	0.0007102	0.0002425	2.93	0.003
Road Length (km)				

National Highway(km)	0.0136347	0.0029051	5.09	0.000
Union road (km)				
Paved road(km)	0.0147939	0.0029051	5.09	0.000
Upazilla road				
Structure span(m)				
Structure span ≤ 4000 (m)	0.4212232	0.2601621	1.62	0.105
Weather				
Rainfall (2011) (mm)	-0.00010005	0.0002625	-3.81	0.000
Rainfall (2013) (mm)	0.0005716	0.0002109	2.71	0.007

4.4.3.1 Model Evaluation

To observe the effect of the different independent variables on the Simple crash occurred every year in Bangladesh, we ran a model in STATA software. For grievous crash, it is meanly dispersed. Log-likelihood is -71.904972. It is used in the LR chi square test of whether all variables' regression coefficients are simultaneously zero or not. *LR* is the test statistic that all regression co-efficient are simultaneously equal to zero. It is calculated as negative two times of the difference of the likelihood for the null model and fitted model from the iteration log of the STATA software we actually can find it. In our model it is -2[-71.904972-(-107.15767)] = -70.51. Pseudo R^2 is used to evaluate the overall model goodness-of-fit. In our model it is 0.3290 which means model is 32.90% fit. It can be calculated as 1- [-71.904972/-107.15767)= 0.3290.

4.4.3.2 Interpretation of significant variables

Negative binomial regression coefficients are used to interpret the results of our model. It can be done as follows: one unit change in the predictor variable, the difference in the logs of expected count of the response variable is expected to change by the respective regression coefficient given the other predictor variables in the model are held constant.

4.4.3.2.1 Road Infrastructure variables

With the increase of the length of RCC Bridge (β= 0.0041094, p=0.000), simple or slight injury type crash occurrence will probably increase. It was same for the Fatal and grievous crash as well. But it is more likely to occur simple crash than fatal or grievous crash. It indicates to the bad infrastructural plan, absence of bridge approaches, inadequate design.

In the regional highway, with the increase of the length of Baily with Steel Deck (BSD) (β= -0.0016141, p=0.001), crash occurrence expected to be decreased.

In the Zilla road, PC Girder Bridge and Truss with Steel Deck (TSD), both are positively significant variables i.e. if the length of these two types of road infrastructure increase then simple crash is expected to increase by factor of 0.0004727 and 0.0007102 respectively. On the other hand, RCC girder bridge (β= -0.000584, p=0.013) and Truss with RCC Slab (TRS) (β= -0.003945, p=0.043) made infrastructure are negatively significant variables which means with the increase of the length of these structures, simple crash occurrence is expected to decrease in the zilla roads in Bangladesh.

In the National Highway (β=0.0136347, p=0.000), simple or slight injury type crash has high probability to occur as well as for paved road (β= 0.0147939, p=0.000) also in the union sector.

4.4.3.2.2 Weather factors

In the year 2011, with the increase of rainfall (p=0.000), simple crash occurrence is expected to decrease by the factor -0.0001005 where as in the year 2013, with the increase of rainfall, crash occurrence probably increases by 0.0005716 unit. This result is consistent with study of Anowar et al 2014 that rainy weather conditions tend to increase the crash severity.

4.4.4 Collision Type Crash Model

From 2009 – 2013, 3% crash occurrence is due to the collision. It is actually property damage crash. From the ARI report 2013, we can find that, in 2013, about 341 crashes due to head on collision, 835 collisions were with pedestrians.

