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Identification of Risk Factors Associated with Motorcycle-Related Fatalities in Ohio

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IDENTIFICATION OF RISK FACTORS ASSOCIATED WITH MOTORCYCLE RELATED FATALITIES IN OHIO

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Abstract: Ohio crash data for 2003-2007 were used to investigate the odds of a motorcyclist being fatally injured in a crash and the risk factors involved. The results show that risk factors for fatality/severe injury significantly increase when the following circumstances apply: the motorcyclist is a female, being the motorcycle rider, use of excessive speeding, use of alcohol and/or drugs, riding without helmet, being involved in a single-vehicle crash or at a non-intersection location, crashing on horizontal curves or on graded segments, and on major roadways. In order to reduce the number of fatal crashes this study indicates that the dangers of excessive speed and operating a motorcycle while intoxicated must be fully stressed to the public and both require an elevated enforcement. The enactment of an Ohio universal helmet law is particularly recommended.

CE Database subject headings: Risk management; Passengers; Fatalities; Traffic accidents.

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Introduction

Out of the 7,138,476 motorcycles operating on U.S. roads, 346,925 were registered in the state of Ohio in the year 2007. Although motorcycles represent only 2.8% of all registered vehicles in the state of Ohio, motorcycling accounts for more than 13% of Ohio highway traffic fatalities. Since 2005, Ohio has had a distressing distinction of being among the fifteen states that have sustained more than half of all motorcycle fatalities recorded in the USA (NHTSA 2007; NHTSA 2008a). For the past ten years, the overall motorcycle crash fatalities have been increasing while the motor vehicle occupant crash fatalities have been almost constant for both the state of Ohio and the United States. In 2007 the fatality rate per registered vehicle for motorcyclist was about six times that of passenger vehicle occupants (III 2009). From 1997 to 2007, motorcycle fatalities have increased by 144 percent (III 2009). Of the 873 motorcyclist fatalities that occurred between years 2003 and 2008, only 25% were reported wearing helmets. Although several risk factors affecting fatal motorcycle crashes have been documented in the U.S. (e.g. Shankar and Mannering 1996; Quddus et al. 2002; Clarke et al. 2004; Chang and Yeh 2006; Elliott et al. 2007, Savolainen and Mannering 2007), problems specific to fatal crashes involving Ohio motorcyclists have not yet been studied.

Some of the reported risk factors relating to the occurrence of injury severity of motorcycle crashes include alcohol-impaired riding, rider’s age, speeding, helmeted-rider/fixed object interaction and no-helmet/alcohol-impaired riding interaction (Shankar and Mannering 1996). Likewise, Preusser et al. (1995) found that alcohol and excessive speed were main factors influencing motorcycle fatal crashes. Quddus et al. (2002) also found that increased engine capacity, collisions with pedestrians and with fixed objects increased the probability of severe injuries in Singapore. Horizontal bends, vertical curves, darkness, unsafe speed, alcohol use and non-helmet use have also been found to cause more severe injuries (Savolainen and Mannering 2007). Mannering and Grodsky (1995) when surveying motorcyclists' perceived likelihood of being involved in accidents also found that exposure in miles ridden, regularly speeding, and overtaking on the shoulder or passing between lanes of traffic were the main factors of fatal crashes.

