# Analysis of traffic injury severity in a mega city of a developing country

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**Abstract**
Despite a considerable amount of research on traffic injury severities, relatively little is known about the factors influencing traffic injury severity in developing countries, and in particular in Bangladesh. Road traffic crashes are a common headline in daily newspapers of Bangladesh. It has also recorded one of the highest road fatality rates in the world. This research identifies significant factors contributing to traffic injury severity in Dhaka – a mega city and capital of Bangladesh. Road traffic crash data of 5 years from 2007 to 2011 were collected from the Dhaka Metropolitan Police (DMP), which included about 2714 traffic crashes. The severity level of these crashes was documented in a 4-point ordinal scale: no injury (property damage), minor injury, severe injury, and death. An ordered Probit regression model has been estimated to identify factors contributing to injury severities. Results show that night time influence is associated with a higher level injury severity as is for individuals involved in single vehicle crashes. Crashes on highway sections within the city are found to be more injurious than crashes along the arterial and feeder roads. There is a lower likelihood of injury severities, however, if the road sections are monitored and enforced by the traffic police. The likelihood of injuries is lower on two-way traffic arrangements than one-way, and at four-legged intersections and roundabouts compare to road segments. The findings are compared with those from developed countries and the implications of this research are discussed in terms of policy settings for developing countries.

***Keywords***
Injury severity; Ordered Probit Model; Developing country; Dhaka; Bangladesh;

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## 1. Introduction

Globally, injuries are responsible for about 5% of the total mortalities and a large proportion out of them is due to road traffic accidents (Huda et al., 2010). More importantly, road crashes are the second leading cause of death globally among young people aged 5 to 29 years and the third leading cause of death among people aged 30 to 44 years – i.e. at their most productive age (World Health Organization, 2004). However, a disproportionate number of these crashes are occurring in developing countries (Agrawal, 2012; Oginni et al., 2009). More specifically, about two-thirds of global injuries occur in this context (Fatmi et al., 2007). Similarly, these countries account for about 85% of the deaths and 90% of annual disability adjusted life years lost by road traffic injury (World Health Organization, 2004). However, little knowledge exists on the factors contributing to traffic injury severity in this context primarily due to a lack of related datasets (Quddus et al., 2002; Rahman et al., 1998).

Numerous studies have been conducted on the topic in the context of developed world. These studies have identified multiplicity of factors that are associated with injury severity level for different groups and/or different modes (discussed in Section 2). Planners and policy makers in developing countries often rely on the findings from these studies in order to develop their traffic safety measures (Rahman et al., 1998). This raises question about the validity of such factors in the context of a developing country because evidence suggests that the significance of these factors vary between contexts such as between developed countries (Oginni et al., 2009), and between urban and rural areas within a country (Li et al., 2008). This research aims to contribute to this gap in the literature by: first, identifying factors that influence traffic injury severity in a mega city of a developing country using Dhaka, Bangladesh as a case study; second, comparing the identified factors with findings from developed country literature.

Section 2 briefly presents different aspects of traffic accidents in Dhaka. A review of factors associated with injury severity level in the context of both developing and developed countries is presented in Section 3. Section 4 discusses the data and method used to reach the above objectives. Section 5 portrays the results of this research. Similarities and differences of the role of different factors in influencing injury severity level between developed and developing countries are discussed in Section 6. Section 5 also discusses the implications of these findings in policy terms and concludes this research.

## 2. Traffic accidents in Bangladesh

Bangladesh has one of the highest fatality rates in road accidents, over 100 deaths per 10,000 motor vehicles (UNESCAP, 2007) which is much higher compared to other developing countries like India (25.3), Sri Lanka (16), Malaysia (5.5) and almost incomparable with developed countries such as the USA (2.1) and UK (1.4) (Ahsan, 2012). The extent of death toll from accidents in Bangladesh can be compared with death toll from wars in countries like Sierra Leone and Liberia (Al-mahmood, 2007). The number of fatalities has been increased 3.5 times to more than 3000 deaths per year in the last 20 years. However, the figure is controversial and some suggested that it could be more than 12000 per year (due to non-reporting and misreporting) (UNESCAP, 2007). It is estimated that road crashes cost roughly 2-3 percent of the country's GDP every year (Ahsan, 2012; Al-mahmood, 2007). This is almost equal to the total foreign aid received by Bangladesh in a given fiscal year (Al-mahmood, 2007).

