UNIVERSITY OF CALGARY

Pedestrian Safety Analyses

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

CALGARY, ALBERTA

DECEMBER, 2008

UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

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Abstract

Priority setting for road safety improvements is a complex issue. Developing countries like Bangladesh suffer from the lack of road safety resources and there is an obvious need for the effective utilization of these scarce resources. The first part of this thesis describes a simple framework for road safety priority setting for different geographical areas in Bangladesh. Data Envelopment Analysis (DEA) is used to examine the relative risks of different regions and identify high risk regions. We found that the relative collision risks of various regions are not directly proportional to the number of casualties and transportation accessibilities of those corresponding regions as commonly believed. We therefore recommend that systematic decision making methods like DEA be used to identify high risk regions to maximize return of scarce road safety resource. Apart from identification of spatial distribution and concentration of pedestrian accidents, identification of the prominent (statistically significant) risk factors is another way to provide cost effective solutions of road safety problem. In the second part of the thesis, an attempt is made to explore the factors that contribute to mortality and injury, using historical traffic collision records. It is found that factors like pedestrian above the age of 55, young pedestrians age under 15 years of age, pedestrian crossing action, involvement of trucks or buses, pedestrian crosswalk locations, locations without traffic control devices, rainy season are some important pedestrian collision risk determinants.

Acknowledgements

I would like to take this opportunity to express my sincere thanks to my supervisor Dr. Richard Tay. I have learnt a lot from him, both academic and otherwise, and I consider myself fortunate for getting the opportunity to work under his supervision. Thanks to Dr. Tay for his advice and guidance throughout this research as well as his constant encouragement in all my endeavours. I thank the faculty members for their dedication and inspiration. Special thanks to Dr. Alex de Barros and Dr. Marc A. Maes for their keen interest in my academic and research progress.

I am indebted to all my fellow researchers in the transportation group who have enriched my experience at University of Calgary in numerous ways. Thanks to the ex-colleagues at the Accident Research Centre (ARC) for their kindness and support.

I am grateful to my family for their constant support and encouragement in pursuing my goals. My teachers at this university and my friends have been a constant source of inspiration. Above all, thanks to my parents for their endless love and sacrifice.

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Chapter One: INTRODUCTION

1.1 Background

Around 88 percent of the 1.2 million deaths every year from road motor vehicle traffic collisions occur in the developing world (WHO, 2004). For every road death, there are far greater numbers of injuries: four persons with severe/permanent disabilities, ten persons requiring hospital admission, and thirty persons requiring emergency room treatment. The economic costs of this epidemic are enormous, ranging from 1 to 5 percent of the GDP of every nation. It is estimated that road traffic collisions will be the third leading cause of life years lost by 2020. Road safety in low and middle income countries thus emerges clearly as a critical and major public health issue.

One of the low income and middle income countries with the highest traffic collision rates in the world is Bangladesh. Collision statistics revealed that Bangladesh has over 100 deaths per 10,000 motor vehicles. This fatality rate is at least 50 times higher than the rates in Western Europe and North America. Moreover, while the traffic fatalities are declining in developed countries, they still on the rise in Bangladesh.

The number of fatalities has increased from 1,009 in 1982 to 3,334 in 2003 which represents a nearly 3.5 times increase in 22 years period. According to the official statistics, there were at least 3,334 fatalities and 3,740 injuries in 4,114 reported motor vehicle collisions in 2003. It is estimated that the actual fatalities could well be 10,000-12,000 each year taking into consideration the underreporting rate and definitional inconsistency. Significant fluctuations in the numbers of fatalities and injuries as reported by police clearly reflect the problems of reporting and recording inconsistencies.

In Bangladesh, pedestrian fatalities account for about half of the total fatalities in traffic collisions, a number that is much higher than that in the United States, Japan, and most Western countries. The high pedestrian collision risk in Bangladesh could be attributed to high prevalence of pedestrian–vehicle conflicts in a densely populated urban area with numerous roadside activities and highways that share the same pathways for pedestrians and high-speed vehicles.

1.2 Pedestrian as Road Users in Developed and Developing countries

Non-motorized transportation is a vital means to reduce congestion in metropolitan areas in many developed countries. Traffic congestion levels in metropolitan areas of the North America have risen substantially over the past decade. This has been, in large part, because of the increasing dependency on the personal automobile for pursuing out-of-home work and non-work activities. For instance, the 2001 National Household Travel

Survey (NHTS) data shows that about 92% of US households owned at least one motor vehicle in 2001 (Pucher and Renne, 2003). Household vehicle miles of travel also increased 300% between 1977 and 2001 (Polzin et al., 2004).

In response to the rising and traffic congestion and associated air quality problems, several metropolitan planning authorities are considering, among other things, transportation demand management strategies to encourage non-motorized mode use, including walking and bicycling for short distance utilitarian trips. In addition to serving as a potential traffic congestion alleviation strategy, promoting non-motorist travel (or active transportation) also provides health and fitness benefits, net of exposure to air pollutants emitted by cars, an issue that is receiving increasing attention at the interface of transportation and public health (Transportation Research Board and Institute of Medicine, 2005; Sallis et al., 2004; Copperman and Bhat, 2007).

According to evidence from the 2001 NHTS, 41% of all trips in 2001 were shorter than 2 miles and 28% were shorter than 1 mile (Pucher and Renne, 2003). However, Americans used their personal vehicles for about 90% of trips between 1 and 2 miles, and about 66% of trips shorter than 1 mile. While there are several reasons for this dominance of the automobile even for short distance trips, safety (or the lack thereof) associated with non-motorized mode use in the North America is an important consideration.

Unlike North America, the proportion of non-motorized trips was found to be far higher in Bangladesh. A household survey was conducted to develop strategic transportation plan in Dhaka, the capital of Bangladesh. The study explored the primary modes of travel in Dhaka city, which was defined as the mode used for the longest (distance) part of trip. The study found that about 29 percent of household travel was made by transit/public transport, 18 percent was made by private motorized transport and 29 percent was made by rickshaws or three wheelers (STP, 2005). Walking as a primary mode of transport constituted 22 percent of all trips.

However, another study that was done in 1998 as a part of Greater Dhaka Metropolitan Area Integrated Transport Study showed that over 60 percent of trips in Dhaka involved walking alone, and of the remaining trips, 11% includes a walking component (DITS, 1998). It is clear that walking plays a vital role in transportation system and requires greater attention.

1.3 Motivation

1.3.1 Pedestrians are more likely to be killed on roads

Engineers and researchers in the field of traffic safety are keenly interested in pedestrian–vehicle collision incidents because they have a much higher likelihood of fatality compared with other types of collisions. Table 1.1 shows the results of a study (ETSC, 2003) comparing the risks of travel in the European Union countries by the four main modes and by different means of road travel. The study found that, compared with a person in a car, a person on a motorized two-wheeler is 20 times more likely to be killed for each kilometre travelled; a person on foot 9 times more likely; and a person on a bicycle 8 times more likely. A person in a car, however, is 10 times more likely to be killed than a passenger in a bus or coach

Table 1.1: Traffic Fatalities in European Union Countries (2001–2002)

		Deaths per *100* million passenger-kilometres	Deaths per *100* million passenger-travel hours
Roads (total)		*0.95*	*28*
	Powered two-wheelers	*13.8*	*440*
	Walking	*6.4*	*75*
	Cycle	*5.4*	*25*
	Car	*0.7*	*25*
	Bus and coach	*0.07*	*2*
Ferry		*0.25*	*16*
Air(civil aviation)		*0.035*	*8*
Rail		*0.035*	*2*

(Source: ETSC, 2003)

1.3.2 Pedestrian Collisions in Bangladesh

Some of the most common collision types in Bangladesh are hit pedestrian (43.7%), rear end collisions (16.4%), head on collisions (13.3%), and over-turnings (9.4%). These four collision types account for nearly 83 percent of all collisions regardless of severity level. With respect to fatal collisions, hit pedestrian collisions account for 52.9 percent, followed by rear end 11.9 percent, head-on 11.9 percent and overturning 9.8 percent.

In Metropolitan Dhaka, the dominant collision types are hit pedestrians 44.4 percent, rear end collisions 29.1 percent, sideswipes 7.1 percent, and head on collisions 6.0 percent. Among the fatal collisions, hit pedestrian collisions are the most frequent and account for 68.9 percent, followed by rear end collisions (17.2 percent).

Pedestrians are therefore the most vulnerable road users Bangladesh. Pedestrians alone are involved in more than 47 percent of road collisions and 49 percent of all traffic fatalities. In all urban areas, pedestrians accounted for 52 percent of fatalities while in Dhaka City alone, this statistic is nearly 70 percent.

1.4 Objectives of Research

The objective of this research is to develop models that will help us understand the factors contributing to the risks associated with pedestrian collisions in Bangladesh and allocate road safety resources efficiently.

1.5 Overview of Research

This thesis consists of two main studies. The first study will evaluate pedestrian collision priorities in different geographic regions of Bangladesh using a data envelopment analysis. This study will help to allocate the budget for pedestrian safety improvement among regions using a more evidence-based approach. The second study will develop a logistic regression model to analyze the injury risk of pedestrian collisions and explore the factors that contribute to mortality and injury.

1.6 Thesis outline

The remainder of this thesis is organized in four chapters. In Chapter 2, a literature review on research related to pedestrian collision factors and existing practices of collision funding prioritization are presented. Chapter 3 describes the methods that are used to address the objectives of this research. Chapter 4 provides conceptual framework for modelling, the statistical analysis and discussion of results. The implications of analytic results and policy implications are presented in Chapter 5 together with some directions for further research.

Chapter Two: LITERATURE REVIEW

2.1 Introduction

As discussed in Chapter 1, the proportion of pedestrian collision is much higher in developing countries like Bangladesh. Therefore, this thesis will focus on pedestrian safety analyses and this chapter will review the literature that is relevant to this topic. Section 2.2 describes some literatures regarding the optimal allocation of resources for safety improvement and transportation developments. Apart from budgetary need, in order to improve pedestrian safety of a region, it is imperative to know the factors related to pedestrian collisions. Relevant researches regarding pedestrian collision factors from many countries around are presented in section 2.3. Finally, some studies regarding pedestrian safety in developing countries are also summarized 2.4.

2.2 Literature on Road Safety Resource Allocation

Funding for road safety initiatives is a critical issue because the human and economic consequences of road collisions are devastating. Also, the resources needed to reduce the economic losses resulting from road collisions in developing and transition countries are greater than the total sum they receive from all donor agencies combined. Although it is clear that, road safety investments could relieve pressure on medical facilities and produce significant savings, the funding of road safety projects is still grossly insufficient in many counties, especially in developing countries. Moreover, general resource scarcity often leads policy-makers in many developing countries to think differently and eventually pay less importance on policy implementation and funding for road safety (PIARC, 2003).

Apart from the insufficiency of road safety resource, there is a considerable amount of inefficiency in the allocation of road safety budget among different geographical regions, particularly in developing countries like Bangladesh. From the perspective of decision makers, investment of resources involves the identification and assessment of the safety needs. This approach demands an accurate measurement of the relative needs for effective budgeting and financing of road safety projects. The optimal allocation of resources for safety improvement is therefore a very complex issue with many considerations.

At a macro level, one important consideration is the division of scarce road safety resources among different geographical regions. To provide evidence-based recommendations for the optimal allocation of the road safety budget, this study will develop a framework for identifying the safety needs in different geographical regions in Bangladesh. Priorities can then be set according to the respective safety needs.

There are several studies on the optimal allocation of resources for infrastructure facilities (Berechman, 1994; Buffington, 1992; Perera, 1990). One relevant study is done by Alam et al. (2004) who examined the role of transportation investments on the regional economic development of Bangladesh. Data Envelopment Analysis (DEA) technique was used to examine the technical efficiency of investments in transportation for each region of the country. Investments in infrastructure in the less-developed regions were found to be more effective because of a higher rate of return. DEA is used to identify investment priorities for specific regions, and their relative impacts are assessed.

However, the relationship between regional development and road safety is yet to be established. Additionally, the correlation of transportation development and road safety improvement is also unknown in Bangladesh. A new model to assess the risk efficiency of various regions of Bangladesh is therefore much needed.

With respect to highway safety, a model was developed by Melachrinoudis (2002) for allocating funds to highway safety improvements. Besides the commonly used binary variables that represent discrete interventions at specific points of a highway, continuous variables are introduced to represent the lengths of a highway over which continuous improvements, such as pavement resurfacing or lighting, are implemented. The problem was formulated as a mixed integer knapsack model with linear multiple choice constraints. This model focused only on specific localized road improvements and not area-wide road safety programs which may comprise engineering, education and enforcement provisions.

Fred et al. 2003 proposed an information system to ensure efficient utilization of limited road safety fund. They criticized the existing collision reduction factors (CRFs) based approach because the results from many previous safety studies are unreliable due to the inability to apply the CRFs to all conditions and also because many safety studies suffer from problems with the evaluation methodology. A safety analysis software known as the information system for estimating collision reductions (ISECR) was developed for estimating collision reductions using a case-based reasoning approach to compile the results from previous road safety research. The system could determine the expected CRFs and the range and reliability associated with a safety improvement at a specific location.

In another study, Elvik (2003) examines how setting priorities for road safety strictly according to cost–benefit analysis would affect the provision of road safety in Norway and Sweden. The study is based on analyses of the efficiency of road safety policies in these two countries. It is found that cost-effective road safety policies could prevent between 50 and 60% of the road collision fatalities in both Norway and Sweden, if pursued consistently during a period of 10 years (2002–2011).

For developing countries like Bangladesh, however, evaluation of the cost effectiveness of road safety measures has thus far received very little attention.. As an initial step, a simple and yet effective efficiency measure to rate the needs and programs of the different regions in Bangladesh is needed to utilize the scarce resources with higher efficiency.

