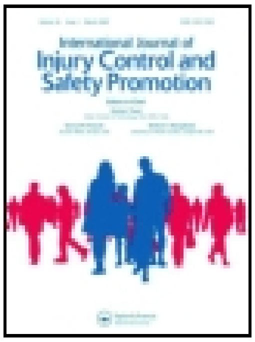

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Exploring the factors influencing pedestrian-vehicle crash severity in Dhaka, Bangladesh

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ABSTRACT

Although the rate of road crashes and their severity is relatively higher in developing countries, there is still a lack of research on pedestrian-vehicle crash severity in these contexts, particularly in Bangladesh. Therefore, this study aimed to identify the contributing environmental, road, and vehicular factors that influenced pedestrian—single-vehicle crash severity in Dhaka, a megacity and the capital of Bangladesh. A binary logistic regression model was developed in this study by analyzing a data set of pedestrian—single-vehicle crashes involving casualties in Dhaka from 2010 to 2015. The model identified seven significant factors influencing pedestrian-vehicle crash severity. Significant factors increasing the likelihood of fatal crashes included crashes during adverse weather, dawn/dusk period, night period (where street light was absent), off-peak period, crashes where road divider was unavailable, road geometry was straight and flat, and crashes those were occurred by heavier vehicles. Besides, crashes at three-legged intersections were less likely to be fatal. Both similarities and differences were found among the significant factors influencing pedestrian-vehicle crash severity in Dhaka from the findings of the developed countries. The findings of this study would help transport engineers and planners to design safer roadways for both pedestrians and vehicles.

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Introduction

Road crashes kill about 1.35 million people every year and it can be envisaged as one of the leading causes of death throughout the world. Considering the fact that about 23% of the total road fatalities involve pedestrians, it can be argued that pedestrians are in fact the most vulnerable group of road-users (World Health Organization (WHO), 2020). Therefore, pedestrian-vehicle crashes are one of the major safety concerns. Compared to the developed countries, the road crash scenario in the developing countries is even worse. Two-third of the global injuries and 93% of the fatal injuries take place in the developing countries, even though these countries have about 60% of the world's vehicles (World Health Organization (WHO), 2020). Despite the disproportionate distribution of road crashes between the developed and developing countries, a number of research were conducted to explore the factors contributing to the pedestrian-vehicle crash severity in the context of developed countries (e.g. Tay, Choi, Kattan, & Khan, 2011; Aziz, Ukkusuri, & Hasan, 2013; Chen & Fan, 2019). On the other hand, very few studies exist in the context of developing countries (Moradi et al., 2019).

Analyzing pedestrian-vehicle crash severity is a convenient way for identifying the factors behind road crashes. It helps the engineers and planners to implement proper countermeasures to mitigate the occurrence of road crashes and minimize their severity by bringing appropriate changes in the identified contributing factors influencing crash severity (Tay et al. 2011; Uddin & Ahmed, 2018; Chen & Fan 2019).

However, due to the lack of research in the context of developing countries, engineers and planners of those countries often rely on the findings of the developed countries for taking safety measures (Rahman, Andersson, & Svanström, 1998). This approach cannot be considered as appropriate since the factors influencing crash severity varies between contexts (Kamruzzaman, Haque, & Washington, 2014). Therefore, the importance and necessity can be emphasized in conducting researches to identify the factors influencing pedestrian-vehicle crash severity in the context of developing countries.

Bangladesh, a developing country, can be considered as one of the most unsafe countries in the world in terms of road crashes. This country has one of the highest traffic fatality rates, about 160 deaths per 10,000 vehicles; whereas, this rate is only 1.4 in the UK and 2.0 in the USA (Hoque, Muniruzzaman, & Ahmed, 2005). This rate is much higher even when compared to the other developing countries, e.g. Sri Lanka (16.0), Malaysia (55), India (25.3), and so on (Ahsan, 2012). In addition, Center for Disease Control (CDC) (2014) estimated that road crashes were one of the leading causes of unnatural deaths in Bangladesh. Even though police reports claimed that about 2,800 or more crashes occur in Bangladesh every year, the actual estimated road crashes number fluctuates from 10,000 to 12,000 (ARI,

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n.d.; Hasanat-E-Rabbi, 2013). When compared to the other cities, road crash scenario is the worst in the megacity Dhaka, the capital of Bangladesh. In Dhaka, from 1998 to 2014, more than 10 thousand crashes occurred, and about 4,514 pedestrians died due to those crashes (ARI, n.d.). In addition, pedestrians represented almost 72% of the total road fatalities in Dhaka (Rahman, Mahmud, Hoque, & Ahmed 2006). Therefore, it is important to address the vulnerability of the pedestrians through conducting proper research. One of the research directions could be identifying factors behind the pedestrian-vehicle crash severity.