Urbanisation and motorisation are often considered as the leading cause of the fatalities in Bangladesh (Rahman et al., 1998). Vehicle ownership has increased steadily in Bangladesh, and at present it is about 2 to 10 vehicles per 1000 persons. However, despite large growth in the number of motor vehicles, the country's level of motorisation is still far below the levels of other countries, such as around 12, 25, 426 and 765 motor vehicles per 1000 persons in India, Sri Lanka, UK and the USA respectively (Ahsan, 2012). As a result, travel demand is still predominantly met by non-motorised modes (e.g. walk, and rickshaw) of transport in this context. A recent mode share statistics in Dhaka justifies the statement: walk (19.8%), rickshaw (38.3%), auto rickshaw (powered three wheeler) (6.6%), car (5.1%), bus (30.1%), waterway (0.1%), and motorcycle (0%) (Ministry of Environment and Forests and Ministry of Communication, 2010). Note that Dhaka is the capital of Bangladesh with more that 14 million population and has the highest level of car ownership in the country, yet non-motorised modes are predominant. As a result, pedestrians or the non-motorised vehicle users are the most vulnerable group and about 61% of urban road accident deaths are pedestrians alone in the country (UNESCAP, 2007).

## 3. Literature review

### 3.1 Factors affecting injury severity in developing countries

Literature on traffic crashes is relatively fewer in the context of developing country. Amongst these, only few studies investigated factors influencing injury severity. Rather most of these studies identified factors contributing to crashes. As a result, both types of studies are reviewed intertwiningly in this section in order to have a better knowledge about the crashes in developing country.

Stephan et al. (2011) found that a majority of transport injuries are associated with the use of motorcycles amongst adults in Thailand. Conard et al. (1996) showed that around 50% motorcycle users do not maintain the helmet wearing law while using motorcycle in Yogyakarta, Indonesia. Oginni et al. (2009) used data from 221 motorcycle injured patients who received treatment in four Nigerian teaching hospitals and identified the risk factors associated with the crashes. This study found that male aged 21-30 years are more likely to be involved in crashes. Factors contributing to motorcycle crashes include alcohol use (31.2%), bad roads (17.6%), and fatigue (13.5%). Similarly, Adesunkanmi et al. (2000) identified injury patterns and severity of 324 children who were injured in road traffic accident between 1992 and 1995 in Nigeria. Using hospital data, this study found that head injuries were the most common injury, followed closely by limb trauma. Injury severity scores (ISS) ranges between 1 and 25 for 306 children (no mortality but significant morbidity) whereas 18 patients had a score between 26 and 54 with a 61% mortality rate (11 patients). The highest scores were found in the group of patients who were passengers in a motor vehicle. Using an ordered probit model, Quddus et al (2002) identified factors contributing to injury severity associated with motorcycle accidents in Singapore. This study found that the motorcyclist having non-Singaporean nationality, increased engine capacity, headlight not turned on during daytime, collisions with pedestrians and stationary objects, driving during early morning hours, having a pillion passenger, and when the motorcyclist is determined to be at fault for the accident are associated with higher level of injury severity.

Schmucker et al. (2011) studied the crash characteristics and injury patterns for auto rickshaw occupants (n=139) and the road users hit-by-motorised rickshaw (n=114) in Hyderabad, India. This study reported that single vehicle collisions are the most common form of crashes. In another study in the same context, Dandona et al. (2011) assessed road use pattern and incidence; and risk factors of non-fatal road traffic injuries (RTI) among children aged 5–14 years using data from 2809 children aged 5–14 years. This study reported that boys and girls had similar RTI rates as pedestrians but boys had a three times higher rate as cyclists. A similar finding has also been reported by Zargar et al. (2003) in Iran by analysing patterns of transport related injuries amongst children aged 19 years or less. This study found that boys were affected 3.5 times as often as girls. Further classification in this study shows that younger children were more prone to pedestrian-related injuries while teenagers were more prone to motorcycle related injuries.

Huda et al. (2010) assessed the impact of the characteristics of car drivers (e.g. professional vs. non-professional) on injury severity in Moradabad, India. This research found that the former group is involved with more accidents, and victims associated with this group faced more severe injuries than the latter group. In contrast, AlEassa et al. (2013) investigated the impacts of different types of vehicles (e.g. sport utility vehicles vs. small passenger cars) on injury severity using data collected from 101 patients who were admitted into two trauma centres of Al-Ain city, UAE. The study found no significant difference between the two groups in terms of anatomical distribution of injuries and severity level.

The above review shows that little has been done so far in identifying the factors contributing to traffic injury severity level in developing countries. Within the studies, most of them again identified factors associated with traffic accidents but not the severity level of these accidents. More importantly, a majority of these studies have focused on the motorcycle crashes which have little implication in case of Dhaka because this mode of transport is almost absent in this context. Barua and Tay (2010) have recently modelled injury severity of transit based crashes in urban Bangladesh using 1998-2005 crash data. This study reported that injury severity level increases if collision occurs on weekends, off-peak periods, two-way street, and involving only one vehicle whereas severity level reduces at locations where some form of police control mechanism exist. However, transit based crashes account only about 33% of all crashes in the country (UNESCAP, 2007), and presumably the figure is much lower in case of Dhaka, and therefore, further investigations are deemed necessary on the validity of the factors for other modes in the country as well as in Dhaka city.