2.3 Research on Pedestrian Collision Factors

A number of studies identified that there exists strong relationship between demographic factors of pedestrians (particularly age) and collision risk. Fontaine and Gourlet (1997) found that children involved in daytime accidents in urban areas whilst playing or running and the elderly pedestrians, who were crossing a road in an urban area were the most vulnerable pedestrians among the different age groups. Oxley et al. (1997) found that when cars approached closely, older pedestrians crossed more frequently and adopted unsafe road crossing behaviour. Similarly, Tarawneh (2001) observed that old pedestrians walked slower than younger pedestrians and their level of exposure to vehicle traffic increased. Al-Ghamdi (2002) found that the fatality rate of the old-age pedestrian group (age 60 and over) was the highest whereas the fatality rate of the young-age pedestrian group (age 20–29) was the lowest.

Al-Ghamdi (2002) suggested that collision attributes, together with the injury and demographic characteristics of the victims, determined the likelihood of mortality in pedestrian–vehicle collisions. Wazana et al. (2000) and Graham et al. (2005) estimated the risk of severe injury and mortality for pedestrians of different socioeconomic status. They found that children were at a greater risk of mortality and injury in traffic collisions, and these collisions were strongly influenced by environment and driver characteristics.

Some studies found that pedestrian's alcohol use to be an important factor affecting pedestrian collisions. Miles-Doan (1996) suggested that alcohol-impaired pedestrians were more involved in pedestrian collisions and their odds of dying relative to surviving were higher than non-alcohol impaired pedestrians. Öström and Eriksson (2001) found that intoxicated pedestrians were more severely injured and suffered more head injuries than non-intoxicated pedestrians. Holubowycz (1995) reported that young and middle-age intoxicated males are high-risk pedestrian groups.

In addition to road user attributes, vehicle characteristics and conditions such as vehicle speed, vehicle types, and vehicle movement have also been found to be closely associated with pedestrian collisions. For instance, Anderson et al. (1997) observed that when the speed limit was reduced, the number of fatal pedestrian collisions was also reduced. Lefler and Gabler (2004) found that the pedestrian fatality rate when struck by light trucks and vans (LTV) was two to three times greater than the fatality rate when struck by passenger cars since LTVs have higher bumpers and more blunt frontal profiles. Preusser et al. (2003) found that turning vehicles often caused pedestrian collisions because drivers failed to yield the right of way to pedestrians at intersections.

Ballesteros et al. (2004), Martinez and Porter (2004), and Roudsari et al. (2004) established a logistic regression model to estimate the associations between pedestrian mortality risk and various human, vehicular, and environmental contributing factors. Pedestrian–vehicle collisions that involved light truck vehicles, vans, or sport utility cars led to a higher risk of mortality and serious injury, which is attributed to the vehicle masses, speeds, and front-end design.

In addition, collision consequence models have been established to determine the injury severity of pedestrian casualties by logistic or ordered probit regression (Davis, 2001; Demetriades et al., 2004; Zajac and Ivan, 2003; Lee and Abdel-Aty, 2005). Lee and Abdel-Aty (2005) estimated the likelihood of different pedestrian injury severity when pedestrians are involved in collisions using an ordered probit model. They found that pedestrian and driver demographic factors as well as road geometric, traffic and environment conditions are closely related to the frequency and injury severity of pedestrian collisions.

A few studies examined the effect of road geometric and traffic characteristics on pedestrian collision risk. Given that a road median or barrier not only blocks vehicle interactions in different directions but also provides safe refuge area for pedestrians, Bowman et al. (1994) demonstrated that different types of median have different effects on pedestrian collisions. LaScala et al. (2000) observed that injuries in pedestrian collisions were greater in the areas with higher population density, average daily traffic, and number of cross-streets per kilometer of roadway.

On the other hand, Garber and Lienau (1996) reported contradicting results that the fatality rate of pedestrian collisions in rural areas with lower population density was higher than the fatality rate in urban areas. Similarly, Zajac and Ivan (2003) found that pedestrian injury severity was higher in village and downtown fringe areas than downtown and low-to-medium density commercial areas. Garder (2004) found that high speeds and wide roads lead to more collisions and that the focus of safety improvement should be on arterials and major collectors. A strong relationship was also found between collision severity and speed.Schneider (2004) showed that high exposure, incomplete sidewalks and high crosswalk density areas within a university were associated with greater observed and perceived pedestrian collision-risk. Additionally, they found that people perceived a lower risk near university libraries, stadiums, and academic buildings, despite the occurrence of collisions.

Sze and Wong (2007) evaluated the injury risk of pedestrian casualties in traffic collisions. It was revealed that there was a decreasing trend in pedestrian injury risk, controlling for the influences of demographic, road environment, and other risk factors. In addition, the influences of pedestrian behaviour, traffic congestion, and junction type on pedestrian injury risk were subject to temporal variation.

Eluru et al. (2007) conducted a study to examine pedestrian and bicyclist injury severity level in traffic collisions. An important policy result from the analysis is that the general pattern and relative magnitude of the elasticity effects of injury severity determinants are similar for pedestrians and bicyclists. The analysis also suggests that the important variables influencing non-motorist injury severity are the age of the individual (the elderly are more injury-prone), the speed limit on the roadway (higher speed limits lead to higher injury severity levels), location of collisions (those at signalized intersections are less severe than those elsewhere), and time-of-day (darker periods lead to higher injury severity).

In another study, Nasar (2008) examined distraction of pedestrians associated with mobile phone use. They had 60 participants walked along a prescribed route, with half of them conversing on a mobile phone, and the other half holding the phone awaiting a potential call, which never came. The analysis revealed that pedestrians noticed significantly more objects in the no conversation condition than in the conversation condition although the effect size was relatively small (0.11). They had three observers record actual pedestrian behaviour of mobile phone users, i-pod users, and pedestrians with neither one at three crosswalks. Mobile phone users crossed unsafely into oncoming traffic significantly more than did either of the other groups.

Gabriel et al. (2007) attempted to identify driving characteristics of injured pedestrians. Patients admitted to a regional adult trauma center were interviewed and evaluated for substance abuse. When compared to the remaining unintentional trauma population, pedestrians were more likely to be black, not married, unemployed, binge drinkers, alcohol dependent, drug dependent, and have a positive BAC level, low income, low educational achievement, younger age, and to not have a driver license.

2.4 Pedestrian Collision Factors in Developing Countries

The World Report on Traffic Injury Prevention indicated that of the 1.2 million people killed in road traffic collisions in 2002, 90% occurred in low- and middle-income countries (WHO, 2004). Compared to other road users, vulnerable road users (pedestrians, cyclists and motorcyclists) bear a higher burden of injuries and fatalities arising from road traffic collisions. Pedestrians, cyclists and motorcyclists also usually suffer the most severe types of injuries and have increased medical problems that require extensive assistance (Mayou and Bryant, 2003).

In low- and middle-income countries in particular, pedestrians account for a major proportion of the road traffic injuries and fatalities (Afukaar et al., 2003). For instance, Odero et al. (1997) found that in Africa, pedestrians accounted for 39% of the traffic fatalities in Tanzania and 75% in Cote d'Ivoire. In contrast to high-income countries where young children and the elderly constitute the most vulnerable pedestrian fatality groups (Assailly, 1997; Fontaine and Gourlet, 1997; Harruff et al., 1998; Öström and Eriksson, 2001), in low- and middle-income countries pedestrian injuries affect the economically productive age group (15–44 years) (Odero et al., 1997). Pedestrian deaths in the economically productive group have significant impacts on the household and national economies (Hijar et al., 2003; Nantulya and Reich, 2003; WHO, 2004).

Mabunda et al. (2008) described the magnitude, demographic, and temporal factors associated with pedestrian fatalities and presents a typological analysis to identify particular groups of at risk pedestrians. Descriptive statistics and multiple correspondence analyses were done to inform the development of prevention programmes tailored to the needs of specific at risk pedestrian groups. Data were obtained from the National Injury Mortality Surveillance System (NIMSS). The results indicated that there were a total of 7433 pedestrian deaths (2001–2004) for the four cities and the majority occurred over weekends. Most pedestrians (56.7%) were between ages 20 and 44 years. Overall, there were 3.3 male pedestrian deaths for every female pedestrian death, and over half (58%) of the 4004 cases tested were found to be positive for alcohol. A typological analysis identified three categories of pedestrian fatalities: (1) male pedestrian fatalities that showed high levels of alcohol concentrations, (2) female and elderly pedestrian deaths that occurred between 6 a.m. and midday, and (3) children, adolescents, and young adult pedestrian fatalities that typically occurred during weekday afternoons and evenings. The findings recommend for multiple strategies for combating pedestrian fatalities.

Road traffic injuries in general and pedestrian injuries in particular are also a major public health problem in Mexico, especially in large urban areas. An analysis of mortality and road collisions at the national level was done by Hijar et al. (2003) using routine data recorded on death certificates. These data were supplemented by a cross-sectional study of pedestrian injuries in Mexico City based on death certificates information for pedestrians who lived and died in Mexico City between 1994 and 1997. Participant observation of physical spaces where collisions occurred was carried out. The spaces were filmed and in-depth interviews of survivors conducted. They reported that 9500 of the fatalities were pedestrians, and for every pedestrian death there were 13 others who sustained nonfatal injuries requiring medical care. The overall crude mortality rate for pedestrian injuries in Mexico City was 7.14 per 100,000 (CI 6.85-7.42). Observational studies conducted in 10 neighbourhoods concluded that dangerous crossings, absence or inadequacy of pedestrian bridges, and negative perceptions of road safety by pedestrians, were some of the risk factors.

Hossain (2006) examined pedestrian collision factors in Thailand using injury surveillance data collected from 28 hospitals over the period 1999-2003. The study used descriptive statistics to evaluate the contributing factors of pedestrian collisions. The study identified motorcycle was the main type of vehicle involved in collisions, causing 51% of pedestrian collision. Children under the age of 10 years were found to be the most vulnerable. Also, a substantial number of drunken pedestrians were found to be involved in collisions between 6:00 p.m. and 3:00 a.m.

Several studies were done on pedestrian collisions in Bangladesh. Collision data stored in the Accident Research Institute in Bangladesh were used. Hoque (2006) found that about one third of the total pedestrian fatalities are children under age of 16 years. Fatalities of female child pedestrians are disproportionately higher than those of male child pedestrians (45% vs. 29%). Mahmud et al. (2006) found that dangerous pedestrian crossing contributed to 46% of all pedestrian fatalities in Dhaka city. It was also found that peak time for pedestrian collision occurrence was between 9 a.m. to noon.

Yang and Otte (2007) conducted a comparative study of pedestrian collisions in China and Germany. They found that pedestrian collision is a common problem in both motorized countries and motorizing countries, which occur frequently in build up areas, but the injury risk for pedestrians in Germany lower than in China. They also found that younger and older pedestrians are more at risk in Germany but adult pedestrians (20 to 50 years old) are more at risk in China. Also, compared to Germany where the major collision partner of a pedestrian was a car (80.6%), 43.9 % of the collisions in China were motorcycle-pedestrian collisions while 30.3 % were collisions with passenger cars.

2.5 Summary

Due to scarcity of resources, the importance of effective road safety resource allocation is paramount in developing countries like Bangladesh. Existing practices for fund allocation are based largely on experience and other non safety considerations. Therefore, it is important to develop suitable resource allocation models based on evidence and taking into account the local conditions and practices.

Also, there is no comprehensive study on pedestrian collision factors in Bangladesh. Existing studies used simple descriptive type of statistics. Since collisions are complex multifactor evens, it is worthwhile to implement multivariate statistical approach.

Chapter Three: METHODOLOGY

3.1 Introduction

This chapter starts by providing some discussions on some of the different dimensions of the road safety problem such as spatial dispersion, collision severity and externality. Next, an outline on the Data Envelopment Analysis (DEA) method will be provided because it will be used to address the issue of spatial dispersion of road collisions and its implications on the efficient allocation of the road safety budget among different geographic regions. . Finally, the binary logit method will be presented because it is used to identify risk factors associated with pedestrian collisions.

3.2 Dimensions of Road Safety Problem

Safety problems are multidimensional. Depending on which dimensions we focused on, different countermeasures may be seen as important for solving the road safety problems. It is obvious that there is no single "right" way of defining a road safety problem. A reasonable definition is that a road safety problem is any factor that contributes to the occurrence of collisions or the severity of injuries. The term road safety problem is broadly synonymous with the term risk factor, interpreted in a wide sense that includes traffic volume as a risk factor (Elvik, 2008).

According to this definition, a road safety problem may exist even if it is not recognized. Before the recent surge in research concerning driver fatigue (Elvik, 2008), this factor was not recognized as a major problem. Moreover, even if research has shown that a certain factor, such as speeding, contributes significantly to collisions, road users may not see it as a problem and may not want action to be taken. One should therefore distinguish between the statistical analysis of road safety problems and the perception of such problems. This distinction is particularly relevant as far as the prospects of solving road safety problems are concerned: Unless a problem is seen as a problem, it is not likely to be solved.

Table 3.1 describes the nine dimensions of road safety problems that are proposed by (Elvik, 2008). Aligned with objectives of this research work, two important dimensions of road safety problems (spatial dispersion and collision severity) are identified.

Table 3.1: Dimensions of Road Safety Problems and Their Numerical Indicators

Dimension	Definition	Numerical indicator
1. Magnitude	The size of the contribution a problem makes to the total number of collisions or killed or injured road users	Population attributable risk represented by a problem
2. Severity	The gradient of the attributable risk associated with a problem with respect to levels of injury severity	Comparison of the attributable risk associated with a problem across levels of injury severity; comparing shares of injuries by levels of severity
3. Externality	The fact that travel performed by one group of road users imposes an additional risk on other groups of road users	The net contribution to the overall risk of a road user group attributable to risks imposed by other groups

4. Inequity	The size of the contribution to risk made by a lack of proportionality between the benefits of transport and the risk run	Difference in number of injuries between: (a) current distribution of risk and (b) a distribution of risk in proportion to shares of exposure
5. Complexity	The extent to which the specific contributions of individual risk factors to the overall risk represented by a problem can be identified	Complexity is indicated by: (a) many factors each making a small contribution to overall risk; (b) correlations among factors preventing their unique contributions from being identified; (c) interactions among risk factors with respect to their effect on collision rate (d) "over-determination", i.e. the sum of known factors more than explain overall risk
6. Spatial dispersion	The degree to which a collision problem is concentrated geographically	Distance between collision concentrations that have been identified statistically
7.Temporal stability	Changes over time with respect to the magnitude of a road safety problem	A time-series of the population attributable risk represented by a problem
8. Perceived urgency	The strength of the support in the population for stronger action or regulations designed to solve a problem	Results of opinion polls regarding the support for stronger action to solve specific road safety problems
9. Amenability to Treatment	The prospect of implementing effective safety treatments, i.e. treatments that will reduce a problem (in particular its magnitude)	A function of complexity, perceived urgency and knowledge of effective treatments

(Source: Elvik, 2008)

Spatial dispersion problem is typically problems related to the quality of infrastructure (roads, traffic control devices, etc,) that have a geographic dimension. Spatial dispersion is related with our first study on the efficient allocation of road safety resources among different geographic regions.