A good number of studies have been conducted on crash severity analysis throughout the world as well as in Bangladesh. The study of Barua and Tay (2007) developed a logistic regression model for identifying the factors that influenced the severity of crashes in intersections of Dhaka by taking traffic and temporal factors into consideration. Another study by Barua and Tay (2010) focused only on the severity of bus crashes in Bangladesh. This study developed an ordered logit model considering the factors of crash, including temporal, vehicular, and road factors. Kamruzzaman, Haque, and Washington (2014) analyzed and identified the road, traffic, and environmental factors that influenced the crash severity in Dhaka. An ordered probit model was developed in the study. Anowar, Yasmin, and Tay (2014) focused on the factors that influenced the severity of crashes in intersections of Bangladesh. This study was conducted developing an ordered logit model and impulsive, environmental, vehicular, road, intersection, and temporal factors were taken into consideration. Siddique (2018) conducted a study on the severity of crashes that occurred in national highways of Bangladesh using an ordered probit model. Factors considered in this study were crash, environmental, vehicular, and road factors. It is clear from the above discussion that although several studies have been conducted in Bangladesh on crash severity analysis, there is still a lack of research that focus on the pedestrian-vehicle crash severity analysis in the context of the megacity Dhaka.

This study aimed to address the existing gap in research and contribute to the literature by identifying the factors influencing the severity of pedestrian–vehicle crashes in a megacity of a developing country. This research focused on the megacity Dhaka, the capital of one of the most unsafe developing countries, Bangladesh. The objective of this study was to identify the contributing environmental, road, and vehicular factors that influenced pedestrian—single-vehicle crash severity. Since single-vehicle crash provides better chance to explore the responsible factors precisely and most of the pedestrian deaths caused by single-vehicle crash (Hamdane, Serre, Masson, & Anderson, 2015), this study solely focused on the pedestrian—single-vehicle crash. The significance of this study lies on the results that are expected to help the engineers and planners of the developing countries to address the pedestrian-vehicle crash risk factors by taking proper countermeasures.

Data

In Bangladesh, the Accident Research Institute (ARI) is responsible for collecting, organizing, storing, and maintaining the road crash data. The ARI stores road crash data in the Microcomputer Accident Analysis Package (MAAP) software. From the MAAP software, pedestrian—single-vehicle crash data of the past six years (2010–2015) of Dhaka were collected and used in this research. Data of total 1,291 crashes were collected. For each of the crash event, corresponding data of crash severity along with data of 13 environmental, road, and vehicular factors were collected. These 13 factors were *(a)* environmental factors (crash occurring month, crash occurring time, weather condition, light condition), *(b)* road factors (location type, traffic control types, road geometry, road surface condition, road surface type, road surface quality, roadway classification, presence of divider on roadway), and *(c)* vehicular factors (vehicle type). After collecting the data, levels of several factors were reclassified to make them clearer, meaningful, and operational. In case of crash severity data, it was collected in four levels, including fatal, grievous, simple injury, and motor collision from the MAAP software. For lower frequency of grievous, simple injury, and motor collision levels data, crash severity was reclassified into two levels: fatal and non-fatal (merging grievous, simple injury, and motor collision levels into non-fatal level). In addition, data of crash occurring month were reclassified into three seasons: summer (March to June), rainy season (July to October) and winter (November to February). Furthermore, data of crash occurring time were reclassified into peak period (8 am- 12 pm and 4 pm-10 pm) and off-peak period (12 pm-4 pm and 10 pm- 8 am) considering the working hours of Dhaka (office hour: 9 am- 5 pm; business hour: although most of the business entities start at 9 am, most of them might finish much later than 5 pm). Several levels of weather condition, location type, traffic control type, road geometry, road surface condition, and road surface quality factors were merged into a single level for their lower frequency (See Table 1). In addition, while reclassifying the roadway classification data, national highway and regional highway levels were combined as highway level, and city road and feeder road levels were kept the same as they were collected. In case of vehicle type data, non-motorized vehicles, motor cycle, taxi, and car were classified as light vehicle; mini-bus, jeep, and mini truck were classified as medium vehicle; bus, truck, oil tanker, and cargo were classified as heavy vehicle. The description of the 13 factors with their comparative proportions is showed in Table 1.

Methodology

Binary logistic regression method has been widely used in the previous crash severity related studies (e.g. MacLeod, Griswold, Arnold, & Ragland, 2012; Chen, Cao, & Logan, 2012; Zhang, Yau, & Zhang, 2014). This method finds the best model to describe the relationship between a binary nature dependent variable and multiple independent variables (Ozdemir, 2011). In this study, the dependent variable was binary nature having two outcome levels: fatal crash

Table 1. Descriptive statistics and univariate statistics of the potential factors.