### 3.2 Factors affecting injury severity in the developed world

A large body of safety literature focuses on the identification of factors associated with the occurrence of crashes whereas another large group of studies identified factors related to severity of crashes in the developed world. Given the abundance of literature, this section focuses on the reviews of literature related to the latter category. Factors that affect injury severity level in the developed countries can broadly be classified into: a) environmental characteristics (e.g. day/night), b) roadway characteristics (e.g. road class), c) crash characteristics (e.g. head on crashes), d) non-motorist characteristics (e.g. socio-demographics of the non-motorist being involved in a crash), e) motorised vehicle driver characteristics (e.g. socio-demographic of drivers, alcohol use while driving), and f) motorised vehicle characteristics (e.g. age/weight of vehicles) (Eluru et al., 2008). The following sub-sections discuss the impact of these factors on injury severity level. However, the discussion is limited to the first three categories of factors for comparison because factors related to the remaining three categories are not considered in this research due to data unavailability.

#### 3.2.1 Environmental characteristics

Environmental factors are commonly used to refer to the specific condition of the environment at the time of an accident such as the time of a day, rural or urban context etc. Some commonly identified significant environmental factors are weather condition, lighting condition, road surface condition, and regional context. Generally adverse weather such as fog and rain increases the injury severity propensity (Kim et al., 2007; Klop and Khattak, 1999; Lee and Abdel-Aty, 2005; Zajac and Ivan, 2003). This is probably due to visibility impairment caused by fog and rain. Darker lighting condition is another important environmental factor that significantly impacts injury severity level (Kim et al., 2007; Lee and Abdel-Aty, 2005; Zajac and Ivan, 2003). For instance, Quddus et al. (2002) found that more severe injuries occur in the early morning (midnight to 3:59 a.m) periods and less severe injuries occur during the day in Singapore. Similar findings have been reported in studies conducted in Florida (Miles-Doan, 1996), and in North Carolina (Klop and Khattak, 1999). A more specific 'darker period' is reported by Sze and Wong (2007) who found that the odds of a fatality are higher for crashes occurring between 7 p.m.–7 a.m. Despite crashes in day time are reported to be less severe, variations, however, exist. Pitt et al. (1990), for example, reported that the most severe injuries occurred between 6 and 9 a.m. and the least severe injuries occurred between 12 and 3 p.m. Consistent with this, Kim et al. (2007) found that crashes occurring during the AM peak (6–10 am) and weekends increase the likelihood of fatality in North Carolina.

Although rain is associated with increased accident severity as discussed above, wet road surface does not increase the severity level. This supports the visibility impairment issue associated with rain as discussed earlier. Zhu and Srinivasan (2011) found that crashes on wet surfaces are less severe as drivers are inherently more cautious during such rainy conditions. Similarly, Kaplan and Prato (2012) have shown that dry road surface is significantly associated with an increase in fatalities. However, this can vary according to gender and age. As Morgan and Mannering (2011) reported, the likelihood of severe injuries increased for females and older males if crashes occur on road surfaces that are wet or snowy or icy relative to dry-surface crashes.

Traffic crashes occurring in rural areas are more severe and more likely to be fatal than those occurring in urban areas for drivers of all age groups (Lee and Abdel-Aty, 2005; Miles-Doan, 1996). However, variations also exist between different parts in an urban area. For instance, Zajac and Ivan (2003) found that crashes occurring in downtown and compact residential areas result in lower injury severity compared to the crashes in low-density residential areas in Connecticut. This study also reported that crashes that occur in low and medium density commercial areas result in less severe injuries compared to the crashes occurring in village and downtown fringe areas.

### 3.2.2 Roadway characteristics

Commonly identified roadway factors included road hierarchy (e.g. highway, local road), geometry of road network (e.g. curve), the type of intersections, and traffic control mechanism. Generally, crashes in highways are more sever than other road classes (e.g. arterial road, feeder roads) for two reasons. First, highways have higher speed limit. Research has shown that an increase in speed limit increases severity level (Renski et al., 1998). This is particularly true when speed limit exceeds 40 mph (Miles-Doan, 1996; Sze and Wong, 2007). Second, highways are generally wider than other road classes. Zajac and Ivan (2003) found that an increase in roadway width increased injury severity propensity in Connecticut.

Zhu and Srinivasan (2011) used a two class road hierarchy (e.g. interstate and other highway) and four classes of road location (e.g. segment, intersection, interchange, and other). By combining these two types of roadway characteristics together, they developed a eight category factor (e.g. interstate highway segment, interstate highway interchange etc.). This work found that crashes in interstate other segments are least severe. Quddus et al. (2002) have used a 12 class road geometry in their analysis of motorcycle injury severity level in Singapore (e.g. bend, T-junction, cross-junction, straight, merging, narrow, sharp turn, blind corner, one way, two way, dual carriageway, expressway). Using an ordered probit model of their 3-point injury severity scale, this work reported that bends result in more severe injuries while T-junctions, cross-junctions, and straight roads increases fatality.