Severity level is one of the extensively used dimensions of road safety problem. It is widely agreed that fatalities are the most serious outcomes of road safety problems, followed by serious injuries, while property damages are the least serious of the road safety problems. Hence, a road safety problem is severe if it makes a greater contribution to fatalities and serious injuries than slight injuries or property damage. There are many ways to assess the severity of a road safety problem. An approach which employs the notion of attributable risk is to compare estimates of attributable risk across levels of injury severity. This severity concept is used in the second study to identify prominent pedestrian collision factors.

3.3 Data Envelopment Analysis (DEA) Model Structure

3.3.1 Basics of Linear Programming and Simplex Method of Optimization

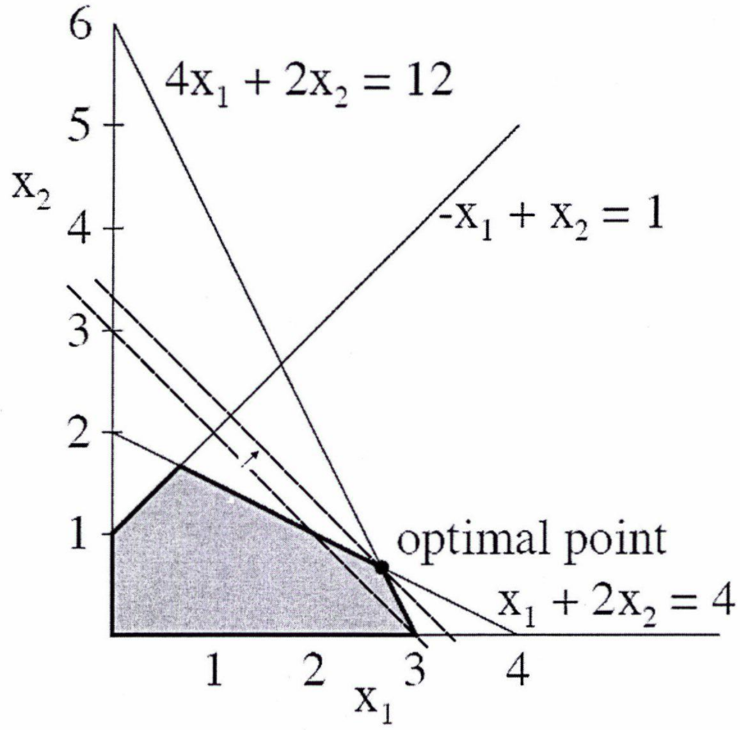
Since the DEA technique uses linear programming method for optimizing objective functions, a brief overview of the linear programming method will be presented in this section. A linear programming problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints. The constraints may be equalities or inequalities. A typical linear problem is shown below.

$$\begin{aligned} \textit{Maximize} \quad & x_1 + x_2 \\ \text{Subject to,} \quad & x_{1,}\ x_2 \geq 0 \\ & x_1 + 2x_2 \leq 4 \\ & 4x_1 + 2x_2 \leq 12 \\ & -x_1 + x_2 \leq 1 \end{aligned}$$

In this problem there are two decision variables, and five constraints. All the constraints are inequalities and they are all linear in the sense that each involves an inequality as a linear function of the variables. The first two constraints, $x_1 \geq 0$ and $x_2 \geq 0$, are special. These are called non-negativity constraints and are often found in linear programming problems. The other constraints are called the main constraints. The function to be maximized (or minimized) is called the objective function.

Since there are only two variables, we can solve this problem by graphing the set of points in the Cartesian plane that satisfies all the constraints (called the constraint set) and then finding which point of this set maximizes the value of the objective function. Each inequality constraint is satisfied by a half-plane of points, and the constraint set is the intersection of all the half-planes. In the present example, the constraint set is the five sided figure shaded in Figure 3.1.

Figure 3.1 Graphical Solution of Linear Programming Problem



We seek the point (x_1, x_2), that achieves the maximum of $x_1 + x_2$ as (x_1, x_2) ranges over this constraint set. The function $x_1 + x_2$ is constant on lines with slope -1, for example the line $x_1 + x_2 = 1$, and as we move this line further from the origin up and to the right, the value of $x_1 + x_2$ increases. Therefore, we seek the line of slope -1 that is farthest from the origin and still touches the constraint set. This occurs at the intersection of the lines $x_1 + 2x_2 = 4$ and $4x_1 + 2x_2 = 12$, namely, $(x_1, x_2) = (8/3, 2/3)$. The value of the objective function there is $(8/3) + (2/3) = 10/3$.

3.3.1.1 Simplex Method

The Simplex method is a commonly used algorithm for solving a linear programming problem. Mathematically, it is much more convenient to deal with equations than inequality relationships. Therefore, the first step in setting up the Simplex method is to convert the functional inequalities constraints into equivalent equality constraints. This is done by introducing slack variables. For example, in the following mathematical programming model with inequality constraints,

$$\begin{aligned} &\text{Maximize } Z = x_1 + 2x_2 - x_3 \\ &\text{subject to:} \quad 2x_1 + x_2 + x_3 \le 14 \\ &\qquad 4x_1 + 2x_2 + 3x_3 \le 28 \\ &\qquad 2x_1 + 5x_2 + 5x_3 \le 30 \\ &\qquad x_j \ge 0 \;\; for\, j = 1, 2, \ldots\ldots, 3. \end{aligned}$$

we can introduce slack variables to get a new set of equality constraints

$$\begin{aligned} 2x_1 + x_2 + x_3 + s_1 &= 14 \\ 4x_1 + 2x_2 + 3x_3 \quad + s_2 &= 28 \\ 2x_1 + 5x_2 + 5x_3 \quad + s_3 &= 30 \\ x_j \ge 0 \;\; for\, j = 1, 2, \ldots\ldots, 3. \end{aligned}$$

To solve the optimization problem using the Simplex method, a Simplex tableau has to be created. In the table, the objective function is presented in the bottom row using the negatives of its coefficients. The lower right corner shows the value of objective function which usually starts out as zero initially. The main constraints are shown in the rows above. Note that the non-negativity constraints are generally not used in the table.

X_1	X_2	X_3	S_1	S_2	S_3	RHS
2	1	1	1	0	0	14
4	2	3	0	1	0	28
2	5	5	0	0	1	30
-1	-2	+1	0	0	0	0

Let the pivot column be the column containing the most negative value in the bottom row; if no value is negative, the tableau is a final tableau. Thus, the pivot column in the above table is column 2 which has a value of -2. Let the pivot row be the row with the smallest non-negative ratio (quotient) of the RHS value of each row to the corresponding value in the pivot column. In the able above, the ratios are (14/1, 28/2 & 6/1) respectively. Therefore, the pivot row is the third row. The pivot number is the value located at the intersection of the pivot row and the pivot column. In the column above, the pivot is 5.

Once the picot row, column and number are identified, pivot transformations are then performed in several steps. First, make the pivot number 1 by diving the pivot's row by the pivot number. The third row in the table below is obtained by dividing the third row in the table above by the pivot number which is 5. The transformation can be expressed by $R_3 = \frac{1}{5} \times r_3$ where R_3 is the third row in the new table and r_3 is the third row from previous table.

2	1	1	1	0	0	14
4	2	3	0	1	0	28
2/5	1	1	0	0	1/5	6
-1	-2	+1	0	0	0	0

Next, the values of the remainder of the pivot's column are made 0 with appropriate linear transformation using pivot row: $R_1 = r_1 - r_2$ and $R_2 = r_2 - 2r_3$ and $R_4 = r_4 + 2r_3$

8/3	0	0	1	0	-1/5	8
16/5	0	1	0	1	-2/5	16
2/5	1	1	0	0	1/5	6
-1/5	0	3	0	0	2/5	12

For this example as one value in the bottom row is still negative, the previous steps are applied again to obtain the following table.

0	0	-1/2	1	-1/2	0	0
1	0	5/16	0	5/16	-1/8	5
0	1	7/8	0	-1/8	1/4	4
0	0	49/16	0	1/16	3/8	13

Since no value in the bottom row is negative, the tableau shown is the final tableau. In the first column, which corresponds to x_1, the row two has a value of 1 whereas rows one and three have a value of zero. The optimal solution for x_1 is given by the value in the RHS of row two, which is equal to 5. Similarly, the optimal value of x_2 is given by value of the RHS o f row three, which is equal to 4 and x_3 is equal to 0. Finally, the maximum value of the objective function is 13.

In addition to finding an optimal solution, the Simplex method also provides other valuable information for further analysis of the model. Linear programming typically can be interpreted as allocating resources to activities under consideration. The Simplex method provides this information in the form of shadow prices for the respective resources. The shadow price for resource measures the marginal value of this resource, that is, the rate at which objective function being made available. The Simplex method identifies this shadow price by value of the slack variables of the final simplex tableau.

3.3.2 DEA Framework

Data Envelopment Analysis (DEA) is a linear programming-based technique for determining the relative efficiency of decision making units (DMUs), based on the performance of all other DMUs in the data set (Charnes, 1994). Using a linear programming model, the best performing ("best practice") DMUs in the data set are used to define an efficiency frontier, against which all other DMUs are benchmarked. The "best practice" DMUs are assigned efficiency score of "1" or 100%. The efficiency score for each DMU is calculated based on its distance from the efficiency frontier. The method of calculating distance from the frontier depends on the type of DEA model used (e.g., input minimizing, output maximizing, additive, etc.).

For brevity, the mathematical formulations, as well as detailed description of the different types of DEA models, are not presented here. Instead, the reader is referred to several excellent, comprehensive texts (Boussofiane, 1991 and Allen, 1997). Currently, several DEA software packages exist to allow managers and researchers to implement DEA models without directly solving a linear program for each DMU (Herrero, 2002). The analysis in this study used Efficiency Measurement System (EMS), which is available free of cost for academic purpose.

DEA found its way to transportation analysis in a variety of assessments and it has been used in benchmarking of railways, aviation and airport performance assessments, and public transportation systems evaluations. A common measure for relative efficiency is given by the following expression.

$$Efficiency = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs}$$

It can be defined mathematically as follows:

$$Efficiency\ of\ DMU_j = \frac{u_i y_{1j} + u_2 y_{2j} + \cdots + u_{k-1} y_{(k-1)j} + u_k y_{kj}}{v_i x_{1j} + v_2 x_{2j} + \cdots + v_{l-1} x_{(l-1)j} + v_l x_{lj}} \leq 1$$

Where

$u_k = weight\ of\ output\ k,$

$y_{kj} = amount\ of\ output\ k\ from\ unit\ j,$

$v_l =$ weight of input l, and,

$x_{lj} = amount\ of\ output\ l\ from\ unit\ j.$

It is assumed that under a given production process, each decision making unit (DMU) will optimize its efficiency under the constraint of availability of input factors. Consequently, for a known input–output volume, Equation 1 becomes an optimization problem. Here the solution produces weights, which are most favorable to unit *j*, and provides a measure of efficiency. Charnes et al. (1978) developed the following version of the DEA model (Model 1).

$$max_{u,v} = \frac{\sum_r u_r y_{r0}}{\sum_i v_i x_{i0}} \; for\; each\; unit\; j$$

Subject to

$$\frac{\sum_r u_r y_{rj}}{\sum_r v_i x_{ij}} \leq 1 \qquad (j = 1, 2, \ldots, n) \; and$$

$$u_r \geq 0 \qquad (r = 1, 2, \ldots, m) and\; v_i \geq 0$$

The $(y_{rj}, x_{ij}) > 0$ in the model are constants that represent observed amounts of the *rth* output and the *i*th input of the *j*th DMU. And h_0 is the efficiency term and it is for unit 0, the DMU whose relative efficiency is to be calculated with respect to other DMUs. Because the efficiency in the analytical framework described above refers to technical efficiency, satisfying the constraint $h_j \leq 1$ as shown in the models above is required. The solution to the model above gives a value h_0 and the weights leading to that efficiency.

The model described above is a fractional linear program. To solve the model it is necessary to convert it into linear form so that linear programming methods can be applied. In the objective function it can be observed that, while maximizing a fraction or ratio, it is the relative magnitudes of the numerator and denominator that are of interest rather than their individual values. It is thus possible to achieve the same effect by setting the denominator equal to a constant and maximizing the numerator. The resulting linear programming model is shown below (Model 2).

$$max_{u,v} \ \ h_0 = \sum_r u_r y_{ro}$$

Subject to

$$\sum_i v_i x_{io} = 1$$

$\sum_i u_r y_{rj} - \sum_i v_i x_{ij} \leq 0 \qquad j = 1, 2, \dots, n$

$$u_r \geq 0 \qquad (r = 1, 2, \dots, m) \ \ and \ v_j \geq 0 \qquad (i = 1, 2, \dots, k)$$

The efficiency of the target unit in a set can be obtained by solving Model 3. The solution to this linear program provides a measure of the relative efficiency of the target unit and the weights leading to that efficiency. These weights are the most favorable ones from the point of view of the target unit. To obtain the efficiencies of the entire set of units, it is necessary to solve a linear program focusing on each unit in turn. Clearly, as the objective function varies from problem to problem, the weights obtained for each target unit may be different.