	Level of severity			
Factors	Non-fatal	Fatal	Total	*p*-value
Season				***0.570***
Summer	86 (20.4%)	336 (79.6%)	422 (32.7%)	
Rainy season	80 (18.8%)	346 (81.2%)	426 (33.0%)	
Winter	96 (21.7%)	347 (78.3%)	443 (34.3%)	
Weather condition				***0.041***
Good	260 (20.7%)	995 (79.3%)	1255 (97.2%)	
Adverse (e.g. rainy, foggy)	2 (5.6%)	34 (94.4%)	36 (2.8%)	
Time of day with light condition				***0.001***
Daylight	188 (23.2%)	621 (76.8%)	809 (62.7%)	
Dawn/dusk	24 (14.2%)	145 (85.8%)	169 (13.1%)	
Night with street lights	46 (19.6%)	186 (80.2%)	232 (18.0%)	
Night without street lights	4 (4.9%)	77 (95.1%)	81 (6.3%)	
Peak hours				***0.049***
Off-peak	126 (18.2%)	565 (81.8%)	691 (53.5%)	
Peak	136 (22.7%)	464 (77.3%)	600 (46.5%)	
Location type				***0.159***
Non-intersection	185 (19.8%)	748 (80.2%)	933 (72.3%)	
Three-legged intersection	31 (26.3%)	87 (73.7%)	118 (9.1%)	
Four Legged intersection	32 (22.5%)	110 (77.5%)	142 (11.0%)	
Roundabout	6 (21.4%)	22 (78.6%)	28 (2.2%)	
Others (e.g. stag-X, railway crossing)	8 (11.4%)	62 (88.6%)	70 (5.4%)	
Traffic control types				***0.186***
Uncontrolled	126 (19.1%)	535 (80.9%)	661 (51.2%)	
Only police	118 (22.7%)	402 (77.3%)	520 (40.3%)	
Both police and traffic signal	9 (36.0%)	16 (64.0%)	25 (1.9%)	
Centerline	2 (6.9%)	27 (93.1%)	29 (2.2%)	
Others (e.g. only traffic light, pedestrian crossing, stop and go sign)	7 (12.5%)	49 (87.5%)	56 (4.3%)	
Presence of divider on roadway				***0.006***
No	47 (14.8%)	270 (85.2%)	317 (24.6%)	
Yes	215 (22.1%)	759 (77.9%)	974 (75.4%)	
Road geometry				***0.155***
Straight and flat	245 (19.9%)	984 (80.1%)	1229 (95.2%)	
Others (e.g. curve, slope)	17 (27.4%)	45 (72.6%)	62 (4.8%)	
Road surface condition				***0.513***
Dry	257 (20.2%)	1015 (79.8%)	1272 (98.5%)	
Skidding (e.g. wet, muddy)	5 (26.3%)	14 (73.7%)	19 (1.5%)	
Road surface type				***0.501***
Brick	1 (11.1%)	8 (88.9%)	9 (0.7%)	
Sealed	261 (20.4%)	1021 (79.6%)	1282 (99.3%)	
Road surface quality				***0.262***
Good	260 (20.5%)	1011 (79.5%)	1271 (98.5%)	
Bad (e.g. rough, under repair)	2 (10.0%)	1029 (90.0%)	20 (1.5%)	
Roadway classification				***0.040***
Highway	71 (16.7%)	354 (83.3%)	425 (32.9%)	
City road	188 (22.3%)	654 (77.7%)	842 (65.2%)	
Feeder road	3 (12.5%)	21 (87.5%)	24 (1.9%)	
Vehicle type				***0.000***
Light vehicle	72 (32.4%)	150 (67.6%)	222 (17.2%)	
Medium vehicle	24 (22.6%)	82 (77.4%)	106 (8.2%)	
Heavy vehicle	166 (17.2%)	797 (82.8%)	963 (74.6%)	
Total	***262 (20.3%)***	***1029 (79.7%)***	***1291 (100%)***	

and non-fatal crash. Thus, a binary logistic regression model was developed to identify the factors influencing pedestrian-vehicle crash severity, and at the same time, to describe the relationship between crash severity and identified factors, using the following equation:

$$logit(P) = \ln\left(\frac{P}{1-P}\right) = \alpha_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_i x_i$$

Here, P is the probability of occurring fatal crashes, α_0 is the intercept, β_i is the model coefficient, and x_i is the independent variables (factors).

This model was developed in two stages. Univariate analysis was conducted in the first stage to identify the factors that should be considered as independent variables for developing the model. In this stage, influence of the potential factors on pedestrian-vehicle crash severity was examined individually using Chi-square test. Hosmer et al. (2000) suggested to consider factors as independent variables for developing the multivariate model if the p-value of that factor is found to be less than 0.25 in the univariate analysis (Chi-square test). Therefore, any factor that had a p-value less than 0.25 was selected for developing the binary logistic regression model in this study. In the second stage, multivariate analysis was conducted where the selected factors in the first stage were used as independent variables to develop the binary logistic regression model to explain the probability of occurring fatal crashes. The developed model showed the coefficient (B), significant level (p-value), and odd ratio (OR) of the independent variables.

In general, the coefficient (*B*) value of a discrete independent variable represents either there is a positive or negative association with dependent variable for a particular level compared to the reference level of that independent variable. Positive value of the coefficient (*B*) represents that the likelihood of fatal crashes increases for a particular level compared to the reference level of the independent variable. Negative value of the coefficient (*B*) represents the opposite. Odd ratio (*OR*), exponentiation of coefficient (*B*), is another statistic which is used for interpreting the model. In case of a discrete independent variable, if the *OR* value *X* is greater than one, then it represents the likelihood of fatal crashes increases *X* times for a particular level compared to the reference level of that independent variable. The relationship is reverse if *OR* value is less than one.

Result and discussion

After analyzing 1,291 pedestrian—single-vehicle crash data, it was observed that 20.3% of the crashes were non-fatal; whereas, 79.7% were fatal. For the purpose of modeling the probability of fatal crashes, at first, univariate analysis was conducted by using each of the 13 collected factors individually. In this analysis, Chi-square test was conducted to show association between each factor with crash severity. Among the 13 factors, six factors were found to be significant at 95% confidence level (p-value < 0.05). Those factors were weather condition, time of day with lighting condition, peak hours, and presence of divider on roadways, roadway classification, and vehicle type; as shown in Table 1.