Table 4.10 Explanatory variable used in Collision Crash Occurrence Model

Explanatory Variables	Mean	Standard Deviation
Road Infrastructures length (m)		
National Highway		
Box Culvert	225.7	257.6
Zilla Road		
Arch Masonry	5.86	10.86
RCC Bridge	48.03	72.21
Union Road Length		
(Surface type wise)		
Rigid Pavement	12.11	32.20
Earthen Road	320.81	248.96
Flexible Pavement (Total)	300.02	172.18
≤200	0.296	0.46
201-400	0.5	0.50
401-600	0.15	0.366
>600	0.046	0.213
Existing Gap Span		
Village Road A	3721.88	3465.53
Weather		
Rainfall (mm)		
Year 2009	2016.32	590.010
2013	2057.17	696.57

Average Minimum Temperature (°C)		
Year 2010	21.9	1.38
Year 2011	21.17	1.249
Year 2013	21.11	1.26

Table 4.11: Parameter estimation of Collision crash occurrence model

Number of Observation	41	**LR χ^2 (12)**	53.99	**Log likelihood at convergence**	-55.157773
Dispersion	mean	**Prob> χ^2**	0.000	**Log likelihood at constants**	-82.154522
Log likelihood	-55.157775	**Pseudo R^2**	0.3286		

Explanatory Variables	**Estimated Co-efficient (β)**	**Standard error**	**t- statistics**	**P-value**
Road Infrastructures Length (m)				
National Highway				
Box Culvert	0.0026011	0.0005544	4.69	0.000
Zilla Road				
Arch masonry	0.0427684	0.011621	3.68	0.000
RCC Bridge	-0.0044745	0.0020573	-2.17	0.030
Union road length (Surface type wise)				
Rigid pavement	-0.0373872	0.0142272	-2.63	0.009
Earthen road	-0.001516	0.0006846	-2.21	0.027
Flexible pavement				

>600	0.6731216	0.4046672	1.66	0.096
Existing gap span				
Village road A	0.0001224	0.0000382	3.20	0.001
Weather				
Rainfall (mm)				
Year 2009	0.0024905	0.000712	3.50	0.000
Year 2013	-0.002551	0.0006084	-4.19	0.000
Average minimum temperature (°C)				
Year 2010	-4.275369	1.054864	-4.05	0.000
Year 2011	3.696963	1.010066	3.66	0.000
Year 2013	1.319212	0.4700395	2.81	0.005

4.4.4.1 Model Evaluation

To observe the effect of the different independent variables on the Collision type crash occurred every year in Bangladesh, we ran a model in STATA software. For grievous crash, it is meanly dispersed. Log-likelihood is -55.157775. It is used in the LR chi square test of whether all variables' regression coefficients are simultaneously zero or not. *LR* is the test statistic that all regression co-efficient are simultaneously equal to zero. It is calculated as negative two times of the difference of the likelihood for the null model and fitted model from the iteration log of the STATA software we actually can find it. In our model it is -2[-55.157775-(-82.154522)] = -53.99. Pseudo R^2 is used to evaluate the overall model goodness-of-fit. In our model it is 0.3290 which means model is 32.86% fit. It can be calculated as 1- [-55.157775/ -82.154522] = 0.3286

4.4.4.2 Interpretation of significant variables

Negative binomial regression coefficients are used to interpret the results of our model. It can be done as follows: one unit change in the predictor variable, the difference in the logs of expected count of the response variable is expected to change by the respective regression coefficient given the other predictor variables in the model are held constant.

4.4.4.2.1 Road Infrastructure Variables

From table 4.11, with the increase length of Box Culvert (β= 0.0026011, p=0.000) in the national highway and arch masonry (β= 0.0427684, p=0.000) type structure in the, collision is expected to occur. The reason behind this may be sufficient cross section at culvert and bridge may not be maintained. In the national highway high speed is generally maintained. Narrow carriageway and shoulder may be the possible reason for accidents due to collision.

With the increase of length of RCC bridge (β= -0.0044745, p=0.030) in the zilla road, collision probably decrease. Roads geometry and vehicle speed has relationship. In the zilla road, driver may be more conscious and careful about acceleration.

In the union roads, rigid pavements and earthen roads both may decrease the collision as they are negatively significant with estimated coefficient of -0.0373872 and -0.001516 respectively. Whereas, Flexible pavements in the union road that have length longer than 600m, it may impact on the collision positively. This may occur due to improper off pavement works and pavement crack sealing works. And also, with the increase of existing gap of the span in the village roads, collision is likely to be increased. Too much structural spans and their existing gaps are likely to increase collision of the vehicles and also fatal crash.