In solving each linear program the solution technique will attempt to make the efficiency of the target unit as great as possible. This search procedure will terminate when either the efficiency of the target unit or the efficiency of one or more other units hits the upper limit of 1. Thus for an inefficient unit, at least one other unit will be efficient with the target unit's set of weights. These efficient units are known as the peer group for the inefficient unit. It is sometimes useful to scale the data on the peer units so that a better comparison of the inefficient unit with the peer units can be made. Input data of the peer units are to be scaled in such a way that each peer unit may use no more of an input than the inefficient unit.

The solution to the DEA model thus provides a relative efficiency measure for each unit in the set, a subset of peer units for each inefficient unit, and a set of targets for each inefficient unit. The dual of the linear program, presented above in Model 2, provides useful information and knowledge concerning the mechanism of efficiency estimation and significance of the parameters. It also involves fewer constraints than the primal and hence is generally the preferred model to solve. The dual is shown below in Model 3.

$$min_{\theta,\lambda} \quad \theta_0$$

Subject to

$$-y_{r0} + \sum_j y_{rj}\lambda_j \geq 0 \qquad r = 1, 2, \dots, m$$

$$\theta\, x_{i0} + \sum_j x_{ij}\lambda_j \geq 0 \qquad i = 1, 2, \dots, k$$

Here θ_0 provides the efficiency score of the 0th unit. Each of the constraints of Model 3 is associated with either the inputs or the outputs. The principle of complementary slackness can be used to obtain the following sets of identities from the results of Model 2 and Model 3 at optimum solution, implying that the values of the weight factors u_r and v_i provide the shadow prices (or marginal rate of return) for the relevant outputs and inputs, respectively. The identities demonstrate that values of the weight factors provide the effect of marginal change in constraint boundary on the value of DMU's efficiency.

$$u_r\left(-y_{ro}+\sum_j y_{rj}\lambda_j\right)=0 \qquad r=1,2,\dots,m$$

$$v_i\left(\theta x_{io}+\sum_j x_{ij}\lambda_j\right)=0 \qquad i=1,2,\dots,k$$

The method is applied in this study to measure the relative risk efficiency of different regions (districts) of Bangladesh and to examine the funding requirements with respect to other production factors in achieving the efficiency level.

3.4 Binary Logit Model

This study aims to evaluate the associations between pedestrian injury risk and possible contributory factors. In our study, the response variable, fatal pedestrian collision or non-fatal pedestrian collision is a binary or dichotomous variable. The dichotomous nature of the response variable facilitates the application of binary logistic regression, for which the probability of fatal collisions against non-fatal collision is estimated by the maximum likelihood method. The logistic regression model is widely used in road safety studies where the dependent variable is binary (Valent et al., 2002; Jones and Whitfield, 1988; Lui et al., 1988; Shibata and Fukuda, 1994; Zhang et al., 2000; Simoncic, 2001). In this model, the logit is the natural logarithm of the odds or the likelihood ratio that the dependent variable is 1 (fatal pedestrian collision) as opposed to 0 (non-fatal pedestrian collision). The probability P of a pedestrian collision outcome is given by

$$Y = logit\ (P) = \ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_j x_j + \cdots + \beta_p x_p + \varepsilon_i$$

Where Y is a latent variable measuring collision severity

β is a vector of unknown parameters

ε_i is the extreme value type I distribution of error term

In our model, the logit g(x) can be interpreted as the index of collision severity which is a latent variable.

$$g(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_j x_j + \cdots + \beta_p x_p$$

where x_j is the value of the jth independent variable, with β_j as the corresponding coefficient, for j=1, 2, 3, . . ., p, and p is the number of independent variables.

The conditional probability of a positive outcome is determined by

$$\pi(x) = \frac{\exp\,(g(x))}{1 + \exp\,(g(x))}$$

The likelihood function can then be expressed as follows:

$$l(\beta) = \prod_{i=1}^{n} \pi\,(x_i)^{y_i}(1 - \pi(x_i))^{1-y_i}$$

where y_i denotes the *i*th observed outcome, with the value of either 0 or 1 only, and i =1, 2, 3, . . ., n, where n is the number of observations.

The best estimate of β could be obtained by maximizing the log likelihood function:

$$LL(\beta) = \ln\big(l(\beta)\big) = \textstyle\sum_{i=1}^{n}\{y_i \ln\big(\pi(x_i)\big) + (1 - y_i)\ln\,(1 - \pi(x_i))\}$$

In the logistic model, it is common to estimate the influence of attribute k on injury outcome by its odds ratio which is given by:

$$OR = \exp\big(\beta_j\big)$$

The odds ratio has a 95% confidence intervals of $[\exp\big(\beta_j - 1.96 s_{\beta i}\big), \exp\big(\beta_j + 1.96 s_{\beta i}\big)]$ where s_β is the standard error of the coefficient β. An odds ratio that is greater than 1 indicates that the concerned attribute leads to a higher injury risk, and vice versa.

The goodness-of-fit of the predictive model should be assessed. To evaluate the significance and predictive power of the logistic regression model, the change in deviance can be determined by comparing the log likelihood functions between the unrestricted model and the restricted model with the following expression:

$$G = -2\big(LL(c) - LL(\theta)\big)$$

where LL(c) is the log likelihood function of the restricted model and LL(θ) is the log likelihood function of the unrestricted model. Under the null hypothesis that the coefficients for the predictive model are equal to zero, G is chi-square distributed with p degrees of freedom, where p is the number of variables that are considered. If G is significant at the 10% level, then the null hypothesis would be rejected, and one could conclude that the proposed model generally fits well with the observed outcome. 10% significance value is used in this study rather than 5% significance because accident as low probability event and the level of uncertainty involved in collision data collection and reporting.

After the model building process with maximum likelihood, a series of analyses should be conducted to further assess the validity of the model. Its effectiveness in describing the associations between the dependent variable and possible contributory factors could be evaluated and revealed by numerical overall measures with the Hosmer–Lemeshow statistic (Hosmer and Lemeshow, 1980) and graphical microscopic illustrations with logistic regression diagnostics (Pregibon, 1981), respectively.

3.4.1 Hosmer–Lemeshow statistic

A summary measure verifies the fit of a model by first computing the difference between the observed and predicted scores throughout the entire collection of observations, then examining the individual contribution of the difference from each pair relative to the error structure of the whole model, and, finally, determining the suitability and efficiency of the model by a single statistic. Empirical consistency, which refers to the observed outcome behaving in accordance with the model prediction, is revealed by a chi-square statistic that is computed with a contingency table that collapses the observations into a fixed number of groups.

Hosmer and Lemeshow (1980) proposed a grouping strategy that is based on the value of estimated probabilities. Supposing that there are n observations in the probability model, Group 1 would consist of the n/g observations with the lowest predicted probabilities, Group 2 would consist of the n/g observations with the next lowest predicted probabilities, and so on. Once all of the groups are created, a Pearson chi-square statistic is estimated based on the observed and expected number of observations in the interest category of every group. When the Pearson chi-square statistic is significant, the null hypothesis that the proposed model sufficiently describes the empirical association is rejected. Let n_k be the number of observations in the *k*th group and y_i be the response of the *i*th observation. Then, the number of observed responses of interest for the *k*th group would be

$$O_k = \sum_{i=1}^{n_k} y_i$$

In contrast, if $\bar{\pi}_i$ denotes the predicted probability for the ith observation, then the average estimated probability for this group would be

$$\bar{\pi}_k = \sum_{i=1}^{n_k} \frac{\bar{\pi}_i}{n_k}$$

Eventually, the Pearson chi-square statistic is determined by

$$\hat{C} = \sum_{k=1}^{g} \frac{(o_k - n_k\bar{\pi}_k)^2}{n_k\bar{\pi}_k(1-\bar{\pi}_k)},$$

with a (g–2) degree of freedom.

The Hosmer–Lemeshow statistic is usually computed using g = 10 groups. However, because the restriction of $g > p+1$, where p is the number of covariates in the proposed model, arose in the simulation process that was demonstrated by Lemeshow and Hosmer (1982), g equals to number covariates plus 1 is used in the current study.

3.4.2 Logistic Regression Diagnostics

The Hosmer–Lemeshow test evaluates the goodness-of-fit with a single number that summarizes the discrepancy between the observed and the predicted probability. It may be considered that the use of a single number to summarize a considerable amount of information is not satisfactory; therefore, a more precise approach may be sought. Regression diagnostics, which scan through the entire collection of observations and illustrate the agreement between the observed and predicted scores for all of the individual observations, should sufficiently satisfy doubts. Let X denote the design matrix for the entire collection of observations, and the quantities that are central to the formation of regression diagnostics are the leverage values that are derived (Pregibon, 1981) by approximating the hat matrix

$$H = V^{1/2}X(X^T VX)^{-1}X^T V^{1/2}$$

where V is a diagonal matrix that is associated with the residuals of the regression model, for which $V^{1/2}$ should be a diagonal matrix with a general element equal to $\sqrt{v}$.

After the estimation of leverage values, one can compute several useful diagnostic statistics that examine the influential power of the deficiency of every observation; in other words, the impact on such attributes as likelihood ratio, deviance, and coefficient estimates. For regression diagnostics, one relies primarily on visual assessment. Generally, the model fits well when the influence diagnostic is not large over the entire collection of observations. In the current study, it is examined by logistic regression diagnostics the influential power throughout the entire collection of observations on coefficient estimates with

$$\Delta\hat{\beta}_i = \left(\hat{\beta} \; - \hat{\beta}_{(-i)}\right)^T (X^T VX)\left(\hat{\beta} \; - \hat{\beta}_{(-i)}\right)$$

where $\hat{\beta}$ denotes the estimated coefficients with a full sample and $\hat{\beta}_{(-i)}$ denotes the estimated coefficients with a full sample that excludes the ith observation.

3.5 Data Structure for Modelling

The data that is used in both studies is obtained from the MAAP5 database that is maintained by the Bangladesh Police and Accident Research Institute (ARI), Bangladesh. Similar to most police reported collision data, there are several issues associated with under-reporting, especially with minor collisions. In Bangladesh, injury severity is divided into four levels: fatal, serious injury, simple injury, and collision only. Fatality refers to immediate death or subsequent death from injuries within 30 days of an collision, serious injury refers to injury that requires hospitalization, and slight injury refers to an injury that does not require hospitalization but requires some medical attention, and collision only refers to collisions that only involves vehicle damage/or loss of property. The last category is commonly referred to as property damage only (PDO) collisions.

According to MAAP database, collisions were distributed as follows: fatal 65 per cent, serious injury 24 per cent, simple injury 6 per cent and collision only collisions 5 per cent. The proportions for non-fatal accidents are expected to be much higher than these numbers. Although the under-reporting of non fatal collision is common in most countries, these statistics clearly demonstrates that the reliability of collision data in a developing country like Bangladesh is very not very high. Besides the under-reporting of non fatal collisions, the database also suffers from the problem of missing values for many important variables. As the collision data are collected from police report, the accuracy of the collision data is largely dependent on the policeman who is recording the information about the collision. Often, the policeman who is recording the collision information does not feel the need to record the roadway information (e.g., road surface type, roadway geometry, road surface, etc). Besides roadway information, the age and sex of the road users involved, the age and type of vehicles involved in collisions, the licensing status of the drivers involved in collisions, the speed limit of the roadway and the manoeuvre of the vehicles during collision are significant variables in collision severity analyses. But accurate data on these variables are often unavailable due to the negligence of the police in recording information. These lacks of information about road traffic collisions in Bangladesh often compel the researchers to discard some variables that might be significant in collision analysis or reporting unreliability associated with those variables. In the first study the issue of under reporting is addressed by using only fatality number which is expected to have a reasonably high reporting rate. In addition, it is assumed that underreporting bias is consistent among various geographical regions.

It should be noted that the problems associated with the reliability of police reported collision data is common in most countries and several researches have compared the reliability of different sources of data. Popkin et al. (1991) carried out a study of hospital emergency department records in North Carolina. Of the 435 vehicle occupants coded by police as having an incapacitating injury, 126 (29%) were rated by medical personnel as having only minor injuries. Police were much better at evaluating non incapacitating injuries. Of the 326 vehicle occupants coded by police as having non incapacitating injuries, 297 (91%) were rated by medical personnel as having minor or moderate injuries. Rosman and Knuiman (1994) linked police collision reports in Western Australia to hospital inpatient records. Of the 3,368 road users (including pedestrians) coded by police as requiring hospital admission, 627 (19%) were transported to a hospital without subsequent admission and another 866 (26%) had no hospital record. Problems in the linkage process may have accounted for some of the missing hospital records, but statistical checks on link quality yielded low estimated error rates. Austin (1995) compared information from police reports in the United Kingdom with information from highway and hospital databases. Information pertaining to the roadway was correctly coded most of the time. For example, posted speed limit was correct in 93% of collision reports. Information pertaining to the injured person was less reliable. Of 1,038 police reports successfully linked to individual hospital records, 163 (16%) had age miscoded and 126 (12%) had injury severity miscoded.

Besides the reliability, there are several other common issues regarding collision database. For example, Kockelman and Kweon (2001) found that different regions may possess systematically different reporting styles or different road geometries, and different relationships between variables of interest, which creates a geographical heterogeneity issue. Matthew and Andrzej (1998) emphasized this issue in their work and clustered their collision data by counties. In comparing their negative binomial models of pooled data with models for distinct clusters, there were statistically significant differences, and the latter performed best.

McCarthy and Madanat (1994) emphasized the continuous nature of collision severity and stress the importance of unconditioning samples (via, e.g., a Tobit specification) to accommodate all degrees of collision severity. Thus, if underreporting is present and/or data are pre-conditioned (e.g., only fatal collisions are examined), parameter estimates may be structurally biased away from the relations of true interest. Research that recognizes the probabilities of collision involvement and collision reporting will allow for an unconditioning away from collision-prone populations and high-reporting situations; unfortunately, such work is largely missing from this field and its literature (for an example emphasizing collision involvement of unlicensed drivers).

3.6 Summary

This chapter provides a brief methodological framework of DEA and binary logit models. For the first study, DEA method is proposed. For the second study regarding pedestrian collision factors, logistic regression approach is proposed to evaluate temporal and interaction effects. Sources of data for modelling and limitations of data are also described in this chapter.