After completing the univariate analysis, multivariate analysis was conducted. In multivariate analysis, a binary logistic regression model was developed using the selected factors to explain the likelihood of fatal crashes. The factor selection process was initiated by the univariate analysis. Any factor that had a p-value less than 0.25 in the univariate analysis was selected for developing the model (Table 1). As a result, a total of nine factors were considered as independent variables for developing the model. Statistical Package for the Social Sciences (SPSS) was used to develop the model. Coefficient (*B*), odd ratio (*OR*), p-value, and odd ratio(*OR*) at 95% confidence interval (*CI*) of the significant independent variables, and model statistics of the developed model are shown in the Table 2. From the model statistics, Chi-square statistics (χ^2), degree of freedom (*df*), and p-value were found to be 71.707, 09, and 0.00, respectively. These values illustrate that the model was found to be statistically significant at 99% confidence level (p-value < 0.01). Interpretations of and discussion on the model results are presented as follows.

Environmental factors

Weather condition was found as one of the significant environmental factors in the developed model (p-value $<$ 0.05). The likelihood of fatal crashes decreased by 1.5 times when the weather condition was good compared to the adverse weather (e.g., rainy, fogged), holding all the other factors constant (Table 2). Similar result was found by Tay et al. (2011).

In the context of Dhaka, impact of rainy weather on crash severity is an important topic for discussion. In the monsoon season, transportation system of Dhaka is highly interrupted even with minimal rainfall resulting in inundation of several areas of the city. Waterlogging is a common phenomenon in Dhaka during the rainy season. When it rains over 25 mm, traffic congestion becomes worse than usual (Khondoker, 2004). In addition, road condition becomes terrible and unusable at that time while some roads become muddy and slippery. For these reasons, both drivers and pedestrians find it very difficult to use the roads. Falling down in open drain and manhole, malfunctioning of the motorized vehicles (e.g. braking, steering, taking an evasive maneuver), having reduce visibility while raining, and increasing driver fatigue are the common consequences of rainfall as well as waterlogging in Dhaka (Subrina & Chowdhury, 2018; Tay et al. 2011). All these issues might increase the probability of occurring fatal crashes.

On the other hand, based on the prepared database for this study, it was found that 23 crashes occurred in Dhaka during foggy weather condition and all of them resulted in fatal crashes. According to the ARI, from 1998 to 2014, approximately 9,620 crashes took place in January and February in Bangladesh. Among them, 988 crashes occurred due to dense fog. In addition, about 2% of the national crashes occurred during foggy weather (ARI, n.d.). Tay et al. (2011) advocated that foggy weather reduces the visibility of both the drivers as well as pedestrians. In line with this, using high beam headlights during foggy weather leads to extensively decrease the visibility of the drivers and pedestrians. In Bangladesh, drivers generally tend to use high beam headlights during foggy weather instead of low beam headlights due to lack of knowledge (Hasan, 2017).

However, effect of weather condition on the pedestrian-vehicle crash severity was hardly seen in the developed countries (e.g. Li & Fan 2019a). Besides, a study of Zheng (2014) showed that decent weather did not reduce the severity of crashes rather it had an adverse impact. Since drivers in suitable weather often tended to be casual and maintained a high speed of their vehicles while in substandard weather, they tended to be more cautious, and as a result, less fatal crashes occurred.

Time of day with light condition factor was found to be significant at 95% confidence level in this study (p-value $<$ 0.05). The chance of occurring fatal crashes at dawn/dusk period and night period (where street light was absent) was 1.7 and 5.3 times higher, respectively, compared to daylight period, holding all the other factors constant. In addition, crash severity at night period was not found to be significant where street lights were available. This result was found to be consistent with the previous studies (e.g. Kim, Ulfarsson, Shankar, & Kim, 2008; Tay et al. 2011; Uddin & Ahmed 2018; Li & Fan 2019a; Chen & Fan 2019). In general, lighting condition is found comparatively poor at dawn/dusk period and night period (where street light is absent) than daylight period and night period (where street

Table 2. Result of the binary logistic regression model.

Independent variable	Coefficient (*B*)	*p*-value	Odd Ratio (*OR*)	95% *CI* for *OR*	
				Lower	Upper
Constant	1.336	0.097	3.805		
Weather (ref: adverse)					
Good	−1.573	0.033	0.208	0.049	0.884
Time of day with light condition (ref: daylight)					
Dawn/dusk	0.554	0.019	1.739	1.095	2.762
Night without street lights	1.673	0.001	5.330	1.918	14.812
Peak hours (ref: peak)					
Off-peak	0.298	0.037	1.347	1.017	1.784
Location type (ref: non-intersection)					
Three-legged intersection	−0.424	0.065	0.654	0.417	1.027
Presence of divider on roadway (ref: yes)					
No	0.584	0.001	1.794	1.260	2.554
Road geometry (ref: others)					
Straight and flat	0.621	0.046	1.861	1.011	3.425
Vehicle type (ref: light vehicle)					
Medium vehicle	0.530	0.058	1.699	0.981	2.942
Heavy vehicle	0.814	0.000	2.256	1.613	3.156