Crashes on road-ways with more lanes were identified to be less severe because of better separation of vehicles in multi-lane highways (Zhu and Srinivasan, 2011). However, multi-dual carriageway roads are more riskier compared to one-way roadways (Sze and Wong, 2007). The situation would be more severe if a two way street does not have a road divider (Quddus et al., 2002).

The effect of road geometry on accident severity is complicated and varies between contexts, and modes. For example, Zhu and Srinivasan (2011) did not find any statistically significant effect of horizontal (straight versus curved) and vertical (flat versus uphill/downhill) alignment of the roadway for large truck crashes in the USA. However, Kim et al. (2007) found that road curvature is positively associated with severity level for bicycle related injuries in North Carolina. In contrast, Shankar et al. (1996) reported that the number of horizontal curves per mile in the roadway segment significantly reduced the likelihood of injury severity for all types of roadways in Washington.

Engineering design of intersections also impacts injury severity level. For example, crashes occurring on intersections with traffic signals are severe than intersections with other traffic signs (Sze and Wong, 2007). However, for signalized intersections, having a pedestrian crossing signal decreases the probability of sustaining severe injuries in crashes because they make drivers of turning vehicles slow down(Lu et al., 2004). The impact of traffic control mechanism is mixed in the literature. Pitt et al. (1990) did not find any impact of the presence of traffic control on injury severity. However, Lee and Abdel-Aty (2005) reported that if the crash occurs at a crossing with a traffic control device the propensity to be injured is lower.

### 3.2.3 Crash characteristics

Although Pitt et al. (1990) did not find any impact of how vehicles collided on injury severity, Kim et al. (2007) reported that frontal impacts increase the odds of a fatality. Similar finding has also been reported by Obeng (2008) for various medium sized cities in the US. In addition, crashes where a vehicle collides straight ahead with the pedestrian result in severe injuries (Miles-Doan, 1996). Injury severity is also higher when a vehicle collides with a stationary object (Quddus et al., 2002). Pedestrian crossing the roads are subject to more severe injuries. Also, pedestrian being inattentive increases the odds of sustaining a fatality (Sze and Wong, 2007). Klop and Khattak (1999), using crashes between two vehicles, has shown that the leading driver is more likely to be injured, whereas, in a three-vehicle crash, the driver in the middle is likely to be more severely injured.

## 4. Data and methods

### 4.1 Data

A 5 year road collision data set dating from 2007 to 2011, supplied by the Dhaka Metropolitan Police (DMP) was used. It consists of 2714 collisions, resulting in injury. The spatial extent of the collisions analysed covers just beyond the Dhaka City Corporation area within the Dhaka Metropolitan Area (DMA) (Figure 1). The attributes of each of the collisions were reported by a police officer as the first investigation report (FIR) based on a pre-designed accident reporting form (ARF). The ARF was designed jointly by the police and the institutional development component of the World Bank in 1995. Prior to nationwide roll over in 1998, the ARF was pilot tested in a police station of the DMA in 1995; and subsequently in all police stations of the DMA in 1996. The ARF contains 69 fields (variables) to be filled in by a concerned police officer responsible for FIR. Among the 69 variables, only 12 were retained for analysis in this paper based on the literature as discussed earlier (Table 1). The 2714 crashes resulted in 2918 causalities (death or injury) which means that more than one person was involved in a crash on average. As a result, it was difficult to take into account the socio-demographic status of the injured person(s) involved in a crash, and therefore, they are not considered in this research.

### 4.2 Method

#### 4.2.1 Outcome variable: injury severity

A number of approaches in the literature exist representing injury severity level such as binary scale (e.g. injured or not), Likert type ordinal scale (e.g. ranges from 3-point to 10-point), and continuous scale etc. For instance, Mujalli and de Oña (2011) used two levels of binary scale: slightly injured vs. killed or seriously injured. Other authors such as Holubowycz (1995) used fatal vs. serious injury binary scale. On the other hand, Stone and Broughton (2003) used fatal vs. non-fatal binary scale in their study. The utilisation of a 3-point ordered scale is also common in the literature. For example, Abdel-Aty (2003) classified the injury severity level into no injury, injury, and fatality in his analysis of 1994-95 crash data in Florida. Morgan and Mannering (2011) also used a 3-point ordered scale but with a slightly different naming convention: no injury, minor injury (e.g. non-incapacitating or possible injury), and severe injury (e.g. fatal or incapacitating). Many researchers have, however, used a 4-point ordered scale. For example, in their study, Savolainen and Mannering (2007) classified severity level as no injury, non-incapacitating injury, incapacitating injury and fatality. Shankar et al. (1996) also used a similar framework but using a slightly different naming convention e.g. property damage only, possible injury, evident injury, and disabling injury or fatality. A number of studies have used a 5-point ordered scale (Delen et al., 2006; Obeng, 2008; Shankar et al., 1996). Possible severity categories in these studies included: no injury/ property damage only, possible injury, minor non-incapacitating injury/evident injury, incapacitating injury/severe injury, and fatality. Unlike the categorical measures as discussed above, various studies have used a continuos scale representing injury severity level (Jehle and Cottington, 1988; Pitt et al., 1990). The scale used in these studies is recognised internationally and has often been referred to as injury severity scale (ISS) in the literature (Osler et al., 1996). Also noticeable is the fact that most of these studies collected data from patients who had received treatments (or admitted) in hospitals.