Chapter Four: MODEL DEVELOPMENT AND RESULTS

4.1 Introduction

Pedestrians, users of non-motorized vehicles – including bicycles, rickshaws and carts – and motorcyclists in low-income and middle-income countries carry a large proportion of the burden of road traffic deaths and serious injuries. Addressing the pedestrian collision problem along with other motorized vehicle collisions is a critical issue for developing countries like Bangladesh. Section 4.2 provides simple model estimates for budgetary need among different geographic locations in Bangladesh. This analysis is particularly important for allocating road safety fund among various regions efficiently. Identification of the prominent (statistically significant) risk factors is another way to provide cost effective solution to the road safety problem. The section 4.3 describes binary logit models and their results, illustrating critical pedestrian collision risk factors.

4.2 Development of Model for Prioritizing Traffic Safety Fund

4.2.1 Data Requirement of DEA model

For this study twenty different districts (regions) of Bangladesh are selected. These regions/districts use as DMU of DEA model. A new term Relative Regional Risk Efficiency (RRRE) is introduced. It measures the road fatality risk corresponding to various inputs. The DEA method is applied in this study to measure the Relative Regional Risk Efficiency (RRRE) of those districts. RRRE are measured as a weighted ratio of output (vehicle collisions) and input elements (population, size, road, income, etc). Areas with higher RRRE values should get higher priority for safety improvements because they have more fatalities for the same level of input or collision contributing factors.

The factors considered in the analysis include length of national, regional and feeder roads, effective land resources, regional population, regional transportation accessibility and sector-specific GDP (Gross Domestic product) as input elements. The output elements include the annual average number of fatality in total as well as separately for pedestrian and motor vehicle fatalities. Collision data for the five years, from 2000 to 2004, is used for this analysis. Also, all input and output variables are normalized with respect to maximum value of the corresponding variable.

Data concerning population and effective land area are obtained from the national census report (BBS, 2002). Effective land area is estimated as the aggregate of actual land of the region weighted by productivity of the land. Transportation accessibility data is collected from a secondary source (Alam, 2004). Widely varying measures of accessibility range from measurement of transportation stock in a region to accessibility measures based on random utility models as summarized in (Niemeier, 1997).

GDP is classified into primary-sector (agricultural) GDP, secondary-sector (manufacturing) GDP, and tertiary-sector (service) GDP. Length of road network is also an important determinant. For this analysis length of national and regional highways are considered as one single input factor and length of feeder road is considered as another input factor. Data on regional contributions to GDP and road length are also obtained from the national census report (BBS, 2002).

Table 4.1 provides a summary of the data set used in the analysis. It is observed that Dhaka is the most collision prone area in terms of fatalities followed by Chittagong, Mymensingh and Sylhet. It is also observed that Dhaka is the most productive region of the country, contributing the highest amount of GPD, and that it utilizes the greatest amount of all input resources except land area. In addition, the central regions, especially Dhaka, are more accessible than the peripheral regions.

Table 4.1: Input and Output Variables Used in the Analysis

Region/District	Population , Millions	Accessibility Index	Effective Land, sq. km	Feeder road, km	Highway (National and Regional), km	GDP in Million Taka			Fatality		
						Agriculture	Industry	Service	Total	Motorized Vehicle	Pedestrian
Dhaka	17.198	6.801	10372	80	70	31208	63365	155498	507	187	320
Mymensingh	8.902	3.332	15500	544	106	38870	10640	70069	159	115	44
Jamalpur	3.335	1.347	5670	140	21	14609	9453	25560	22	17	5
Tangail	3.254	1.674	5362	242	144	14771	5739	27181	165	136	29
Faridpur	5.985	1.756	10761	208	83	24192	9503	57960	79	60	19
Chittagong	8.302	1.785	10328	1020	208	35159	56425	91267	249	169	80
CHT	1.325	0.165	13729	1094	133	39527	3379	19131	83	74	9
Noakhali	5.208	1.292	8778	401	41	18378	7477	41289	35	19	15
Comilla	9.163	2.818	11052	734	167	32202	16100	86227	152	121	31
Sylhet	7.9	1.56	15767	298	142	33861	14123	68991	158	97	61
Rajshahi	7.579	2.259	12796	200	124	32950	8371	56970	87	47	40
Dinajpur	4.643	1.271	10959	256	108	21322	6009	35319	58	40	19
Rangpur	9.074	2.532	16062	252	71	39005	10742	66242	63	43	20
Bogra	3.833	1.303	6912	337	164	19768	5141	31548	70	54	15
Pabna	4.861	1.568	7430	256	116	15124	6540	33698	88	54	33
khulna	5.693	1.715	13889	246	67	34761	14951	56076	37	21	16
Barisal	5.83	1.818	12343	453	100	25487	8431	57213	26	19	7
Patuakhali	2.282	0.545	6625	211	68	13573	3796	16539	12	7	4
Jessore	5.494	1.725	10963	109	171	28547	7205	44956	90	52	38
Khustia	3.28	1.197	5597	135	106	14366	6198	25102	16	5	11

Table 4.2: RRRE and Weights of Total Fatalities Model

Region/District	RRRE (%)	Weight of the Parameters					GDP in Million Taka			
		Population	Accessibility Index	Effective Land	Feeder road	Highway (National and Regional)	Agriculture	Industry	Service	Total Fatality
Dhaka	100	0.000	0.000	0.000	11.230	0.531	0.00	0.000	0.000	1.000
Mymensingh	95	0.000	0.000	0.000	0.000	1.080	0.00	2.679	0.000	3.189
Jamalpur	26	0.000	0.000	0.000	0.000	2.123	0.00	5.267	0.000	23.045
Tangail	100	0.743	0.000	0.962	0.000	0.000	0.00	5.944	0.000	3.073
Faridpur	57	0.000	0.000	0.000	0.000	1.297	0.00	3.218	0.000	6.418
Chittagong	100	0.000	2.812	0.408	0.000	0.000	0.00	0.000	0.000	2.036
CHT	100	0.000	31.278	0.000	0.000	0.000	0.00	4.522	0.000	6.108
Noakhali	40	0.000	0.000	0.000	0.000	2.041	0.00	5.065	0.000	14.486
Comilla	60	0.000	1.249	0.000	0.000	0.411	0.00	0.599	0.000	3.336
Sylhet	98	0.000	3.585	0.000	0.653	0.000	0.00	0.000	0.000	3.209
Rajshahi	53	0.000	0.000	0.000	3.403	0.000	0.00	2.860	0.000	5.828
Dinajpur	45	0.000	3.406	0.000	0.200	0.543	0.00	0.365	0.000	8.741
Rangpur	46	0.000	0.000	0.000	0.000	1.312	0.00	3.256	0.000	8.048
Bogra	51	0.000	4.339	0.000	0.484	0.000	0.00	0.243	0.000	7.243
Pabna	60	0.000	0.000	0.000	0.000	1.229	0.00	3.049	0.000	5.761
khulna	25	0.000	2.923	0.000	0.172	0.466	0.00	0.314	0.000	13.703
Barisal	18	0.000	0.000	0.000	0.000	1.233	0.00	3.060	0.000	19.500
Patuakhali	19	0.000	9.524	0.000	1.062	0.000	0.00	0.534	0.000	42.250
Jessore	83	0.000	0.000	0.000	5.123	0.000	0.00	4.306	0.000	5.633
Khustia	14	0.000	4.433	0.000	1.781	0.000	0.00	0.000	0.000	31.688

Table 4.3: RRRE and Weights of Separate Motorized and Pedestrian Fatalities Model

Region/District	RRRE (%)	Weight of the Parameters									
			Accessibility Index	Effective Land	Feeder road	Highway (National and Regional)	GDP in Million Taka: Agriculture	GDP in Million Taka: Industry	GDP in Million Taka: Service	Motor Vehicle Fatality	Pedestrian Fatality
Dhaka	100	0.000	0.000	0.000	7.584	1.324	0.000	0.000	0.000	0.000	1.000
Mymensingh	100	0.000	0.000	0.000	0.000	1.593	0.000	1.120	0.000	1.629	0.000
Jamalpur	46	0.000	0.000	0.000	0.000	4.820	0.000	3.192	0.226	11.000	0.000
Tangail	100	0.000	0.000	1.104	0.682	0.000	0.000	1.365	2.042	1.375	0.000
Faridpur	66	0.000	0.096	0.000	0.000	1.955	0.000	1.301	0.000	3.138	0.000
Chittagong	100	0.000	2.847	0.393	0.000	0.000	0.000	0.000	0.000	0.646	1.674
CHT	100	0.000	36.716	0.000	0.000	0.000	0.000	2.049	0.000	2.534	0.000
Noakhali	41	0.000	0.000	0.000	0.000	0.067	0.000	8.363	0.000	0.147	20.449
Comilla	69	0.000	0.783	0.000	0.000	0.842	0.000	0.000	0.000	1.543	0.000
Sylhet	100	0.000	3.530	0.000	0.366	0.000	0.000	0.406	0.000	0.911	2.765
Rajshahi	91	0.000	0.000	0.000	0.000	0.058	0.000	7.306	0.000	0.057	7.959
Dinajpur	60	0.000	0.492	0.000	0.000	0.000	0.000	9.576	0.000	0.180	16.537
Rangpur	51	0.000	0.000	0.000	0.067	2.132	0.000	1.516	0.000	4.369	0.000
Bogra	59	0.000	0.565	0.000	0.000	0.000	0.000	10.992	0.000	0.213	19.482
Pabna	99	0.000	0.000	0.000	0.000	0.000	0.084	9.379	0.000	0.029	9.494
khulna	26	0.000	1.671	0.000	0.000	1.796	0.000	0.000	0.000	8.821	0.000
Barisal	19	0.000	0.084	0.000	0.000	1.717	0.000	1.143	0.000	9.740	0.000
Patuakhali	23	0.000	3.283	0.000	0.000	0.000	0.000	12.300	0.000	3.346	63.059
Jessore	100	0.000	0.000	0.000	0.054	0.000	0.000	8.747	0.000	0.008	8.398
Khustia	34	0.000	0.000	0.000	0.000	0.000	0.000	9.740	0.293	0.000	29.611

4.2.2 DEA model outcome

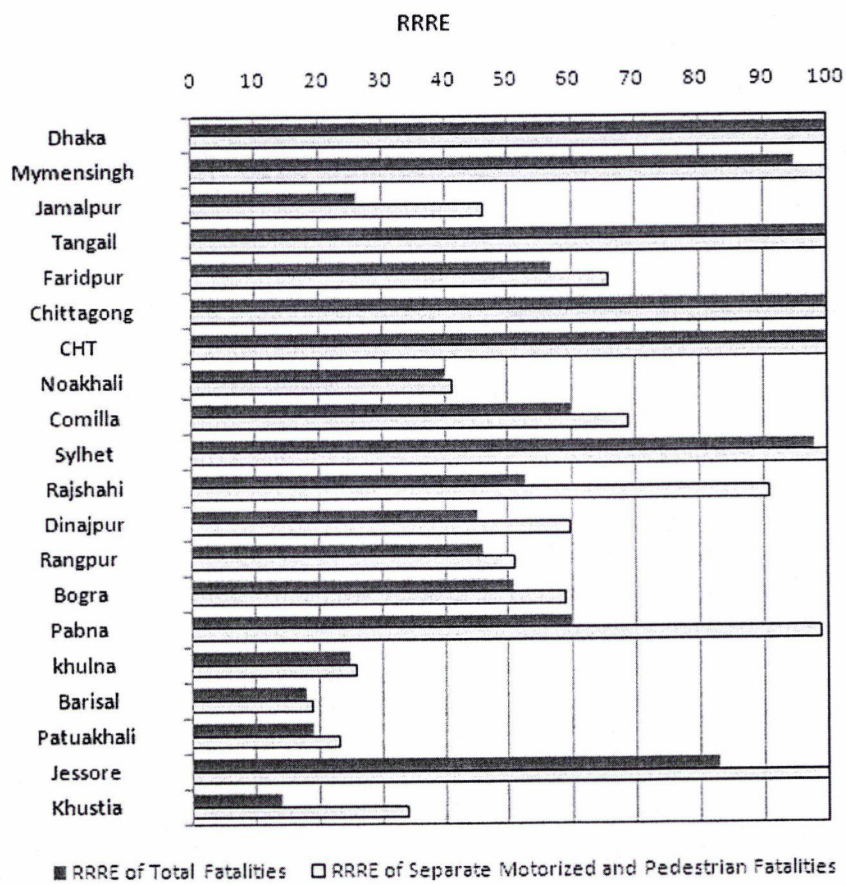
The following sections illustrate results obtained in the study. The first analysis is for the Relative Regional Risk Efficiency (RRRE) of the total number of fatalities, followed by analyses with separate vehicle occupants and pedestrian fatalities. The results of the aggregate fatality model are shown in Table 4.2. The results of separate pedestrian and motorized vehicular fatalities are shown in Table 4.3.

RRRE is defined as the ratio of weighted fatalities and weighted sum of input factors. The estimated RRRE explains the overall level of collision risk with respect to the input factors. Also, lower values of the weights of input variables imply that such variables become binding constraints in the process of optimization. As explained earlier the marginal rate of return for each specific input factor is provided by the values of the weights. A uniform value of the weight implies a balanced utilization of resources.

Among the 20 regions considered in the analysis, it is observed from Table 4.2 that four regions (shaded) are found to operate at relatively higher RRRE levels. These four regions are presumed to have higher collision risks. But even among these four regions, an imbalance exists in the roles of input factors. In the case of Dhaka, length of feeder road is an important factor with relatively higher value for its weight. Most of the collisions occurred in city streets of Dhaka and a large share involves pedestrian collisions. Thus, an increase in feeder road increases the fatalities for Dhaka region. For Chittagong Hill Tracts (CHT), on the other hand, an increase in the accessibility of the transport network has a larger impact on the number of traffic fatalities. As most part of the CHT and some part of Chittagong is mountainous, there is a greater need for road safety improvements with the growing transport infrastructure.