Model summary statistics.
n = 1291, χ^2= 71.707, ***df***= 09, ***p*-value**= 0.000.

lights are present). Visibility of both the pedestrians and drivers are usually affected by poor lighting condition, and it consequently occurs more fatal crashes. In Dhaka, sodium and fluorescent street lights are used for road lighting purpose. Though street lights are found in most of the roads of Dhaka, few roads, especially secondary and feeder roads do not have adequate street lights. In addition, faulty street lights, lack of maintenance work, difficulty in monitoring and controlling, absence of street lights, and load shedding are some of the drawbacks of road lighting system in Dhaka (Siddiqui, Nafis, & Mazumder, 2017) that might influence the pedestrian-vehicle crash severity. In the recent past, local government of Dhaka has taken initiative to replace all sodium lights by LED bulbs in all the roads of Dhaka for increasing visibility and reducing electricity consumption (Alam, 2013).

Peak hours of the day factor was also found to be significant in the developed model (p-value < 0.05). The result showed that pedestrian-vehicle crashes that occurred during off-peak period were 1.3 times more likely to be associated with fatal crashes compared to the crashes that occurred during peak period, holding all the other factors constant. Unbearable traffic congestion is a common phenomenon in Dhaka during peak period that reduces the speed of the vehicles significantly. Here, the average speed of the vehicles is about seven kilometers per hour (Gallagher, 2017). In addition, this value is much lower during peak period compared to off-peak period. Slow speed of the vehicle during peak period might reduce the severity of crashes. This result was found to be consistent with Kim et al. (2008). However, several studies were found the opposite result (e.g. Tay et al. 2011; Chen & Fan 2019). Findings of those studies showed that the likelihood of fatal crashes tended to increase at peak period as the drivers' irritation, aggression, and exhaustion when driving during peak period in congested roads remained substantially high which caused more of fatal crashes.

To minimize the impact of environmental factors on pedestrian-vehicle crash severity, locations where fatal crashes occurred frequently in adverse weather condition, poor lighting condition, and off-peak period need to be identified and necessary steps (e.g. improving level of lighting, providing adequate logistics and resources to illuminate road network, continuous monitoring and maintenance of street lights, installing traffic sign and signal, providing warning sign for both the vehicles and pedestrians, providing necessary road marking using appropriate color, taking steps to reduce waterlogging, installing proper drainage system, improving road surface condition, taking speed control measures for controlling speed of the vehicles at off-peak period, assigning speed limit for different roads) are suggested to be taken to prevent further crashes as well as to reduce their severity. Furthermore, appropriate authorities are recommended to arrange proper training for the drivers to train them on how they should drive during unusual environmental condition. In addition, behavior of both the driver and pedestrian needs to be investigated during adverse weather, poor lighting condition, and off-peak period to get more insights on their complex interaction at these periods. This would eventually help to ensure safer road for pedestrians as well as vehicles.

Road factors

Among the various crash occurring locations, crashes occurred at three-legged intersections had shown a significant association with crash severity at 90% confidence level (p-value < 0.10). In particular, the likelihood of fatal crashes decreased by 0.6 times when crashes occurred at three-legged intersections compared to non-intersection locations, holding all the other factors constant. The likely explanation could be that at three-legged intersection locations, conflict between vehicles is higher than non-intersection location, and enormous number of conflicts reduces the speed of the vehicles. In addition, traffic polices mostly control the intersections of Dhaka because traffic lights in the intersections are neither available nor functional (Rahman & Khadem 2012; Pervaz & Newaz, 2016). Moreover, midblock crossing facilities for pedestrians are not available in Dhaka. No control system such as traffic lights, traffic police or road marking is available in the midblock crossing locations. Crosswalks are found in very few mostly used midblock crossing locations. Therefore, no protection is available for pedestrians while crossing at midblock (non-intersection) location of the road and driver could drive vehicle with a high speed in those locations. Therefore, probability of fatal crashes was found higher at non-intersection locations than three-legged intersections.

Presence of divider on roadway factor was found to have a significant (p-value <0.01) and negative relationship with crash severity. The chance of fatal crashes increased by 1.7 times if divider was not available on the roadway, holding all the other factors constant. A plausible explanation could be that presence of divider on the roadway improves the road geometric design and works as a refuge island for the pedestrian while crossing the road. As a result, when pedestrians cross the road, they could wait on the divider, and when the road condition becomes safe then they could cross the far-side of the road. Therefore, fatal crashes occurred less in the road where divider was available. However, several studies (Li & Fan 2019a; Kim et al. 2008) found opposite result from this study. They explained the result in the way that presence of divider on the road reduced conflicting traffic and increased vehicle speed, and consequently increased the probability of fatal crashes.