This research used a 4-point Likert type ordered scale to represent injury severity and used as the outcome variable to model the severity as shown in Table 1.

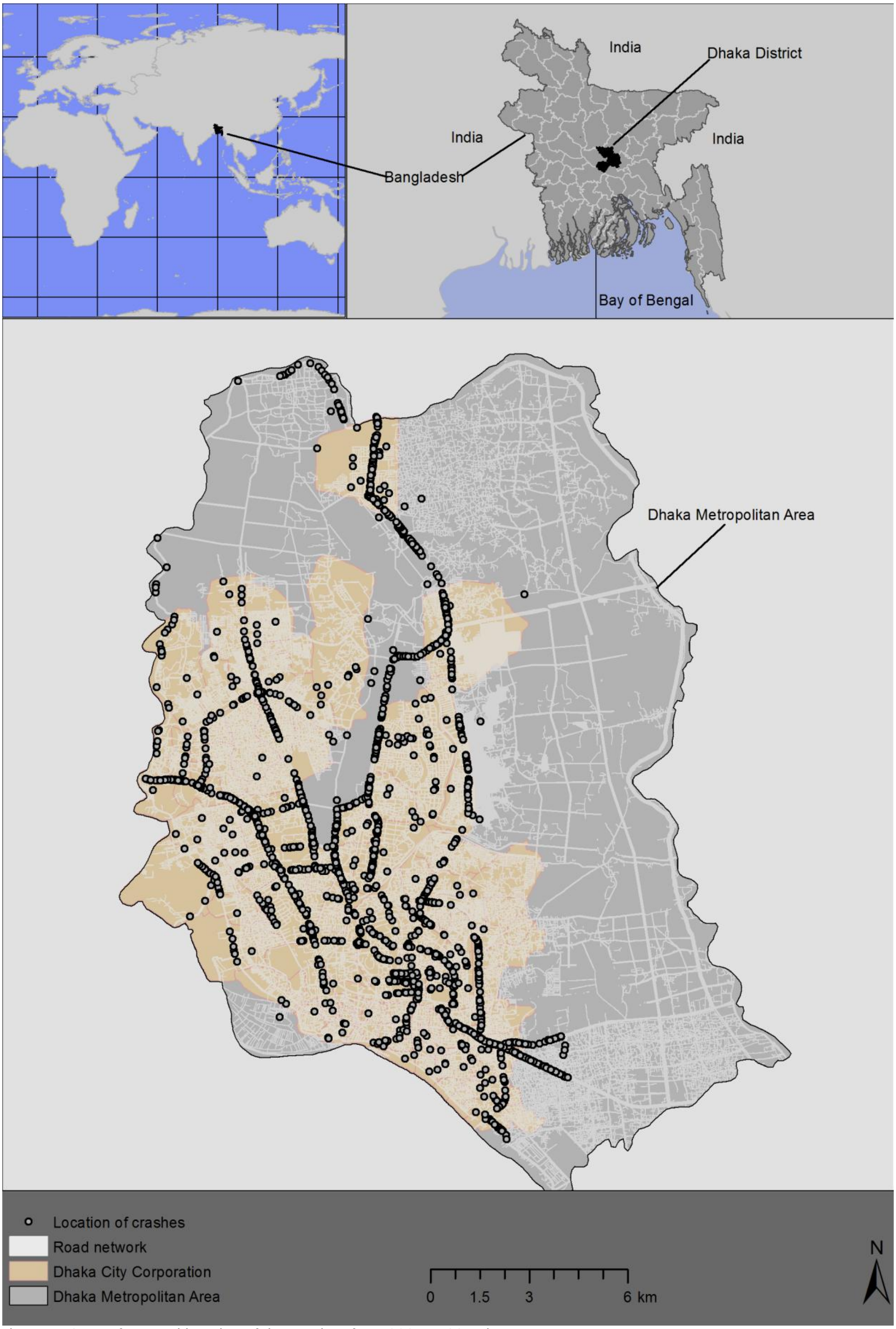

Figure 1: Geo-referenced location of the crashes from 2007 to 2011 in DMA

Table 1: Variables extracted from the ARF and included in the analysis

| Variable | Frequency | % |
|---|---|---|
| Injury severity | | |
| Vehicle damage | 333 | 12.3 |
| Minor injury | 104 | 3.8 |
| Severe injury | 411 | 15.1 |
| Death | 1866 | 68.8 |
| Weather condition | | |
| Good | 2691 | 99.2 |
| Foggy and rainy | 23 | 0.9 |
| Daylight condition | | |
| Day | 1472 | 54.2 |
| Night | 901 | 33.2 |
| Dawn/Dusk | 341 | 12.6 |
| Road surface condition | | |
| Dry | 2693 | 99.2 |
| Wet & muddy | 21 | 0.8 |
| Type of intersection where accident occurs | | |
| Not in an intersection | 1920 | 70.7 |
| 3 way or T junction | 426 | 15.7 |
| 4 way intersection | 320 | 11.8 |
| Roundabout | 28 | 1.0 |
| Railway crossing | 15 | 0.6 |
| Other | 5 | 0.2 |
| Traffic flow direction | | |
| One way | 1976 | 72.8 |
| Two way | 738 | 27.2 |
| Traffic control and management | | |
| Both police and traffic signal | 38 | 1.4 |
| Only police | 883 | 32.5 |
| Only traffic signal | 44 | 1.6 |
| Uncontrolled | 1749 | 64.5 |
| Presence of road divider | | |
| Yes | 2174 | 80.1 |
| No | 540 | 19.9 |
| Road geometry | | |
| Straight and plain | 2630 | 96.9 |
| Other (e.g. curve, slope, peak) | 84 | 3.1 |
| Road condition | | |
| Good | 2684 | 98.9 |
| Rough | 30 | 1.1 |
| Road classification | | |
| City and feeder road | 1819 | 67.0 |
| Highway | 895 | 33.0 |
| Number of vehicles involved in crashes | | |
| Single | 1730 | 63.7 |
| Multi | 984 | 36.3 |
| N | 2714 | 100 |

### 4.2.2 Explanatory variables

A total of 11 independent factors were used to explain the injury severity outcome in this research that falls into the three categories of factors: a) environmental (e.g. daylight condition, weather condition, and road surface condition), b) roadway characteristics (e.g. type of intersection where accident occurs, traffic flow direction, traffic control and management, presence/absence of road divider, road geometry, road condition, and road class), and c) crash characteristics (e.g. number of vehicles involved in crashes). Further classification used for each these categories are shown in Table 1.

Number of vehicle involved in crashes data were filled in using a range from one to six vehicles in the ARF. This was recoded into single and multi-vehicle due to a limited number of responses in the higher order categories. The traffic control and management variable in the ARF form contains six categories (e.g. police and traffic signal, only police, only traffic signal, median separation, pedestrian crossing, and uncontrolled). This variable was recoded into four categories as shown in Table 1 by merging the median separation and pedestrian crossing into uncontrolled category. Weather condition data was originally collected using three categories (e.g. good, foggy, and rainy). The latter two categories were merged together due to a lower response rate in these categories. The ARF form contains four categories of the daylight condition variable (e.g. day, night with the presence of street lights, night without the street lights, and dawn/dusk). The two night categories were merged to represent a single night category in this research. Road geometry data were initially collected using 5 categories (e.g. straight and plain, curve, curvilinear and sloppy, slope, and peak) which were recoded into straight and plain, and other categories. In a similar way, the originally collected 4 category of road class (e.g. city road, feeder road, highway, regional highway) were recoded into city and feeder road, and highway categories.

### 4.2.3 Analytical method

The analytical method used in the literature to model injury severity level is largely determined by the approaches used to represent injury severity level. To address discrete type of outcome data, over the years researchers have used a variety of methodological approaches including binary logit models, ordered probit models, multinomial logit models, nested logit models, mixed (random parameters) logit models etc. Miles-Doan (1996) applied logistic regression to analyse fatal vs. non-fatal, fatal vs. minor, and fatal vs. seriously injured binary outcome variables in Florida. Ballesteros et al. (2003) also applied a similar modelling framework in their analysis in Maryland. Various studies have used multinomial logit (MNL) models in the modelling of injury severity level with 3 or more categories due to their ease of computation and the wide availability of software packages capable of estimating the MNL model (Kim et al., 2007). In these studies, the different levels of injury severity have been considered as a separate unordered category.

Although the MNL models are also more flexible in terms of the functional form and consistent coefficient estimates with under-reporting data, however, they do not recognize the natural ordering (increasing severity) of the alternatives (injury severity levels). As a result, the use of an ordered-response discrete-choice model (either probit or logit) has been highlighted in the literature (Klop and Khattak, 1999; Lee and Abdel-Aty, 2005; Zajac and Ivan, 2003). Another limitation of the multinomial logit model is that the disturbance terms among the severity outcomes are assumed to be independent. Previous studies have shown that there are shared unobserved effects at lower crash severity levels (Savolainen and Mannering, 2007; Shankar et al., 1996). As a result, the use of mixed multinomial logit (MMNL) model has been advocated by many researchers because this model can relax the heterogeneity of preferences assumption in the MNL model (Xie et al., 2012). Eluru et al. (2008) have developed a mixed generalised ordered response logit model to the analysis of injury severity that recognizes the ordinal nature of the categories while also allowing flexibility in capturing the effects of explanatory variables on each ordinal category and allowing heterogeneity in the effects of contributing factors due to the moderating influence of unobserved factors. Nested logit models, yet another group of discrete choice model, have also been used by researcher particularly due to its capability to relax the IID assumption of the MNL model (Shankar et al., 1996).