Figure 4.1 compares RRRE between aggregate fatality model and separate pedestrian and motor vehicle fatalities. It is observed from Figure 4.1 that the estimated risk efficiencies of the separate motor vehicle and pedestrian fatalities are higher than the same measures of the aggregate model, which is due to better correlation among input and output factors because of the incorporation of a wider spectrum of outputs corresponding to different types of collision.

Figure 4.1: RRRE of Total Fatalities and Separate Motorized and Pedestrian Fatalities.



Figures 4.2 & 4.3 represent the comparison of the RRRE values from the aggregate fatality model with respect to relative accessibility (normalized accessibility) and relative fatalities (normalized normalized). Both figures reveal that there is no significant correlation between relative risk efficiency and accessibility or relative fatality number. These results indicate that resource allocation based on fatality number or accessibility alone is often misleading and can lead to inefficiency in the utilization of scarce road safety resources.

Figure 4.2: RRRE of Total Fatality and Relative Accessibility of Various Regions of Bangladesh

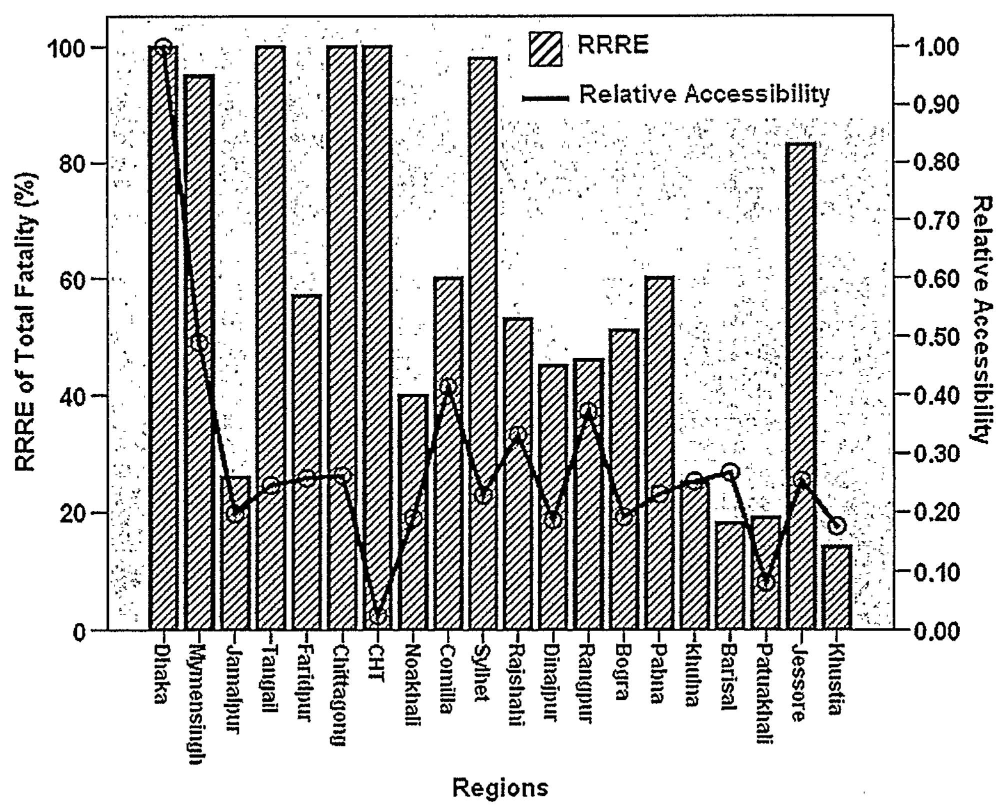
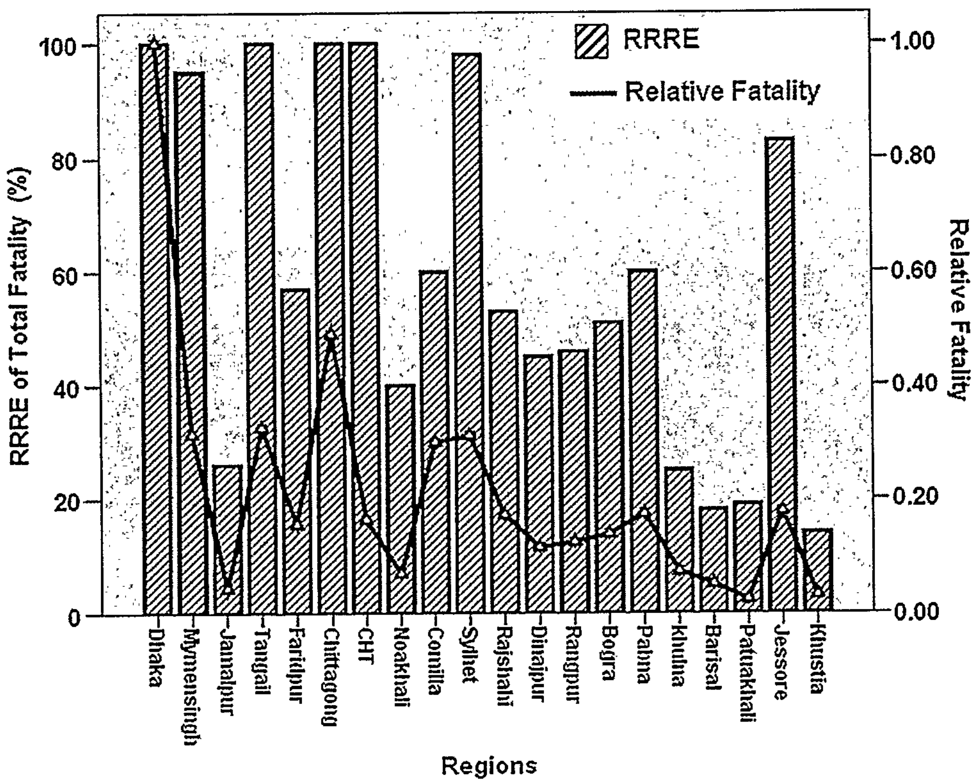
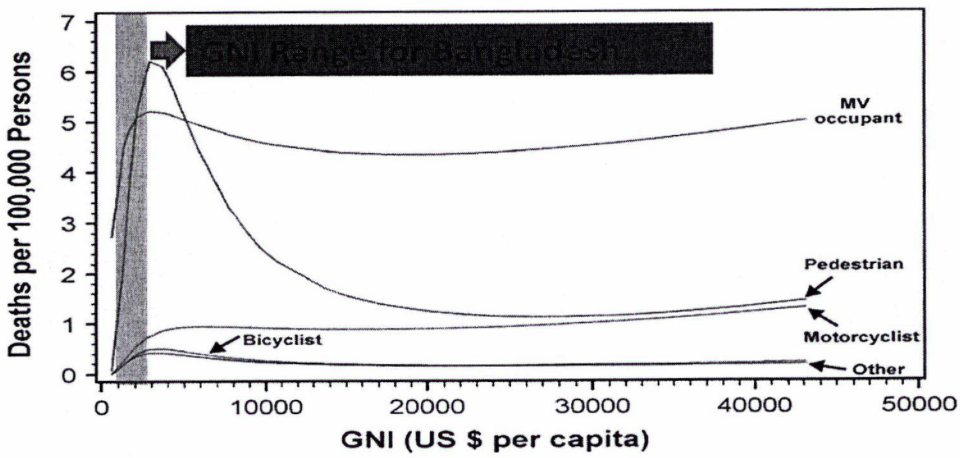


Figure 4.3: RRRE of Total Fatality and Relative Fatality of Various Regions of Bangladesh



We found that the two models with separate pedestrian and motor vehicle accident resulted in greater efficiency in optimization. Therefore, for allocation of funding for road safety improvement in countries like Bangladesh where pedestrian safety is a major issue, it is important to consider pedestrian accident distribution among different geographic regions. As highway departments like RHD are responsiable for safety improvement for both pedestrians and motor vehicle occupants, it is more appropropriae to use separate motorized and pedestrian crash outcomes as two output variables. Figure 4.4 shows various road users collision rate with respect to Gross National Icome (GNI) and could be used for theorethical model validation.

Figure 4.4 Various Road Users Collision Distribution with respect to Gross National Income (GNI)



(Source: Paulozzi, 2007)

4.3 Model Development of Pedestrian Fatality Risk Factors

4.3.1 Data Requirements

MAAP5 database is again used for this analysis. Brief description of this database is mentioned before in section 4.2.1. This database consists of three components: road environment profile, casualty injury profile, and vehicle involvement profile. Only pedestrian collisions those occurred in National Highways in the period of 1998 to 2006 were extracted. For simplicity, only collision involving single pedestrian were considered.

The road environment profile illustrates precisely the collision date, time, location, number of vehicles and casualties that were involved, weather conditions, road type, traffic conditions, and status of traffic control. The casualty injury profile indicates the role (whether the casualty is the driver, a passenger, or a pedestrian) and demographic characteristics of every victim, the injury characteristics, the location of the passenger and/or pedestrian that was involved, the actions of the pedestrian, and any other special circumstances. The vehicle involvement profile provides driver information, vehicle class, license status, and age, and collision information for each of the vehicles that were involved.

This study measures the associations between the injury severity level of pedestrian casualties and several contributory factors for which data are readily available. By aggregating the road environment profile and the casualty injury profile, this study attempted to establish a predictive model for pedestrian injury risk in which the predicting variables reflect the demographic characteristics of the pedestrian, including sex and age; the collision characteristics, including the collision location, collision time, season, weekend and weekdays, pedestrian actions; the traffic and roadway characteristics, including the road environment, location type, road geometry, traffic conditions, traffic controls, surface conditions, surface quality and junction type and vehicular characteristics including vehicle type, vehicle loading etc.

Table 4.4 presents a summary of the data used in the pedestrian fatality risk model. There were 4,976 pedestrian casualties, from 1998 to 2006, of which 4,173 (83.9%) were fatal. Note that most of the factors are recorded in categories and several dichotomous variables have to be created to represent each factor in the model.

Table 4.4: Summary of Data

Factor	Attribute	Count (proportion)
Injury severity	Fatal	4,173(83.9)
	Non-fatal	803 (16.1)
Year	1998	416 (8.4)
	1999	548(11.0)
	2000	555 (11.2)
	2001	479 (9.6)
	2002	596 (12.0)
	2003	609 (12.2)
	2004	459 (9.2)
	2005	613 (12.3)
	2006	701 (14.1)
Pedestrian age	Under 15	1,019 (32.4)
	15 to › 55	1,534 (48.8)
	Above 55	591 (18.8)
Pedestrian sex	Male	3,899 (81.3)
	Female	898 (18.7)
Pedestrian action	None	679 (13.8)
	Crossing	1,126 (22.9)
	Walking on edge	2,720 (55.3)
	Moving on road or playing	393 (8.0)
Pedestrian location	On the crossing	1,045 (21.2)
	Within 50m of crossing	190 (3.9)
	Centre	781 (15.8)
	Footpath	78 (1.6)
	Road side	2,771 (56.2)
	Others	68 (1.4)

Vehicle type	Motor cycle	107 (2.2)
	Babytaxi, tempo, tractor	121 (2.4)
	Car, microbus, jeep, pickup	722 (14.5)
	Bus, minibus	2,357 (47.4)
	Truck, heavy truck, oil truck, articulated truck	1,669 (33.5)
Vehicle loading	Normal	4,456 (96.2)
	Bad	178 (3.8)
Junction	Link	4,054 (82.5)
	Cross, T, staggered T &roundabout	471 (9.6)
	Others	383 (7.9)
Traffic control	None	4,257 (86.2)
	Police/or signal	155 (3.1)
	Stop sign, pedestrian crossing	226 (4.6)
	Others	301 (6.1)
Location type	Urban	810 (16.5)
	Rural	4,089 (83.5)
Surface condition	Dry	4,810 (96.8)
	Wet	157 (3.2)
Surface quality	Good	4,878 (98.2)
	Bad	90 (1.8)
Road geometry	Straight	4,700 (94.6)
	Others (curve, crest, slope etc)	266 (5.4)
Movement	One-way	325 (6.5)
	Two-way	4,637 (93.5)
Divider	Yes	257 (5.2)
	No	4,650 (94.8)
Weather	Fair	4,764 (95.8)
	Bad	208 (4.2)

Light	Day Night	4,046 (81.5) 918 (18.5)
Month	Winter(December-February) Summer(March-May) Rainy (June-August) Autumn(September-November)	1,251 (25.1) 1,297 (26.1) 1,264 (25.4) 1,164 (23.4)
Day of week	Weekday Weekend	4,237(85.1) 739 (14.9)
Time	7:00-9:59 a.m. 10:00 a.m.-3:59 p.m. 4:00-6:59 p.m. 7:00 p.m.-6:59 a.m.	765 (15.5) 2,151 (43.6) 867 (17.6) 1,152 (23.3)

Number of Observation = 4976

4.3.2 Model Outcome

4.3.2.1 Associations measure

A logistic regression model was estimated to measure the associations between the likelihood of fatality in a collision involving a pedestrian and primary risk factors, including demographics, collision, environment, and traffic characteristics. Table 4.5 shows the results of odds ratio estimation. The age of the casualty, pedestrian action, vehicle type, traffic control, season and time of day all significantly determined the probability of mortality.

The following factors led to a significantly lower probability of fatal collisions: no pedestrian action (odd ratio=0.549) as compared with pedestrian walking on edge of highways; and afternoon peak time (OR = 0.716) as compared with night time.. In contrast, the following risk factors led to a higher probability of fatal collisions: the involvement of elderly pedestrians above the age of 55 years (odds ratio =1.976) and young pedestrians under age of 15 years (OR = 1.310) as compared with young adult pedestrians with 15-55 years of age; pedestrian crossing on road (OR = 1.571) as compared with pedestrian walking on edge; involvement of trucks (OR = 3.158), buses (OR = 3.025), and baby-taxi, tempo and tractor involvement(OR = 2.405) as compared with cars; no traffic control (OR = 2.713) and stop sign and pedestrian crossing (OR = 2.691) as compared with signalized or police presence location; and rainy season (OR = 1.317) as compared with autumn.