Results reported in the developed model showed that road geometry was a significant factor that influenced pedestrian-vehicle crash severity (p-value < 0.05). The probability of fatal crashes increased by 1.8 times where road geometry was straight and flat compared to other road geometry types (e.g. curve, slope), holding all the other factors constant. In Dhaka, most of the primary and secondary roads are straight and flat. In addition, a large number of residential areas were designed following gridiron pattern, e.g. Baridhara, Gulshan, Dhanmondi, Purbachal, Uttara (Ahmed, Hasan, & Maniruzzaman, 2014; Ibrahim, Shoma, & Tariq, 2017). Ideally, speed of the vehicle on the access roads of residential areas should be lower and these roads should be more pedestrian friendly as pedestrians of all age groups frequently use these roads. However, due to the gridiron pattern of the residential areas as well as other areas, drivers can drive fast on the access roads. Furthermore, they also use the access roads as bypass road during severe traffic congestion on the primary roads which leads to increase the traffic volume in the access roads. These reasons might also stimulate to increase crash severity in Dhaka. According to Rifaat & Tay (2008), traditional gridiron street pattern are associated with higher frequency and severity of crashes compared to limited access roads. Therefore, conclusion could be drawn in such way that more pedestrian-vehicle fatal crashes occurred due to higher vehicle speed on the straight and flat roads compared to the roads having other geometries. Chen and Fan (2019), Aziz et al. (2013), and Kim et al. (2008) also found same result in their studies. However, several researchers also found different result from this (e.g. Li & Fan 2019a; Li & Fan 2019b). They explained that the line of sight might be absent at curved or sloped road which influenced to increase the fatal crashes.

To minimize the impact of road factors on pedestrian-vehicle crash severity, concern authorities are advised to take proper steps to make the roads pedestrian friendly. Wide, usable, and continuous footpaths need to be provided along the roads for the pedestrians. Pedestrian and vehicular traffic should be separated to reduce the crash risk of pedestrian. It could be done through providing railing on footpath, raising height of the footpath, planting trees, and so on. In addition, footpaths are advised to be kept neat and clear as well as free from blockage. Traffic control mechanism (e.g. traffic signal, countdown signal, traffic sign, road marking, crosswalk, stop sign) need to be provided at midblock crossing locations where pedestrian cross the road frequently. Proper vehicular speed control mechanism is suggested to be installed in the pedestrian crossing locations, straight and flat roads, and residential areas. Roads of residential areas are advised to be designed more pedestrian oriented and proper initiatives need to be taken to restrict through traffic in residential areas. It also has to be ensured that the curvy and sloppy roads have proper line of sight for avoiding pedestrian-vehicle conflict. In the context of Dhaka, divider has a significant role in reducing the severity of crashes, and thus, divider is recommended to be provided on roads maintaining appropriate standards.

Vehicular factor

A significant relation was found between the severity of crashes and vehicle type (p-value < 0.05). Crashes involving light vehicle had lower chance of resulting in fatal crashes compared to medium and heavy vehicle. Involvement of heavy vehicle in pedestrian-vehicle crashes was found as one of the most significant influential factors responsible for fatal crashes (p-value < 0.01). This result was consistent with previous studies (e.g. Li & Fan 2019a; Li & Fan 2019b; Aziz et al. 2013; Uddin & Ahmed 2018; Tay et al. 2011). This was an expected result as heavier vehicles (e.g. bus, truck) had greater mass which led to greater momentum compared to lighter vehicles (e.g., car, motor cycle), and consequently caused more fatal crashes. Unskilled, unlicensed, and inadequate heavy vehicles' drivers, fatigue of the heavy vehicles' drivers, unfit heavy vehicles on the road might be some of the main reasons behind high traffic fatalities in Dhaka. According to the Bangladesh Road Transport Authority (BRTA), about 39% of the heavy vehicles' drivers do not have any driving license. Moreover, a large number of drivers having light and medium vehicle driving license, drive heavy vehicles though they do not have heavy vehicle driving license (Hossain, 2019). Furthermore, the limit of heavy vehicle driving for a driver is at most eight hours daily as international standard; whereas, in Bangladesh, drivers would maneuver vehicle for far more hours than the standard. To maintain the standard, triple numbers of heavy vehicles' drivers are needed (Hossain, 2019). In addition, almost 0.5 million unfit vehicles are on the road without valid fitness certificates as per BRTA. A large number of the unfit vehicles include heavy vehicles (Titihila, 2019). Therefore, government needs to arrange training program to produce more skilled driver as well as to enforce laws to keep unfit vehicles and unlicensed drivers off the road. At the time of issuing heavy vehicle driving license, the authority should be ensured that the driver has sufficient driving skill and adequate knowledge about traffic laws. On the other hand, the roads of Dhaka are a paradise of heterogeneity where all types of vehicles plying together on the road. Therefore, it is essential to control the vehicles properly. In addition, heavy vehicles at particular locations for a particular period is recommended to be restricted if required. The provision of different traffic signs and alerts on the roads for both the pedestrians and drivers is also essential that would help to control the vehicles.

Conclusion and future work

The objective of this study was to identify the factors affecting the severity of pedestrian—single-vehicle crashes in Dhaka, Bangladesh. To fulfill the objective, a binary logistic regression model was developed considering nine factors. Results of the model showed that seven factors had significant influence on crash severity, including weather, time of day with light condition, peak hours, location type, presence of divider on roadway, road geometry, and vehicle type. Severity of crashes tended to be intensified with adverse weather and dark conditions, as well as during off-peak periods. This study also found that the fatal crashes decreased in three-legged intersections of the roads compared to non-intersection locations. In addition, the severity of crashes increased where the roads were straight and flat. Besides, divider had a significant role in reducing fatal crashes. Finally, it was also found that the probability of fatal crashes increased if the pedestrian crash occurred with heavier vehicle than crash occurred with lighter vehicle.