4.4.4.2.2 Weather Factors

In the year 2009, with the increase of rainfall, collision likely to be increased on the contrary, in 2013, collision decreases (β= -0.002551, p=0.000). Statistical report of ARI 2013 can also be used as evidence. From 2009 to 2013 crash number due to rain decreases with time. Experience of the driver, low speed of the vehicles during rainfall helps to decrease the crash due to rainfall.

For minimum average temperature in 2010, collision is likely to be decreased but for 2011 and 2013, with increase of average minimum temperature, collision seems perhaps increasing. There are fluctuations in the crash trend in those 5 years' of time duration.

4.5 Summary Findings

Table 4.12 compares the effect of different predictors or independent variables on the four individual crashes i.e. *Fatal injury crash, Grievous injury crash, Simple injury crash and Collision or no damage or property damage crash* that are occurring every year in Bangladesh. This thesis has done to seek the probable connections among different road infrastructures constructed in Bangladesh, different categories of road lengths, some socio economic and demographic factors and lastly, weather factors (Rainfall, Fog and Temperature).

Table 4.12: Estimated Coefficient (β) for All the Crash Models

Variables	**Estimated Coefficient(β) of Different Crash Occurrence Model**			
	Fatal	**Grievous**	**Collision**	**Simple**
Road Infrastructure				
National Road				
Box Culvert	+	+	+	x
RCC Bridge	+	+	x	+
Steel Beam & RCC Slab	-	x	x	x
PC Girder	x	-	x	x
Regional Highway				
Baily with Steel Deck	x	x	x	-
PC Girder	+	+	x	x
RCC Girder	+	x	x	x
Steel Beam & RCC Slab	+	x	x	x

Zilla Road				
Arch Masonry	+	x	+	x
PC Box	-	x	x	x
PC Girder	+	x	x	+
Truss with RCC Slab	-	x	x	-
Steel Beam & RCC Slab	x	-	x	x
RCC Bridge	x	x	-	x
RCC Girder Bridge	x	x	x	-
Truss with Steel Deck	x	x	x	+
Road Length				
National Highway	+	x	x	+
Zilla Road	-	x	x	x
Village Road A	-	x	x	x
Length not Surveyed	*	+	x	x
Union Road Length				
Flexible Pavement	+	x	+	x
Rigid Pavement	+	x	-	x
Pavement Brick	x	-	x	x
Earthen Road	x	x	-	x
Paved Road	x	x	x	+
Structure Span	+	x	x	x
Upazilla Road Length				
Structure Span	x	x	x	+
Pavement Brick	x	+	x	x
Existing Gap Number	-	x	x	x
Village Road A				
Existing Gap Number	-	x	x	x

Structure Span	x	+	x	x
Existing Gap Span	x	x	+	x
Village Road B				
Existing Gap Number	+	x	x	x
Socio economic & Demographic Characteristics				
General Household	+	x	x	x
Other Household	x	-	x	x
Female	-	x	x	x
Sex Ratio (M/F)	+	X	x	x
Weather				
Rainfall				
Year 2009	-	x	-	x
2011	x	x	x	-
2013	x	x	-	+
Average Minimum Temperature				
Year 2009	x	-	x	x
2010	x	x	-	x
2011	x	x	+	x
2012	x	+	x	x
2013	x	x	+	x

Chapter Five

Discussion and Conclusion

5.1 Introduction

The principal objective of this study is to identify the affecting factors on individual crashes i.e. Fatal injury crash, Grievous injury crash, Simple injury crash and Collision/ property damage crash occurred in Bangladesh which would be helpful in developing proper counter measures to reduce harmful effects from crash. In order to achieve this objective, various types of road infrastructures constructed in Bangladesh, different types of roads in different locations in Bangladesh, various socio economic and demographic factors and lastly, weather factors i.e., rainfall, fog and temperature effects have been investigated. To establish the relationship between individual crash occurrences (response variables) and risk factors or independent variables, negative binomial regression model was utilized. Four case studies, namely, fatal crash occurrence, grievous crash occurrence, simple or slight injury type crash occurrence and lastly, collision or no injury type crash occurrence have been chosen to fulfill the goal of this research work.