Table 4.5: Results of Logistic Regression on the Base Model

Factor	Attribute	Control	Odd ratio (95% CI)
Pedestrian age	Under 15	15 to › 55	1.310 (1.002-1.711)**
	Above 55		1.967 (1.406-2.752)***
Pedestrian sex	Female	Male	1.229 (0.926-1.631)
Pedestrian action	None	Walking on edge	0.549 (0.366-0.824)***
	Crossing		1.571 (1.004-2.456)**
	Moving on road or playing		1.405 (0.825-2.393)
Pedestrian location	On the crossing	Others	0.674 (0.217-2.093)
	Within 50m of crossing		0.622 (0.183-2.108)
	Centre		0.625 (0.196-1.993)
	Footpath		0.502 (0.135-1.858)
	Road side		0.551 (0.175-1.736)
Vehicle type	Motor cycle	Car, microbus, jeep, pickup	1.461 (0.733-2.913)
	Babytaxi, tempo, tractor		2.405 (1.142-5.065)**
	Bus, minibus		3.025 (2.267-4.036)***
	Truck, heavy truck, oil truck, articulated truck		3.158 (2.317-4.304)***
Vehicle loading	Bad	Normal	1.306 (0.691-2.470)

Junction	Link	Cross, T, staggered T &roundabout	0.916 (0.613-1.387)
	Others		0.680 (0.395-1.169)
Traffic control	None	Police/or signal	2.713 (1.513-4.864)***
	Stop sign, pedestrian crossing		2.691 (1.203-6.018)**
	Others		1.721 (0.868-3.413)
Day of week	Weekday	Weekend	1.160 (0.853-1.577)
Time	7:00-9:59 a.m.	7:00 p.m.-6:59 a.m.	0.904 (0.588-1.388)
	10:00 a.m.-3:59 p.m.		0.760 (0.522-1.105)
	4:00-6:59 p.m.		0.716 (0.486-1.056)*
Restricted log likelihood		-1104.95	
Unrestricted log likelihood		-1023.77	
Likelihood ratio statistic		162.34***	
Hosmer-Lemeshow statistics		45.04 (d. f. =54)	

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

4.3.2.2 Pedestrian demographics

Pedestrian fatality risk was found to be strongly associated with various factors, including demographic, traffic, and environmental characteristics. With regard to demographics, the mortality risk of the elderly was almost double that of younger adults. Sze and Wong (2007) also reported that fatal or serious injury risk for elderly pedestrians were twice that of young adults. Also, some studies (Eluru et al., 2008; Stone and Broughton, 2003; Miles-Doan, 1996; Kim et al., 2007) found that older individuals tend to have higher perception and reaction times, are more physically fragile, and may suffer from various medical conditions, all of which contribute to their higher injury risk

The mortality rate of children under 15 is also higher than young adults. This result is consistent with other studies from low and middle income countries but in contrast to developed countries where the young adults are most at risk (WHO, 2004). The higher injury severity risk to child pedestrians may be a result of children being more likely to be unaware of a collision developing situation just before the actual impact (and hence may not be able to react in ways to reduce the consequences of the impact). The peculiarity of higher children pedestrian involvement in developing countries might be due to greater unprotected road use by children in low or middle income countries.

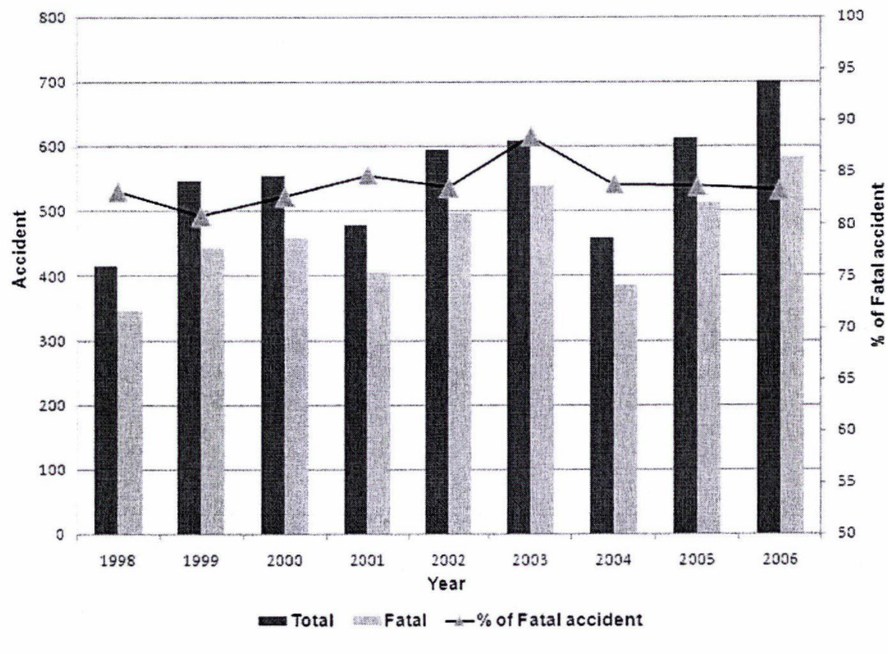
4.3.2.3 Road and traffic environmental factors

With regard to pedestrian action, pedestrians crossing the road are the most at risk compared with those walking on the edge of road whereas those who are not moving experience at a significantly lower risk. This is mainly due to the direction and location of impact in a collision affecting the injury sustained in the collision. In particular, pedestrian crossing actions cause frontal impacts over the carriageway resulting more severe collisions compared to all other kinds of impacts. This finding is consistent with the results obtained by Kim et al. (2007), Eluru et al. (2008) and Sze and Wong (2007). The vehicle type involved in the collision with a pedestrian has an influence on fatality risk. Specifically, a pedestrian struck by a truck or a bus has a higher fatality risk as compared with pedestrian struck by a car. The reasons may be attributed to higher speeds, heavier vehicle masses, "above-the-knee" injuries due to higher bumper heights, and larger impact areas on pedestrians and bicyclists (Sze and Wong, 2007, Ballesteros et al., 2003; Lee and Abdel-Aty, 2005). The mortality rate of pedestrians struck by baby-taxi, tempo or tractor is also higher. This might be due to poor braking and control system of those kind of locally developed vehicles.

4.3.2.4 Temporal change in pedestrian injury risk

As as shown in Figure 4.4, the proportion of mortality increases slightly over the time period analysed. This indicates general increase in pedestrian collision risk on national highways in Bangladesh.

Figure 4.4: Pedestrian collisions by injury severity from 1998 to 2006



Controlling for the temporal confounding effect on mortality probability, the pedestrian injury model is revised by introducing a design variable, t, in the following expression:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \propto t,$$

where t denotes the collision year ($t = 0$ for 1998, $t = 1$ for 1999, t=2 for 2000, and so on). Table 4.6 shows the results of logistic regression on the revised model, incorporating the temporal confounding effect. As expected, the temporal trend significantly altered the pedestrian injury risk at the 5%level. The mortality likelihood has increased over the years (odds ratio = 1.058).

Table 4.6: Results of Revised Model, Controlling for the Temporal Effect

Factor	Attribute	Control	Odd ratio (95% CI)
Pedestrian age	Under 15 Above 55	15 to › 55	1.314 (1.005-1.718)** 1.975 (1.411-2.766)***
Pedestrian sex	Female	Male	1.246 (0.938-1.655)
Pedestrian action	None Crossing Moving on road or playing	Walking on edge	0.565 (0.376-0.849)*** 1.566 (1.001-2.447)** 1.410 (0.826-2.406)
Pedestrian location	On the crossing Within 50m of crossing Centre Footpath Road side	Others	0.623 (0.200-1.946) 0.603 (0.177-2.051) 0.609 (0.190-1.952) 0.472 (0.127-1.754) 0.506 (0.160-1.603)
Vehicle type	Motor cycle Babytaxi, tempo, tractor Bus, minibus Truck, heavy truck, oil-truck, articulated truck	Car, microbus, jeep, pickup	1.425 (0.713-2.844) 2.428 (1.150-5.126)** 2.967(2.222-3.961)*** 3.167 (2.323-4.318)***
Vehicle loading	Bad	Normal	1.341 (0.708-2.539)
Junction	Link Others	Cross, T, staggered T & roundabout	0.916 (0.605-1.388) 0.620 (0.358-1.078)*
Traffic control	None Stop sign, pedestrian crossing Others	Police/or signal	2.701 (1.504-4.852)*** 2.688 (1.199-6.026)** 1.689 (0.850-3.358)

Location type	Urban	Rural	0.805 (0.605-1.072)
Surface condition	Wet	Dry	0.910 (0.368-2.248)
Surface quality	Bad	Good	1.129 (0.414-3.081)
Road geometry	Straight	Others (curve, crest, slope etc)	0.784 (0.461-1.335)
Movement	One-way	Two-way	1.215 (0.705-2.095)
Divider	Yes	No	0.694 (0.415-1.159)
Weather	Bad	Fair	0.833 (0.378-1.836)
Light	Night	Day	1.267(0.869-1.846)
Month	Winter(December-February) Summer(March-May) Rainy (June-August)	Autumn(September-November)	1.185 (0.859-1.634) 1.000 (0.730-1.371) 1.326(0.958-1.835)*
Day of week	Weekday	Weekend	1.157 (0.851-1.573)
Time	7:00-9:59 a.m. 10:00 a.m.-3:59 p.m. 4:00-6:59 p.m.	7:00 p.m.-6:59 a.m.	0.934 (0.606 -1.439) 0.794 (0.544-1.160) 0.751 (0.508-1.111)
Temporal effect			1.058 (1.010-1.108)**
Restricted log likelihood		-1104.95	
Unrestricted log likelihood		-1020.92	
Likelihood ratio statistic		168.05	
Hosmer-Lemeshow statistics		53.05(d.f.=48)	

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

In addition to the impact of primary risk factors, such as demographic, environmental, and traffic characteristic, it is also essential to take into consideration the temporal trend in pedestrian injury risk. Research has been conducted to identify the factors that are associated with temporal changes in accident and injury rates. Some studies found that both the frequency and severity of traffic collisions are decreasing over time (Noland and Quddus, 2004a; Beenstock and Gafni, 2000; Sze and Wong, 2007). However, our study found that the fatality risk of pedestrian collisions has been increasing over the study period. The increasing trend of pedestrian mortality in Bangladesh therefore indicates poor road safety situation for vulnerable road users and demands urgent attention.

4.3.2.5 Interaction effect

To further enhance the model, a careful investigation of the temporal variation in the associations between pedestrian injury risk and individual primary contributory factors (which are discussed in Section 3.4) was conducted. This might lead to understanding of the complexity of road safety problem (which is discussed in Section 3.2).

In epidemiology, researchers apply the concepts of confounding and interaction to describe the change in associations between the outcome variable and the primary risk factors by any additional covariate adherence (Clayton and Hills, 1993; Sahai and Khurshid, 1995; Selvin, 1996). Confounding refers to the presence of partial or complete changes of the associations between the dependent and the independent variables of primary interest by a third variable. However, in interaction, the associations between the dependent and independent variables are significantly differentiated at different levels of the third variable. The confounding and interaction effects are normally assessed by logistic regression, adjusting the association measure with the potential confounders. As revealed in the previous section, the presence of a temporal confounding effect on pedestrian injury risk was significant. Pedestrian mortality likelihood increased steadily between 1998 and 2006.

Now, by interaction modeling, we further examine the temporal variations over the underlying associations between pedestrian mortality likelihood and every primary risk factor. This is to identify the significance of a change in the influential power of any primary risk factor on injury severity over the years.

The logistic regression modeling technique (Hosmer and Lemeshow, 2000) can be applied to assess the confounding and interaction effects. Denote Models (I) and (II) as the profiles with primary risk factor (x) only and with a potential confounder (t, the design variable for the collision year), respectively, as follows

Model (I): $y = \beta_0 + \beta_1 x.$

Model (II): $y = \beta_0 + \beta_1 x + \beta_2 t, where\ t = 0, 1, 2, \ldots, T,$ And T is the number of years, which is taken to be 13 in this study. To determine the significance of a confounding factor, the odds ratio estimates for the primary risk factor between Models (I) and (II) should be compared. For the interaction effect, Model (III), in which an interaction term ($x \times t$, the product of the primary risk factor and time variate) is induced as follows, should also be considered.

Model (III): $y = \beta_0 + \beta_1 x + \beta_2 t + \beta_3 x \times t, where\ t = 0, 1, 2, \ldots, T.$

Now, the change in deviance (G) and the fit for the logit models with (III) and without (II) the interaction term should be determined. If the change in deviance (chi-square distributed with 1 degree of freedom) is significant, then the interaction effect should not be neglected, and, consequently, the odds ratio estimate of the concerned primary risk factor should be modified accordingly.

Table 4.7 illustrates the results of hypothesis test for interaction modeling. The significance of temporal variation over the underlying associations between every potential risk factor and pedestrian injury risk was determined. Out of the 11 primary attributes under investigation, 3 experienced significant temporal change, for which the interactions by t on no pedestrian action (G= 9.020), pedestrian crossings (4.340) and accident involving buses and mini-buses (6.260) were significant.

Table 4.7: Results of the Hypothesis Test for the Temporal Interaction Effect

Factor	Attribute	Control	G
Pedestrian age	Under 15	15 to › 55	0.600
	Above 55		0.180
Pedestrian action	None	Walking on edge	9.020***
	Crossing		4.340**
Vehicle type	Babytaxi, tempo, tractor	Car, microbus, jeep, pickup	1.580
	Bus, minibus		6.260**
	Truck, heavy truck, oil truck, articulated truck		0.000
Junction	Others	Cross, T, staggered T, roundabout	0.000
Traffic control	None	Police/or signal	0.560
	Stop sign, pedestrian crossing		0.320

Month	Rainy (June-August)	Autumn(September-November)	0.080

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level.