Researchers used analysis of variance method to analyse continuously measured accident severity level such as the ISS (Pitt et al., 1990). However, many studies have classified the continuously derived ISS score and subsequently used binary logistic regression. For example, Ballesteros et al. (2003) derived two classes of the ISS (e.g. ISS ≥ 16 vs. ISS <16) whereas Roudsari et al. (2004) tested different combinations of classes generated from the ISS (e.g. ISS ≥ 15 vs. ISS <15 or ISS ≥ 9 vs. ISS < 9).

Given that the injury severity level was collected as an ordinal outcome based on a 4-point Likert scale in this research (Table 1), the ordered probit regression model was estimated to identify factors contributing to the severity level in this research. The model was estimated in Stata. The categorical independent variables were either dummy or binary coded to fit into the model. Only statistically significant ($p<0.1$) and logically defensible explanatory factors were retained in the final models, although the initial model specification included all variables shown in Table 1.

## 4. Results

Table 2 provides the ordered Probit model estimates of injury severity along with significant parameters. The Pseudo $R^2$ value of 0.19 indicates that the model has sufficient explanatory power in explaining injury severities in the dataset. Since the dependent variable, or severity level, increases with injury severity, a positive coefficient suggests a higher likelihood of severe injuries.

Number of vehicles involved in a crash has been found to be significant at 5% significance level in explaining injury severities of traffic crashes. The likelihood of injury severities has been found to be increased for single vehicle crashes than multi-vehicle crashes. Further analysis shows that about 93% of single vehicle crashes include collisions involving pedestrian (93%), which is expected to be more severe because this road user is unprotected and vulnerable.

A crash in a highway section within the city has been found be associated with higher injury severities compare to arterial or feeder roadway sections. Speed is supposed to be higher along highway sections, which might resulted in higher injuries.

Table 2: Ordered Probit regression model estimates of significant parameters associated with traffic injury severities

| Explanatory factors | Coef. | Std. Err | z | P>\|z\| | 95% confidence interval | |
|---|---|---|---|---|---|---|
| Number of vehicles: single (ref: multi) | 1.48 | 0.05 | 27.30 | 0.00 | 1.37 | 1.58 |
| Traffic control: only police (ref: uncontrolled) | -0.31 | 0.06 | -5.20 | 0.00 | -0.42 | -0.19 |
| Intersection type: 4 way (ref: not in an intersection) | -0.13 | 0.08 | -1.61 | 0.10 | -0.28 | 0.03 |
| Intersection type: roundabout (ref: not in an intersection) | -0.41 | 0.23 | -1.76 | 0.08 | -0.87 | 0.05 |
| Traffic flow direction: two way (ref: one way) | -0.16 | 0.09 | -1.87 | 0.06 | -0.34 | 0.01 |
| Presence of road divider: no (ref: yes) | 0.41 | 0.10 | 4.13 | 0.00 | 0.22 | 0.61 |
| Time of day/light condition: night (ref: day) | 0.20 | 0.06 | 3.36 | 0.00 | 0.08 | 0.31 |
| Time of day/light condition: dawn/dusk (ref: day) | 0.42 | 0.09 | 4.74 | 0.00 | 0.25 | 0.59 |
| Road class: city and feeder road (ref: highway) | -0.40 | 0.06 | -6.87 | 0.00 | -0.52 | -0.29 |
| /cut1 | 0.89 | 0.13 | | | 0.63 | 1.16 |
| /cut2 | 1.13 | 0.13 | | | 0.86 | 1.39 |
| /cut3 | 1.81 | 0.14 | | | 1.55 | 2.08 |
| Log likelihood | | | | | | -2032.71 |
| LR $Chi^2$ (9) | | | | | | 961.51 |
| Pseudo $R^2$ | | | | | | 0.19 |
| N | | | | | | 2716 |

Night time influence has been found to be significant and positively associated with higher injury severities in traffic crashes. A reduction of visibility and sight distance during the night time might be responsible for higher injury severities.

Road way locations where traffic are controlled and monitored by the traffic police are associated with a lower level of injury severities compare to locations where there are no traffic police enforcements or other traffic controls, e.g. signals. Traffic police enforcements seem to improve the safety behaviours of various road users and thus are likely to reduce the injury severities.

In contrast to road segments, injury severities are lower at four-legged intersections and roundabouts. Speed of a traffic stream is likely to be slower at intersections and this may result in a lower severity in case of any crash at those locations.