This chapter gives an overview of the important findings of this research. The findings are discussed in detail based on their effects on the severity of the considered four types of crash model. This is followed by suggestions for precautionary measures to be taken to enhance safety as well as suggestions for future research.

5.2 Discussions

After the crash frequency analysis, we can conclude that in the national highways, Box culverts and RCC made infrastructures may have severe impact on the crash occurrences. Both are likely to increase the fatal and grievous crash if their length increases. But in regional highways and zilla roads, no significant effect is found for both of these structures, except, increase of RCC made structures may probably decrease collisions in the zilla roads. PC girder type structures may be a reason to cause for fatal and grievous crash in the regional highways and for fatal crash in zilla roads. But it possibly prevents the grievous crashes from the national highways. Most of the steel made structures and structures made with composite materials (Steel – concrete mix), may behave like decreasing the crash severity. These types of infrastructures that are constructed in Bangladesh are Steel Beam and RCC Slab (SBRS), Baily with Steel Deck (BSD), Truss with RCC Slab (TRS). Among these, SBRS is found statistically significant for all types highways (i.e. National, Regional, Zilla) and is found to decrease the fatal and grievous crash in national highways and zilla roads respectively. Concrete made road infrastructures in the zilla road are found negatively significant on crashes that means with the increase of these infrastructures lengths crash occurrence decreases.

Our result indicates that when the length of the national road, paved road, roads that are not surveyed increases, it enhances the chances of fatal and grievous crashes. Roads that are made of flexible pavement and rigid pavement in the union sector, chances of fatal crash increases whereas brick pavements decreases the chances of grievous crashes in the union road but increases in the upazilla roads. It is important to mention that in all union, upazilla and village roads, increasing the number of structure span enhances the likelihood of fatal, grievous and collision type crash occurrence respectively.

Our model has not found any statistical significant socio-economic and demographic variables that effect on simple and collision type crashes. But general household and sex ratio is found positively significant over fatal crash and female is found negatively significant.

Interestingly, with the increase of rainfall in the year 2009, 2011 and 2013 fatal, simple and collision type crashes are likely to decrease year by. No statistical significance is found regarding fog on any type crashes. Effect of average minimum temperature is not found significant for fatal crash and simple or slight injury type crashes but both positive and negative significance is found for grievous and collision type crashes.

5.3 Limitations

Conducting this thesis, it was found out that it had quite a number of limitations. The study could not include some important factors which might increase the crash occurrence. This study did not include the effects of the district wise registered vehicles, licensing information, solvency rate, permanent insolvency, temporary insolvency, saving amount, vehicles miles traveled, literacy rate in each district due to lack of official information. For time limitations district wise AADT data is not included though it is an important variable.

5.4 Recommendations and Future Research Scopes

The results of this study will provide policy makers as well as transportation engineers and planners with important information while planning for any road infrastructure construction on any highways. This study is useful for developing countries like Bangladesh**.** From our result we can suggest to give more attention on the national and regional highways. Box culverts, RCC bridges, SBRS, PC girder and RCC girder made bridges are found vulnerable to the crash occurrence in our model. Appropriate traffic signs, bus bays provisions in the national, regional and zilla roads, sufficient widening of the roads, speed restriction, improvement of sight distance and intersection design should be enforced to avoid human and economic losses.

Regarding road infrastructures proper maintenance, regular inspections, essential retrofitting of the structure if needed, better quality of material selection before construction should be practiced to avoid any type of crashes. In the paved road, curve widening, increasing carriageway width over the road section can ease to make roads easier to drive.

Inclusion of AADT data is strongly recommended. The result of this study is used in developing the future forecasting model for predicting crash based on severity. More variables should be incorporated for improving the explanatory power of the model. GIS application is recommended for improving the identification of accidents hotspots.