Table 4.8 shows the results by logistic regression of the final model, controlling for the influence of significant temporal interaction on underlying attributes by incorporating corresponding temporal interaction terms. . The model prediction fit well, with the observed outcome at the 95% confidence level (Hosmer–Lemeshowstatistic = 58.81, d.f. = 54). The odds ratio estimation in the enhanced model revealed that the no pedestrian action-temporal interaction (odds ratio= 0.901) and involvement of buses and minibuses-temporal interaction (0.924) were significant at the 10% level.

Table 4.8: Results of the Final Model, Controlling for the Temporal Interaction Effect

Factor	Attribute	Control	Odd ratio (95% CI)
Pedestrian age	Under 15	15 to › 55	1.311 (1.002-1.716)**
	Above 55		1.976 (1.410-2.768)***
Pedestrian sex	Female	Male	1.240 (0.932-1.648)
Pedestrian action	None	Walking on edge	0.812 (0.460-1.433)
	Crossing		1.331 (0.749-2.366)
	Moving on road or playing		1.407 (0.821-2.409)
Pedestrian location	On the crossing	Others	0.682(0.218-2.134)
	Within 50m of crossing		0.665 (0.195-2.272)
	Centrė		0.705 (0.219-2.268)
	Footpath		0.534 (0.143-1.995)
	Road side		0.563 (0.177-1.788)

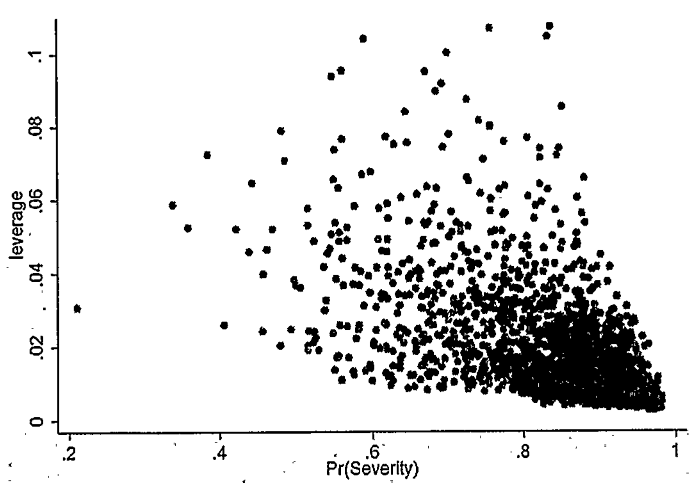
Vehicle type	Motor cycle Babytaxi, tempo, tractor Bus, minibus Truck, heavy truck, oil truck, articulated truck	Car, microbus, jeep, pickup	1.378 (0.686-2.767) 2.501 (1.177-5.313)** 3.910 (2.517-6.074)*** 3.160 (2.316-4.311)***
Vehicle loading	Bad	Normal	1.341 (0.708-2.539)
Junction	Link Others	Cross, T, staggered T, roundabout	0.940 (0.620-1.426) 0.631 (0.364-1.096)
Traffic control	None Stop sign, pedestrian crossing Others	Police/or signal	2.799 (1.553-5.043)*** 2.710 (1.206-6.090)** 1.732 (0.868-3.458)
Location type	Urban	Rural	0.817 (0.613-1.090)
Surface condition	Wet	Dry	0.869 (0.351-2.151)
Surface quality	Bad	Good	1.057(0.388-2.878)
Road geometry	Straight	Others (curve, crest, slope etc)	0.757 (0.443-1.292)
Movement	One-way	Two-way	1.242 (0.717-2.149)
Divider	Yes	No	0.678 (0.405-1.135)
Weather	Bad	Fair	0.886 (0.400-1.959)
Light	Night	Day	1.266(0.868-1.848)
Month	Winter(December-February) Summer(March-May) Rainy (June-August)	Autumn(September -November)	1.180 (0.855-1.628) 0.98 (0.715-1.344) 1.319(0.952-1.827)*

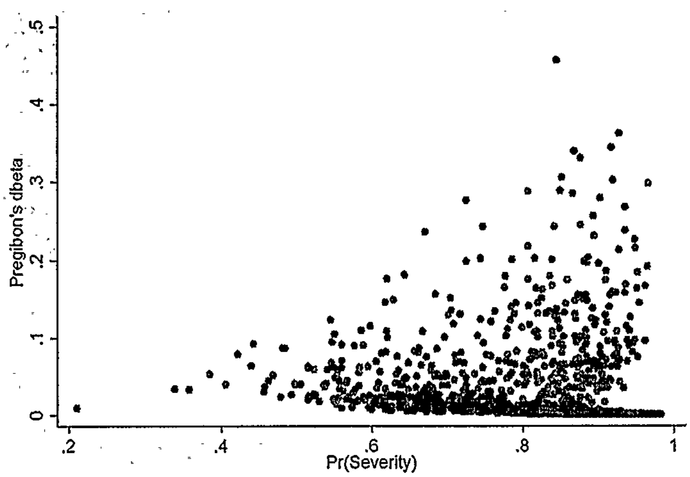
Day of week	Weekday	Weekend	1.154 (0.847-1.571)
Time	7:00-9:59 a.m.	7:00 p.m.-6:59 a.m.	0.915 (0.593 -1.411)
	10:00 a.m.-3:59 p.m.		0.785 (0.537-1.147)
	4:00-6:59 p.m.		0.756 (0.510-1.119)
Temporal effect			1.106 (1.030-1.187)***
Temporal Interaction effect			
	None		0.901 (0.805-1.009)*
	Crossing		1.056 (0.938-1.188)
	Bus, minibus		0.924 (0.843-1.012)*
Restricted log likelihood		-1104.95	
Unrestricted log likelihood		-1016.75	
Likelihood ratio statistic		176.40	
Hosmer-Lemeshow statistics		58.81 (d.f.=54)	

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level.

In addition to the summary measure with the Hosmer–Lemeshow statistic, with a graphical illustration by logistic regression diagnostics, the agreement between the observed and predicted probability throughout the entire set of observations is also examined, As shown in Figure 4.5a, the leverage values were negligible (only few values are greater than 0.1), which indicated that there was no significant outlying observation that lay far away from the rest of the data. However, as is shown by the influence diagnostic in Figure 4.5b, the changes in the coefficient estimate were very minor (few values are greater than 0.3). There was no significant extremity throughout the entire collection of observations, and their influential powers on the model estimate were negligible. These factors collectively verified the goodness-of-fit of the final model.

Figure 4.5: Logistic Regression Diagnostics of Final Model





(4.5.b)

The primary risk factors of the demographic, traffic, and environmental characteristics that contribute to mortality and severe injury in pedestrian casualties were identified in the first attempt with logistic regression. Through a step-by-step investigation, the temporal confounding and interaction effects on the associations between mortality likelihood and primary risk factors were then explored. By incorporating these influences, the efficiency and predictive power of the proposed injury risk model were progressively enhanced.

A consideration of temporal variation in predictive models is not rare in road safety research. Kopits and Cropper (2005) applied time-series data to identify that factors such as income level, demographics, motorization, road infrastructure, population, and the growth of vehicle fleets and urban areas had led to a decline in passenger and pedestrian fatalities in industrialized countries. Road–time and vehicle–time interactions were incorporated into the predictive model to approximate the effects of motorway building and vehicle fleet expansion on pedestrian fatalities over a number of years. The impact of vehicle fleet growth magnified over the years, whereas that of road construction diminished. Other researchers have applied panel data to measure the change in fatality and injury rate that is associated with improvements in road infrastructure and medical technology. Proxy variables, including road length and width, number of lanes, length of hospital detention, hospital staff, and hospital density, were applied to approximate the influence of implicit attributes on the casualty rate trend. It was revealed that medical technology enhanced road safety performance over a time-series course in terms of total fatalities, severe injury, and slight injury (Noland, 2003; Noland and Quddus, 2004).

From the results of the enhanced model, temporal effect was found to modify significantly the underlying associations between mortality likelihood and certain primary risk factors. First, pedestrians with no action on roads had lower mortality likelihood than did those standing or walking at the edge of road. The negative coefficient of no pedestrian action-temporal interaction suggested that the favourable impact further reduced favourably over the years. This could be attributed to better road side management, pavement markings or lane marking, the frictional resistance of road surfaces etc overtime. Second, pedestrian mortality likelihood is higher for pedestrian accident involving buses or minibuses. This adverse impact favourably diminished over time, which is affirmed by the negative coefficient of temporal interaction. This may have been brought about by pedestrians' greater adaptability with highways, improved models, and better frontal design over the years etc.

4.4 Summary and Applications

In this chapter, the outcomes from two models have been derived. The first model provides a framework for efficient budget allocation among different geographic regions. Using the example of Bangladesh, this model shows how the budget for reducing motorized vehicle collision and pedestrian collisions of different regions can be allocated efficiently.

- Road authorities like Roads and Highways Department (RHD) could use this model for efficient safety budget allocation, giving higher priorities to high RRRE regions like Dhaka, Mymensingh, Tangail, Chittagong, Sylhet and Jossore, for safety improvement.
- Ministry of Communications could get some ideas how different regions are behaving with respect to road safety, transportation and regional economic variables to improve its transportation policy formulation.
- Foreign donor agencies could get idea of areas to focus the various demonstration projects, especially in the high risk regions.
- The results may be helpful for formulating better insurance policy and selecting long distance bus and truck routes among different geographic regions.

The second model shows that pedestrian fatality risk is strongly associated with various factors, including demographic, traffic, and environmental characteristics. Factors like pedestrian above the age of 55, young pedestrians age under 15 years of age, pedestrian crossing action, involvement of trucks or buses, pedestrian crosswalk locations, locations without traffic control devices, rainy season are some important pedestrian collision risk factors. Here are some specific policy measure that could introduced for safety improvements.

- Young child under 15 years of old was found with high risk of mortality. Since most of this group are students, engineering and planning measures could be targeted at identifying locations of school with respect to residences. Examining safe route to school, conducting safety reviews of schools close to highways, and performing safety audits of locations where children need to cross highways to reach school.
- Providing more road safety education focusing the school children and providing education appropriate for this age cohort.
- Pedestrians with age over 55 are also found to be at higher risks. Thus, community based safety improvements should be targeted to that age group people. Recommendations from NCHRP 500 (Guide for Reducing Collisions) volume 9 (older drivers) and volume 10 (pedestrians) should be considered.
- High collision concentration locations could be audited to check whether locations meet the requirements for old pedestrians (like pedestrian crossing timing set up etc)
- The model shows the pedestrian crossing action is a risky action. It shows need for marked /raised pedestrian crossings, with appropriate signs.
- Sanctions and community based approaches to discourage random pedestrian crossing behaviours outside the crosswalks should be considered.
- Appropriate speed limit set up for high crossing locations.

- Model also shows high involvement of buses and trucks in pedestrian mortality. This issue could be addressed with heavy vehicle driver education program.
- Other measures could include speed enforcement of buses and trucks as well as conducting more vehicle fitness checks.
- Stopping random lane changing behaviours by bus drivers by reducing aggressive competition among bus drivers for passengers on the same route buses.

Chapter Five: DISCUSSION AND FUTURE RESEARCH

5.1 Introduction

This chapter summarizes the research reported in this thesis and highlights the main results and recommendations. The limitations of the research conducted are discussed together with some directions for future research.

5.2 Summary of Findings and Recommendations

- The first study uses the DEA method to provide some recommendations for road safety fund allocation
  - Several regions with high risk values were identified. These regions include Dhaka, Mymensingh, Tangail, Chittagong, Sylhet and Jossore. All else held constant, these regions should get higher priority in road safety resource allocation.
  - This model is also able to show how transportation accessibility, GDP, population and road length have an effect on traffic fatalities.
  - This study found that the RRRE values of separate pedestrian and motor vehicle fatality model were higher than that of aggregate fatality model. These results suggest that pedestrian and motor vehicle collision can be considered separately in the allocation of funding and in setting the priorities for improvements.

- The second study examined the fatality risk in a collision as a function of several risk factors.
    - This model examined how pedestrian fatality risk in Bangladesh varies with various demographic, roads environmental and vehicular factors.
    - Factors like pedestrian above the age of 55, young pedestrians age under 15 years of age, pedestrian crossing action, involvement of trucks or buses, pedestrian crosswalk locations, locations without traffic control devices, rainy season were found to be important pedestrian fatality risk factors.
    - A Pedestrian Safety Action Plan comprises of a comprehensive set of programs and activities for improving pedestrian safety through street redesign such as more crosswalks and the use of engineering countermeasures such as more traffic control devices. It should also include other safety-related treatments and programs, such as enforcement and education, that involve the whole community as well as targeting the at risk population like younger and older road users.

5.3 Limitations and Future Research

The research is not without its limitations. The current study focuses on the impact of various factors on pedestrian fatality risk conditional on the occurrence of a collision. It is important to note here that factors that reduce overall injury severity may increase likelihood of a collision and vice versa. Also, as with several earlier studies, the use of police-reported collisions can skew injury severity levels toward more severe collisions (since collisions with no injury or minor injury may be under reported). Moreover, there is room for improving the model specification by including additional variables, such as grades, road curvature, detailed roadway geometrics, and average speeds at the location of collision or speed limits. Also, the specification adopted in the current study, while quite comprehensive, is limited by the variables available in the police reported accident data.

Also there is inherent problem of reliabilities of police reported accident data. This limitation could be reduced by cross checking accident data from different sources. Future research could be directed towards checking reliability of different sources and how modeling outcome varies with different sources.

It is also anticipated that the information on pedestrian flow and pedestrian–vehicle conflicts would help to reveal the influence of temporal variation on pedestrian exposure to traffic collisions. A more extensive data collection, such as from travel surveys (Allsop, 2005) and comprehensive analysis of the interaction effects between pedestrian flow and all risk factors could be an interesting topic in future research.

A more comprehensive model should include the impact of education, health facilities, emergency response, existing road safety initiatives, population, and age distribution to provide a better insight into the impacts of various input factors on collision risk. Performing a similar analysis on time series data will also facilitate the development of a new planning tool for planners and decision makers as well as the identification of dynamic factors in the interaction between economic, social, transportation development and road safety.

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