Furthermore, a number of statistical methods have been employed in analyzing factors affecting traffic crash-related injury severity. These methods include: log-linear models that can be used to investigate the relationship between driver age and crash factors (Abdel-Aty et al.1998); the ordered logit and ordered probit models used to predict the severity of motor vehicle injuries (O'Donnell and Connor 1996) ; the multinomial logit models used to assess factors affecting motorcycle injury severities (Shankar and Mannering 1996); a joint binary logit-ordered logit structure used to examine the factors affecting seat belt use and crash-related injury severity used by Eluru and Bhat (2007) and the mixed logit model used to examine highway accident severities (Milton et al. 2008). The ordered models (logit and probit) (e.g. O'Donell and Connor 1996; Khattak et al. 2002; Kockelman and Kweon 2002; Abdel-Atty 2003; Quddus et al. 2002; etc) and unordered models (multinomial and nested logit) (e.g. Shankar and Mannering 1996; Shankar et al. 1996; Khorashadi et al. 2005; Savolainen and Mannering 2007; etc) have been the most preferred modeling methods. However, both of these preferred methods have potential disadvantages. According to Savolainen and Mannering (2007) one potential problem with ordered probability models in determining injury severity levels underlies with the police officers' underreporting of non-injury crashes. This may result in biased and inconsistent model coefficient estimates. Another potential problem is the restrictive nature of parallel lines (same slope) condition, which dictates the equivalence of the location parameters across the levels of the dependent variable (Long 1997; Park 2009). None of the reviewed studies explained how this condition was met. Chimba and Sando (2010) also note that ordered probit models are weak in appropriately classifying injury severity. In this case, the unordered multinomial models are highly recommended in evaluating the effects of variables in each injury severity because they do not impose restrictive conditions (Savolainen and Mannering 2007). The main disadvantage of (unordered) multinomial logit models however, is the risk of independence of irrelevant alternatives (IIA) specification error related to unobserved terms in some dependent variables (Shankar and Mannering 1996). According to Hujer (2010) two ways of avoiding the IIA errors include the use of nested logit models or the use of multinomial probit models. In addition, the mixed logit models have been successfully used in recent years for the same reasons (e.g. Pai et al. 2009; Malyshkina and Mannering 2010). The use of multinomial probit models however, has been very limited. This may be related to their complex computations (Chimba and Sando 2010) and also possibly the lack of adequate statistical analysis software packages that could run these model procedures.

Therefore, the primary objective of this study was to identify risk factors related to motorcycle crashes that result into fatalities or severe injuries in the state of Ohio using both the ordered probit and the multinomial probit models. The extent and the characteristics of fatal motorcycle collisions were also examined. Understanding how the risk factors are related to the occurrence of a crash is critical for road safety efforts, especially in the identification of appropriate countermeasures to reduce motorcycle related fatalities and severe incapacitating injuries.

Method

Data

The 2003-2007 crash data for this study were obtained from the Ohio Department of Public Safety (ODPS). These are crash records reported by police officers in Ohio. The crash database contains crash related information (e.g., crash severity, location of crash, number of units involved, date of crash, etc.); records for each unit (e.g., motor vehicle, motorcycle, non-motorized, e.g., pedestrian, bicycle, etc.); and people records for each person involved in a traffic crash, except in some cases of hit and run crashes where the information is not available. A total of 21,914 motorcycle-related records, with complete motorcycle crash information data were retrieved. The data revealed 3.5% fatalities, 23.4% incapacitating, 39.7% non-incapacitating, 13.0% possible injuries, and 20.4% no injury. Injury in the ODPS datasets is assigned to all people involved in a traffic crash and it describes the injury severity level each person sustained when a traffic crash occurred. In the ODPS datasets, the variable injury is coded with the following options: (1) No Injury, (2) Possible Injury, (3) Non-Incapacitating, (4) Incapacitating, (5) Fatal Injury and (6) Unknown. The selected explanatory variables used in the analysis are shown in Table 1. All the variables with the exception of season were re-coded into binary responses, i.e., either “0” or “1”. For example, if a crash involved a female motorcyclist, the variable gender was assigned “1” as its value, otherwise (that is, if it was male), “0” was assigned to this variable.

Statistical Analysis

A multinomial probit model assumes that error terms are correlated across choices and hence breaks down the IIA assumption, which is a major problem with multinomial logit models. For multinomial probit model (MNP), suppose there are **m** categories of the dependent variable (i.e., injury severity), then there will be **m-1** equations for the MNP comparing each category against the base (reference) category. The probability that a response for the j^{th} observation is equal to the i^{th} outcome is given as in Eq. 1 (Greene 2003):

$$\pi_{ij} = P(y_j = i) = \left\{ \begin{array}{l} \dfrac{1}{1 + \sum_{i=1}^{m} \exp(x_j \beta_i} \text{ if } i = 0 \\ \dfrac{\exp(x_j \beta_i)}{1 + \sum_{i=1}^{m} \exp(x_j \beta_j} \text{ if } 1 > 0 \end{array} \right\} \tag{1}$$