References

Accident Research Institute (ARI) Annual Report 2012

Accident Research Institute (ARI) Annual Report 2013

Ahsan, H.M., Raihan, M.A and Rahman, M (2011), A study on car involvement in road traffic accidents in Bangladesh, *4th Annual Paper Meet and 1st Civil Engineering Congress*, December 22-24, 2011, Dhaka, Bangladesh

Ahsan, H.M., Raihan, M.A and Rahman, M.S, Arefic, N.H. (2011). Reporting and recording of road traffic accidents in Bangladesh, *4th Annual Paper Meet and 1st Civil Engineering Congress*, December 22-24, 2011, Dhaka, Bangladesh

Ahsan, H.M., Newaz, M S., Alam, A K M S., Alam, M. (2011). Application of GIS in hazardous road location (HRL) identification, *4th Annual Paper Meet and 1st Civil Engineering Congress*, December 22-24, 2011, Dhaka, Bangladesh

Alam, M S., Mahmud, S.M., Hoque, M S. (2011). Road accident trends in Bangladesh: A comprehensive study, *4th Annual Paper Meet and 1st Civil Engineering Congress*, December 22-24, 2011, Dhaka, Bangladesh

Albalate, D., Fernandez, L., Yarygina, A. (2013). The road against Fatalities: Infrastructure spending vs Regulation, *Accident Analysis and Prevention*, Volume 59, Pages 227-239

Anowar, S., Yasmis, A., Tay, R. (2014). Factors influencing the severity of intersection crashes in Bangladesh, *Asian Transport Studies*, Volume 3, Issue 2, pp.1-12

Asmer, J., Zuylen, H.V. (2011). Saturation Flow Under Adverse Weather Conditions, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2258, pp. 103-109

Brijs, T., Karlis, D., Wets, G. (2008). Studying the effect of weather conditions on daily crash counts using a discrete time series analysis model, *Accident Analysis and Prevention*, Volume 40, Issue 3, pages 1180-1190

Caliendo, C., Guida, M., Parisi, A. (2007). A crash prediction model for multilane roads, Accident Analysis & Prevention, Vol. 39, 657-670.

Camacho, F., Garcia, A., Belda,E. (2010). Analysis of impact of adverse weather on freeway free-flow speed in Spain, *Transportation Research Record: Journal of Transportation Research Board,* Vol. 2169, pp. 150-159

Das, A., Abdel-Aty, M A. (2011). A combined frequency-severity approach for the analysis of rear end crashes on urban arterials, *Accident Analysis& Prevention* Volume 49, issues 8-9, Pages 1156-1163

Eisenberg, D. (2004).The mixed effects of precipitation on traffic crashes, *Accident Analysis& Prevention,* Vol.36, 637-647.

El-Basyouny, K., Barua,S., Islam,M., Li, R. (2014). Assessing the effect of weather states on crash severity and type by use of Full Bayesian Multivariate Safety Models, *Transportation Research record: Journal of Transportation Research Board*, Vol.2432, pp. 65-73

Flahaut, B. (2004). Impact of infrastructure and local environment on road unsafety: Logistic modeling with spatial autocorrelation**,** *Accident Analysis and Prevention*, Volume 36, issue 6, Page 1055-1066

Fridstrom, L., Liver, J., Ingebrigtsen, S., Kulmala, R. and Thomsen, L. (1995), Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts, *Accident Analysis and Prevention*, Vol. 27, 1–20.

Geometric Design Standards for Roads and Highways Department, Draft Version 4, October 2000, Government of the People's Republic of Bangladesh, Ministry of Communication, Roads and Highways Devision

Gomes, S V. (2013). The Influence of the infrastructure characteristics in urban road accidents occurrence**,** *Accident Analysis and prevention*, Volume 60, Page 289-297

Greibe, P. (2003). Accident prediction models for urban roads, Accident Analysis & Prevention, Volume. 35, 273−285.