However, in this study, several notable factors were not considered, e.g. socio-demographic factors of drivers and pedestrians, speed factors, vehicle license and fitness factors. Thus, future research can focus on these factors and enhance the model presented here. Finally, it can be said that identification of environmental, road, and vehicular factors in this study would help the transport engineers and planners to design safer roads for the pedestrians and vehicles.

Disclosure statement

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References

Ahmed, B., Hasan, R., & Maniruzzaman, K. M. (2014). Urban morphological change analysis of Dhaka city, Bangladesh, using space syntax. *ISPRS International Journal of Geo-Information*, *3*(4), 1412–1444. https://doi.org/10.3390/ijgi3041412

Ahsan, H. M. (2012). Road safety in Bangladesh: Key issues and countermeasures. *Forum*, (7), 6. https://archive.thedailystar.net/forum/2012/July/road.htm

Alam, H. (2013). Eight city corporations to get LED street lights. *The daily Star*. https://www.thedailystar.net/news/eight-city-corporations-to-get-led-street-lights

Anowar, S., Yasmin, S., & Tay, R. (2014). Factors influencing the severity of intersection crashes in Bangladesh. *Asian Transport Studies*, *3*(2), 143–154.

ARI. (n.d.). *Road Safety Facts 2014*. http://ari.buet.ac.bd/downloads/Facts%202014.pdf

Aziz, H. A., Ukkusuri, S. V., & Hasan, S. (2013). Exploring the determinants of pedestrian–vehicle crash severity in New York City. *Accident; Analysis and Prevention*, *50*, 1298–1309. https://doi.org/10.1016/j.aap.2012.09.034

Barua, U., & Tay, R. (2007). *Severity of Intersection Crashes in Bangladesh [Paper presentation]*. Road Safety on Four Continents Conference.

Barua, U., & Tay, R. (2010). Severity of urban transit bus crashes in Bangladesh. *Journal of Advanced Transportation*, *44*(1), 34–41. https://doi.org/10.1002/atr.104

Center for Disease Control (CDC). (2014). *CDC in Bangladesh*. https://www.cdc.gov/globalhealth/countries/bangladesh/pdf/bangladesh_factsheet.pdf

Chen, H., Cao, L., & Logan, D. B. (2012). Analysis of risk factors affecting the severity of intersection crashes by logistic regression. *Traffic Injury Prevention*, *13*(3), 300–307. https://doi.org/10.1080/15389588.2011.653841

Chen, Z., & Fan, W. D. (2019). A multinomial logit model of pedestrian-vehicle crash severity in North Carolina. *International Journal of Transportation Science and Technology*, *8*(1), 43–52. https://doi.org/10.1016/j.ijtst.2018.10.001

Gallagher, R. (2017). Prioritising dhaka's urban transport system. *Journal of Business and Technology (Dhaka)*, *11*(1-2), 141–144. https://doi.org/10.3329/jbt.v11i1.34247

Hamdane, H., Serre, T., Masson, C., & Anderson, R. (2015). Issues and challenges for pedestrian active safety systems based on real world accidents. *Accident; Analysis and Prevention*, *82*, 53–60. https://doi.org/10.1016/j.aap.2015.05.014

Hasan, M. (2017). No significant steps to reduce fog-related accidents. *Dhaka Tribune*, https://www.dhakatribune.com/bangladesh/2017/01/03/no-significant-steps-reduce-fog-related-accidents?fbclid=IwAR2yXJy0CmbBwvLrAnCILK04O2A7vTecowYASNX8XaPW63ouRL1NyZWGe0s

Hasanat-E-Rabbi, S. (2013). *Modeling critical overturning criteria for single vehicle run-off-road crashes for Bangladesh context* [Unpublished master's thesis]. Bangladesh University of Engineering and Technology.

Hoque, M. S., Muniruzzaman, S. M., & Ahmed, S. N. (2005). Performance evaluation of road safety measures: a case study of the Dhaka-Aricha highway in Bangladesh. *Transport and Communications Bulletin for Asia and the Pacific*, *74*, 33–56.

Hosmer, D. W., Lemeshow, S., & Sturdivant, R. X. (2000). Introduction to the logistic regression model. *Applied Logistic Regression*, *2*, 1–30.

Hossain, A. (2019). 38pc heavy vehicles run by unlicensed drivers. *Prothom Alo*. https://en.prothomalo.com/bangladesh/38pc-heavy-vehicles-run-by-illegal-drivers

Ibrahim, M. A., Shoma, A. N., & Tariq, S. H. (2017). Predictions for 'Purbachal': Learning from 'Dhanmondi. *AIUB Journal of Science and Engineering (AJSE)*, *16*(1), 11–18.

Kamruzzaman, M., Haque, M. M., & Washington, S. (2014). Analysis of traffic injury severity in Dhaka. *Transportation Research Record:*

Journal of the Transportation Research Board, *2451*(1), 121–130. https://doi.org/10.3141/2451-14

Khondoker, T. (2004). *Causes and effects of water logging in Dhaka City* [Unpublished master's thesis]. Royal Institute of Technology.