Where x_i = the row vector of observed independent variables for the j^{th} observation; β_i = coefficient vector for outcome n. The resulting log-pseudo likelihood function is shown in Eq. 2 obtained by fitting the model

$$\ln L = \sum_j w_j \sum_{i=1}^{m} I_i(y_j) \ln(P_{im)} \tag{2}$$

Where w_j = weight and

$$I_i(y_j) = \left\{ \begin{array}{l} 1, \text{if } y_j = i \\ 0, \text{otherwise} \end{array} \right\}$$

The ordered probit model is usually motivated in a latent (i.e., unobserved) variable and generally specified as in Eq. 3 (Quddus et al. 2002; O'Donnell and Connor 1996):

$$y_i^* = \mathbf{X}_i\beta + \varepsilon_i \qquad (3)$$

Where y_i^* = latent variable measuring injury severity of the i[th] crash victim; $\mathbf{X}_i$ = a (k×1) vector of observed non-random independent variables measuring the attributes of crash victim *i*, *β*= a (k×1) vector of unknown parameters; ε_i = is a random error term.

Therefore, the observed injury severity variable y_i is determined as shown in Eq. 4

$$y_i = \left\{ \begin{array}{l} 1 \text{ if } -\infty \le y_i^* \le \mu_1 \text{ (No injury)} \\ 2 \text{ if } -\infty \le y_i^* \le \mu_2 \text{ (Possible injury)} \\ 3 \text{ if } -\infty \le y_i^* \le \mu_3 \text{ (Non-incapacitating injury)} \\ 4 \text{ if } -\infty \le y_i^* \le \mu_4 \text{ (Incapacitating injury)} \\ 5 \text{ if } -\infty \le y_i^* \le \mu_5 \text{ (Fatal injury)} \end{array} \right\} \qquad (4)$$

Where μ_1, μ_2, μ_3, μ_4, μ_5, = parameters to be estimated.

Fitting the Model

The ordered probit model was fitted first using all five categories of the dependent variable as shown above. The parallel regression assumption was violated. When this assumption is violated, it is advised to combine categories and test again. Additional four models were then created by combining some of the categories as follows: *Model 1*: (1) fatality, (2) incapacitating (3) non-incapacitating (4) no injury + possible injury; *Model 2*: (1) fatality (2) incapacitating injury (3) non-incapacitating + possible injuries (4) no injury*; Model 3*: (1) incapacitating + fatality injuries (2) non-incapacitating injury (3) possible (4) no injury' *Model 4*: (1)

incapacitating + fatality injuries (2) possible +non-incapacitating injuries (3) no injury. All the ordered probit models tested violated the parallel lines assumption; therefore, the ordered probit modeling is not appropriate for fitting this particular crash data. The response variable with three category levels as in model 4 above was the one that was used in specifying the multinomial probit modeling. The most appropriate model among the five tested was determined by likelihood ratio test (2LL), the one with the lowest -2LL value was selected. For the multinomial probit model, all other injury categories were compared against the no injury category, which was made the base category.

Results

Descriptive Results

The characteristics of the risk factors are descriptively shown in Table 2 where the percent of motorcyclists who sustained fatal and incapacitating injuries for each factor are computed as a preliminary look at the propensity of a fatality or an incapacitating injury happening in a motorcycle crash. The number in bold indicates that its percentage is higher than average.

Motorcyclist Related Characteristics

While the average percent of fatality in the Ohio motorcyclists data between 2003 and 2007 was 3.5%, it was found that the fatality rate was highest for those who were drug impaired (15.7%), then alcohol use (13.8%), speeding (6.2%) and no helmet use (4.0%). In addition, the same risk factors had higher percentages of incapacitating injuries than the average rate observed in the data.

Roadway Related Characteristics

Road bends and grades had substantial effect in the motorcyclist's fatality and incapacitating injury rates. Table 2 shows that curved and graded segments have higher rates of 5.3% and 4.8%, respectively. Moreover, the fatality rates on major roads (4.2%) and on non-intersection segments (3.8%) tended to be higher than the overall fatality average rate. Likewise, the incapacitating injury percentages for all the above mentioned factors were also higher than their average rate.

Environmental and Crash Type Related Characteristics

Nighttime crashes tended to result into a higher than average fatality rate of 4.8%. Moreover, lighting condition reflects the same observation with dark condition resulting into a higher fatality rate (4.9%). Other factors that showed higher than average fatality rates include bad weather condition (4.1%), weekend crashes (3.7%), and summer season (3.6%).