Hayat, R B., Debbarh, M., Antoniou, C., Yannis, G. (2013). Explaining the road accident risk: Weather effects, *Accident Analysis and Prevention*, Volume 60, pages 456-465

Hoque, M. M.(2008). The prevention of road traffic accidents: An overview of behavioural modification techniques. *Journal of Scientific Research*, 22(2), 85-97.

Hoque, M. M., Hossain, D Z., Mahmud, S.M. (2010). Improving highway safety in Bangladesh: Road improvement and the potential application of iRAP, 24^{th} ARRB Conference – Building on 50 years of road and transport research, Melbourne, Australia 2010

Hoque, M M., Mahmud, S M S., Paul, S. (2011). The cost of Road Traffic Accidents in Bangladesh

http://www.brsa.org.bd/PRSCO/papers/Transport%20Studies%20II/088_SanjayPaul.pdf

Hoque, M. M., Sarkar, S., Rahman, M. F., Ashrafuzzaman, M. (2006). Hazardous road locations (HRL) on National Highways in Bangladesh. *Proceedings of the Conference on Road* Safety in Developing Countries, Bangladesh, p 229-237

Hoque, M. M., Sarkar, S., Rahman, M. F., Talukdar, M. A. 2006. Heavy vehicles safety in Bangladesh: Accident involvement, drivers behavior & understanding road safety. *Proceedings of the Conference on Road Safety in Developing Countries, Bangladesh*.

Hoque, M. M., Azad, A. K., Mahmud, H. M. I., Mahmud, S. M. S., Sarkar, S. (2006). The risk of children in road traffic accidents in Bangladesh. *Proceedings of the Conference on Road Safety in Developing Countries, Bangladesh*

Holdridge, J M., Shankar, V N., Ulfarsson, G F. (2005). The crash severity impacts of fixed roadside objects, *Journal of Safety Science*, Volume 36, Issue 2, pages 139-147

Hughes, B P., Newstead, A., Anund, A., Shu, C C., Falkner,T. (2015). A review of models relevant to road safety, *Accident Analysis and Prevention*, Volume 74, pages 250-270

Kopelias, P., Papadimitriou, F., Papandreou, K., Prevedouros, P. (2007).Urban freeway crash analysis: Geometric, Operational and weather effects on crash number and severity, *Transportation Research Record: Journal of Transportation Research Board,* Dec 2007, Vol.2015, pp. 123-131

Kopits, E., Cropper, M. (2005). Traffic fatalities and economic growth, *Accident Analysis and Prevention*, volume 37, Issue 1, pages 169-178

Laureshyn, A., Svensson, A., Hyden, C. (2010). Evaluation of traffic safety, based on micro-level behavioral data: Theoretical framework and first implementation, *Accident Analysis and Prevention,* Volume 42, Issue 6, pages 1637-1646

Lee, C., Aty, M A., Park, J., Wang, J H. (2015). Development of crash modification factors for changing lane width on roadway segments using generalized nonlinear models,

Accident Analysis and Prevention, Volume 76, Pages 83-91

Lindenmann, H. (2007). The design of roads and of the road environment in small rural communities, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2025, pp. 53-62

Local Government Engineering Department (LGED) Annual Report 2013 – 2014

Mahmud, S.M., Hoque, M.S. (2011). Road safety research in Bangladesh: Constraints and requirements, 4th Annual Paper Meet and 1st Civil Engineering Congress, December 22-24, 2011, Dhaka, Bangladesh

Mahmud, S.M., Sarker, A., Hoque, M. (2011). Identification and investigations of hazardous road locations on Dhaka-Aricha Highway, 4th Annual Paper Meet and 1st Civil Engineering Congress, December 22-24, 2011, Dhaka, Bangladesh

Maintenance and Rehabilitation Needs Report of 2012 – 2013 for RHD Paved Roads, HDM Circle, RHD, November, 2012, Government of the People's Republic of Bangladesh, Ministry of Communication, Roads and Highways Department

Martensen, H., Dupont, E. (2013). Comparing single vehicle and multivehicle fatal road crashes: A joint analysis of road condition, time variables and driver characteristics, *Accident Analysis and Prevention*, Volume 60, Pages 466-471

Milton, J., and Mannering, F. (1998). The relationship among highway geometrics, traffic related elements and motor-vehicle accident frequencies. *Transportation*, 25(4), 395−413.