Kim, J. K., Ulfarsson, G. F., Shankar, V. N., & Kim, S. (2008). Age and pedestrian injury severity in motor-vehicle crashes: A heteroskedastic logit analysis. *Accident; Analysis and Prevention*, *40*(5), 1695–1702. https://doi.org/10.1016/j.aap.2008.06.005

Li, Y., & Fan, W. (2019a). Pedestrian injury severities in pedestrian-vehicle crashes and the partial proportional odds logit model: accounting for age difference. *Transportation Research Record: Journal of the Transportation Research Board*, *2673*(5), 731–746. https://doi.org/10.1177/0361198119842828

Li, Y., & Fan, W. D. (2019b). Modelling severity of pedestrian-injury in pedestrian-vehicle crashes with latent class clustering and partial proportional odds model: a case study of North Carolina. *Accident; Analysis and Prevention*, *131*, 284–296. https://doi.org/10.1016/j.aap.2019.07.008

MacLeod, K. E., Griswold, J. B., Arnold, L. S., & Ragland, D. R. (2012). Factors associated with hit-and-run pedestrian fatalities and driver identification. *Accident; Analysis and Prevention*, *45*, 366–372. https://doi.org/10.1016/j.aap.2011.08.001

Moradi, A., Ameri, P., Rahmni, K., Najafi, M., Jamshidi, E., Fakhri, Y., Khazaei, S., Moeini, B., & Amjadian, M. (2019). Factors affecting the severity of pedestrian traffic crashes. *Archives of Trauma Research*, *8*(2), 46–56. https://doi.org/10.4103/atr.atr_6_19

Ozdemir, A. (2011). Using a binary logistic regression method and GIS for evaluating and mapping the groundwater spring potential in the Sultan Mountains (Aksehir, Turkey). *Journal of Hydrology*, *405*(1–2), 123–136. https://doi.org/10.1016/j.jhydrol.2011.05.015

Pervaz, S., & Newaz, K. M. S. (2016). Pedestrian safety at intersections in Dhaka metropolitan city. Proceedings of the 17th International Conference Road Safety on Five Continents (RS5C 2016), 1–11.

Rahman, F., Andersson, R., & Svanström, L. (1998). Health impact of injuries: a population-based epidemiological investigation in a local community of Bangladesh. *Journal of Safety Research*, *29*(4), 213–222. https://doi.org/10.1016/S0022-4375(98)00048-6

Rahman, M. M., & Khadem, R. (2012). Deficiencies of traffic signal system in Dhaka City. *Journal of Society for Transportation and Traffic Studies*, *3*, 63–73.

Rahman, R., Mahmud, S., Hoque, M., Ahmed, S. (2006). Pedestrian accident characteristics in Dhaka: A comparative investigation. *Proceedings of the International Conference on Road Safety in Developing Countries*, 84–90.

Rifaat, S. M., & Tay, R. (2008). Grid or limited acess roads: effects of street pattern on road crashes. In *Secouer Les Systèmes de Transports Au Canada Pour Faire Face Aux Besoins Futurs: Actes de la 43è Conférence Annuelle Fredericton, New Brunswick, Juin 2008*. (Vol. 43, p. 404). Canadian Transportation Research Forum.

Siddique, T. (2018). Accident severity analysis on national highways in Bangladesh using ordered probit model. *Scientific Research and Essays*, *13*(14), 148–157.

Siddiqui, S., Nafis, M. N. I., & Mazumder, N. M. N. R. (2017). *Smart street lighting system* [Unpublished thesis]. Military Institute of Science and Technology.

Subrina, S., & Chowdhury, F. K. (2018). Urban dynamics: An under-valued issue for water logging disaster risk management in case of Dhaka city. Bangladesh. *Procedia engineering*, *212*, 801–808. https://doi.org/10.1016/j.proeng.2018.01.103

Tay, R., Choi, J., Kattan, L., & Khan, A. (2011). A multinomial logit model of pedestrian–vehicle crash severity. *International Journal of Sustainable Transportation*, *5*(4), 233–249. https://doi.org/10.1080/15568318.2010.497547

Titihila, K. K. (2019). A million unlicensed drivers? *Dhaka Tribune*. https://www.dhakatribune.com/bangladesh/2019/07/29/a-million-unlicensed-drivers?fbclid=IwAR3dUDy979pcA6qhQ-qe7ojRRT5EzHYl7t59mjoWtsr0GmC2zeF_Qp2f9lY

Uddin, M., & Ahmed, F. (2018). Pedestrian injury severity analysis in motor vehicle crashes in Ohio. *Safety*, *4*(2), 20. https://doi.org/10.3390/safety4020020

World Health Organization (WHO). (2020). *Road traffic injuries*. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

Zhang, G., Yau, K. K., & Zhang, X. (2014). Analyzing fault and severity in pedestrian–motor vehicle accidents in China. *Accident; Analysis and Prevention*, *73*, 141–150. https://doi.org/10.1016/j.aap.2014.08.018

Zheng, Y. (2014). *Analysis of factors influencing pedestrian injury severity in pedestrian-vehicle crashes* [Paper presentation]. T&DI Congress 2014: Planes, Trains, and Automobiles (pp. 448–457). https://doi.org/10.1061/9780784413586.043