Motorcyclist Risk Factors Results

The multinomial probit model results are presented in Table 3. The estimated coefficients of the independent variables for each injury category are interpreted against the no injury category, the base category. Shown in Table 3 are variables that were statistically significant at $\alpha = 0.05$ only. Each of the significant variables (factors) is briefly discussed below.

Motorcyclist Related Characteristics

The age-group indicator variable was only significant for the possible + non-incapacitating injury model (which will be referred to as "minor injuries") only. The sign of the coefficient indicates that motorcyclists aged 25 years and above have a higher probability of sustaining minor injuries compared with those under 25 years of age. But, age group has no statistically significant difference on incapacitating + fatal injury model (which will be referred to as "severe injuries"). The coefficients of the person type indicate that motorcycle operators (riders) have a higher probability of sustaining both minor and major injuries than their passengers, this probability increases from minor to severe injuries. Another significant parameter is gender whose coefficients indicate that female motorcyclists have a higher likelihood of sustaining both minor and major injuries than male motorcyclist. Speeding increases the likelihood of both minor and severe injuries and the results show that the probability of severe injuries doubles that of minor injuries if speeding is involved. Riding under the influence of alcohol/drugs is not significant for minor injuries but it becomes the strongest risk factor for severe injuries. Another very important risk factor is riding without helmet, which significantly increases the chances of being injured especially in sustaining severe injuries.

Roadway Related Characteristics

The sign of the horizontal alignment coefficients indicate that curved road sections increase the probability of both minor and severe injuries but with much higher likelihood of severe injuries than minor injuries. On the other hand, vertical alignment does not have significant effects to the minor injuries, but graded road sections have increased probabilities of causing severe injuries.

Major roads have higher probabilities of severe and minor injuries than minor roads. In addition, their probabilities of severe injuries are much higher than in minor injuries, which indicate that motorcycle crashes occurring on major roads are likely to result in severe injuries. Crashes occurring at intersections have a higher probability of resulting in minor injuries compared with those occurring on open roadway segments but both are not significant to severe injuries.

Environmental and Crash Type Related Characteristics

Motorcyclists crashing during daylight have a higher chance of sustaining minor injuries compared with those crashing when there is no daylight. This may be due to riders being more careful and vigilant during dark times and both light conditions did not have significant contributions to severe injuries. Weekend crashes have higher probabilities of resulting in minor crashes than those occurring on weekdays but not to severe crashes. Single vehicle crashes significantly contribute to both minor and severe injuries as compared to multivehicle crashes. However, their probability of causing minor injuries is higher than that of severe injuries.

Discussion of Results

The main objective of this study was to identify risk factors related to fatalities or severe injuries involving motorcyclists in traffic crashes. The model that gave better results and was used is the one that combines the incapacitating and fatalities categories together into a severe injuries category and the possible and non-incapacitating injuries categories together into a minor injury category. The no injury category remained separate and was used as a base category in this study. Therefore, two separate regression models were developed estimating the likelihood of a motorcyclist being mildly or severely injured in a traffic crash. The results indicate nine risk factors that increase the probability of severe injuries of motorcyclists, which include horizontal curves (bends), graded sections, single-vehicle collisions, major roadways, being a motorcycle rider, being female, speeding, and riding under the influence of alcohol/drugs.

In this study, a motorcyclist was more likely to be killed or severely injured in a traffic crash that occurred on a major road as compared to a local road. The main reason may be due to both the high travel speeds and traffic volumes on major roads. Speeding also increased the probability of a severe injury. This finding was consistent with earlier studies (e.g. Shankar and Mannering 1996; Clarke et al. 2004; Lardelli-Claret et al. 2005; Chimba and Sando 2010), NHTSA 2003; Shankar and Varghese 2006).