Noland, RB., Oh, L. (2004). The effect of Infrastructure and demographic change on traffic-related fatalities and crashes: A case study of illinois-level data, *Accident Analysis & Prevention, Volume 36, Issue 4, Pages 525-532*

Noland, RB. Traffic fatalities and injuries: the effect of changes in infrastructure and other trends, 2003, *Journal of Accident Analysis and Prevention*, Pages 599-611

OECD. (1997), Road safety principles and models: Review of descriptive, predictive, risk and accident consequence models, OECD, *Road Transport Research*, Paris.

Raje,S., Kertesz, R., Maccarone, K., Seltzer, K., Siminari, M., Simms, P., Wood, B., Sansalone, J. (2013). Green infrastructure design for pavement systems subject to rainfall-runoff loadings, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2358, pp. 79-87

Ray,M., Carrigan,C., Plaxico,C. (2014). Method of modeling crash severity with observable crash data, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2437, pp. 1-9

Rifaat, S., Rahman, H., Mohammad, Pasha M. (2014). Study on the Effect of Road Infrastructure, Socio economic and Demographic features on road crashes in Bangladesh, *World Academy of Science, Engineering and Technology, International Journal of Social, Education, Economics and Management Engineering*, Volume 8 No 4

Rifaat, S., Tay, R., Perez, A., and de Barros, A. 2009b. Effects of neighborhood street patterns on traffic crash frequency, *Journal of Transportation Safety and Security*, 1(4), 241- 253.

Rifaat, S.M., Tay, R. (2009). Effects of street patterns on injury risks in two-vehicle crashes, *Transportation Research Record*, 2102, 61–67.

Schneider,W., Savolainen,P.(2011). Comparison of severity of Motorcyclist Injury by Crash Types, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2265, pp. 70-80

Standard Designs and Costing for Zila, Upazila and Union Roads, Bridges and Culverts, May, 2004, Road Design Standards, Government of the People's Republic of Bangladesh, Planning Commission

Thakali, L., Hossain, M., Kanitpong, K. (2009). Development of Accident Prediction Models, their Possibilities and Efficacy for the Developing Countries; a Thai Experience, Proceedings of the Eastern Asia Society for Transportation Studies, Vol 7

Traynor, T L. (2008). Regional economic conditions and crash fatality rates – a cross country analysis, *Journal of Safety Research*, Volume 39, Issue 1, Pages 33-39

Theofilatos, A., Yannis, G. (2014). A review of the effect of traffic and weather characteristics on road safety, *Accident Analysis and Prevention*, Volume 72, pages 244-256

Van Petegem., JW., Wegman, F. (2014). Analyzing road design risk factors for run-off-road crashes in the Netherlands with crash prediction models, *Safety Science*, volume 49, Pages 121.el-127

Wang, C., Stamatiadis,N. (2014). Derivation of a new surrogate measure of crash severity, *Transportation Research Record: Journal of Transportation Research Board*, Vol.2432, pp. 37-45

Wang, X., Wu, X., Aty, M A., Tremont Paul, J. (2013). Investigation of road network features and safety performance, *Accident Analysis & Prevention*, *Volume 56, July 2013, Pages 22-31*

Wang, C., Quddus, M A., Ison, S G. (2013). The effect of traffic and road characteristics on road safety: A review and future research direction, *Safety Science*, Volume 57, Pages 264-275

Washington, S., Karlaftis, M., Mannering,F. (2003). Statistical and Econometric Methods for Transportation Data Analysis. Chapman and Hall/CRC, Boca Raton,

Zhang, Y., Xie, Y., Li, L. (2012). Crash frequency analysis of different types of urban roadway segments using generalized additive model, *Journal of Safety research*, Volume 43, issue 2, pages 107-114