The presence of a divider results in a lower likelihood of injuries compare to a roadway without any divider. A roadway median or divider reduces the likelihood of head-on collisions in general and hence the likelihood of severe injuries.

Interestingly, injury severities seem to be lower in a two-way traffic arrangement compare to one-way traffic. One-way traffic generally has less conflicting points than two-way traffic arrangements but associated with a higher likelihood of severe injuries. Whether higher speed on one-way traffic, higher lane indiscipline, or higher side frictions e.g. pedestrians and parked vehicle along both sides of the roadway are responsible for higher injury severities on roads with one-way traffic merit further investigation.

**5. Discussion and conclusion**

This research models traffic injury severity in a mega city of a developing country. Using a 5 five year crash dataset from the Dhaka Metropolitan Area, it identifies factors related to the environmental characteristics, roadway characteristics, and crash characteristics that contributed to the injury severity level in this context. The findings of this research bear important transport safety policy implications for developing countries given that little research exists on the topic that focuses on developing country. It also provides a foundation to compare and contrast the role of different factors between developed and developing countries.

Clearly, most of the findings in this research are consistent with the findings reported in the developed country literature. However, contrasting findings were also identified. For instance, it has long been recognised in the developed world that crashes where a vehicle collides straight ahead with the pedestrian result in severe injuries (Miles-Doan, 1996). The evidence in this research not only supports this but it shows that this is the most important factor associated with injury severities in this context. This finding is also similar to other developing country context (Schmucker et al., 2011).

As mentioned earlier, the impact of traffic control mechanism is mixed in the literature. Some identified that there is no impact of traffic control (Pitt et al., 1990); whereas others identified a lower severity level if traffic control mechanism exists (Lee and Abdel-Aty, 2005). The findings in this research are also mixed. Unlike developed countries, many of the intersections are not signalised in Dhaka. Even though there are signals, they are out of order most of the time. As a result, those intersections are mainly controlled by traffic police. However, traffic police are also present in all signalised (operational) intersections most of the time. Evidence in this research shows that the presence of traffic police based control mechanism reduced the severity level. This is well explanatory as drivers take more care if they see a traffic police presents compared to uncontrolled locations in Dhaka city. Probably for a similar reason, no difference observed in the severity level between uncontrolled and only signalised intersections because traffic police is not there. Therefore, it was expected that the presence of both police and signal based control mechanism would reduce the severity level although it did not. A lower response rate in this category might have an influence in this result. Future studies should seek to clarify this using a larger dataset.

Unlike the findings of previous research that shows that the 4-way intersections increase fatality (Quddus et al., 2002), this research shows that it reduced the severity level compared to non-intersection location. In a similar way, roundabouts also reduced the severity of crashes. Consistent with the traffic control factors, non-intersections locations are rarely monitored by traffic police, and as a result, drivers are able to drive recklessly which results in higher severity of crashes. The provision of petrol police is, therefore, a way forward to reduce the injury severity level in non-intersection locations.

The impact of traffic flow direction in this context was found to contrast with the findings of most studies in developed countries. Most previous studies have identified that crashes in two way roads are more severe than crashes in one way roads (Quddus et al., 2002; Sze and Wong, 2007). The finding in this research shows the opposite. This is particularly due to the fact that most of the crashes are involved between a pedestrian and a single vehicle in this context. In a one way road, some pedestrians cannot see the vehicles coming from their back (in one side of the road). As a result, they remained completely unaware of their crashes and failed to take any action to prevent injury (Sze and Wong, 2007). However, this finding is unique even within Bangladesh because previous studies have shown that one way road is safer in other urban areas in Bangladesh (Barua and Tay, 2010).

Consistent with previous studies, this research also identified that crashes in highways are more severe than crashes in ordinary roads in a city due to higher speed of vehicles in the highways (Miles-Doan, 1996; Sze and Wong, 2007). Necessary adjustment in speed limits might improve traffic safety in highways located within a city. However, the adjustment must be enforced through the provision of adequate petrol police in highways.

Despite a number of environmental factors were analysed in this research, only the daylight condition appears to be significant in this context. Results shows that crashes in darker periods of time are associated with sever injuries. Therefore, the direction and impact of this factor was found to be consistent with most of studies cited in this paper (Kim et al., 2007; Klop and Khattak, 1999; Lee and Abdel-Aty, 2005; Miles-Doan, 1996; 2002; Sze and Wong, 2007; Zajac and Ivan, 2003).

Many factors (e.g. non-motorist characteristics, motorised vehicle driver characteristics, and motorised vehicle characteristics) were not included in this research that are identified to have significant impact on injury severity in the literature. Despite this omission, the model presented here accounted for 19% variance in data which was found to be representative of many studies reported in the safety literature. However, further research should seek to include the omitted factors and improve upon the explanatory power of the model presented here.

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