Alcohol and drug use increased the likelihood of being fatally/severely injured. Several previous studies (e.g. Shankar and Mannering 1996; Clarke et al. 2004; Lardelli-Claret et al. 2005) agree that motorcyclists are more likely to be involved in severe traffic crashes when they are under alcohol or drug impairments. Motorcyclists involved in single vehicle crashes have an elevated fatality/severe injury risk compared with those involved in multivehicle crashes. Some studies have reported a strong association between single-vehicle crashes and speeding (Zhang et al. 1998). A motorcyclist crashing on a graded road segment had higher probability of a fatality/severe injury than on a level segment. A motorcyclist who did not wear a helmet had an elevated risk of a fatal/severe injury. This finding is supported by several other studies, which have consistently reported the effects of helmet use in reducing motorcyclists' fatalities (e.g. Lardelli-Claret et al. 2005; Chang and Yeh 2006; Pickrell and Starnes 2008; NHTSA 2008b; Lin and Kraus 2009). In addition, the current study has found that a motorcycle operator has an elevated risk of fatal/severe injuries than a motorcycle passenger. This may be due to positioning on the motorcycle, with the operator being in the front seat, he/she is likely be the first one to experience the full impact of the collision (especially in multivehicle crashes and in cases of hitting fixed objects).

The most important feature of this study is the use of the multinomial probit model in assessing the risk factors pertaining to motorcycle injury severity. Although most previous studies used the ordered probit models, the restrictive assumption of parallel lines (similar slopes) required to be achieved between the severity levels remains difficult to attain. No previous studies reviewed mentioned whether or not they checked for this condition. Using the ordered probit or logit models without achieving this condition may lead into estimating unrealistic parameters. Multinomial probit models were not highly used in the past due to their complex computations (Chimba and Sando 2010) and most commercially available statistical software packages did not have routines that could run them. It is our hope that it will be highly utilized in injury severity studies in the future because some packages such as STATA recently incorporated routines that can easily perform multinomial probit procedures. The multinomial probit modeling provides an alternative to other commonly used methods such as nested logit and mixed logit models when the researcher wants to avoid the independence of irrelevant alternatives property (IIA). This is a major problem common to multinomial logit models, which determine odds without referencing them to the other outcomes that might be available (Long 1997).

Conclusions and Recommendations

The findings in this study demonstrate that several risk factors are associated with the likelihood of a motorcyclist involved in a traffic crash of being fatally/severely injured. The multinomial probit regression analysis showed that there are higher chances of a motorcycle crash resulting in a fatality/severe injury when alcohol/drugs or excessive speeding are involved. This study also shows that the chances of being severely injured or killed when not wearing a motorcycle helmet are significantly higher than when a helmet is used. Motorcycle crashes occurring at non-intersection locations (open roadway) and single-vehicle crashes pose elevated likelihood of fatal/severe injuries (most likely due to speed) compared to intersection locations and multi-vehicle crashes. Additionally, motorcycle crashes occurring on horizontal bends, graded sections, and on major highways have an elevated likelihood of resulting into fatal/severe injuries. A motorcyclist who is either the operator or a female (this includes both a female passenger and a female operator) has an increased chance of being fatally or severely injured when involved in a crash.

Some risk factors contributing to motorcyclists' fatal injuries can be counter-measured through educational and enforcement strategies. Alcohol use and excessive speeding are the two major concerns in traffic safety. We therefore recommend that the current prevention efforts should be continued with an increased stress on making motorcyclists aware of the adverse risks of injuries and fatalities caused by speeding and/or riding while alcohol/drug impaired through educational efforts such as media, advertisement boards, licensing bureaus, and motorcycle riders' organizations and clubs. Educational materials should include evidence-based recommendations and should be presented in a manner that an average rider can easily understand.

Almost three-quarters of fatally injured motorcyclists in Ohio were not helmeted when the crash occurred. The motorcyclist should be educated on the elevated risks of fatal head injuries in a motorcycle crash when riding without wearing a helmet. One of the most effective solutions to motorcycle fatalities in Ohio, and one that we highly recommend, would be the adoption of a universal helmet use law coupled with effective enforcement and a hefty fine for offenders. Motorcycle training and public education should focus toward the risk of operating a motorcycle on major roads such as freeways, interstates and other major arterials where both traffic volumes and speeds are usually high.

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Table 1. Description of explanatory variables as coded in the model

Variable	Variable description
Age Group	25+ years old = 0; <25 = 1
Gender	Male = 0; Female = 1
Speed-related	No = 0; Yes = 1
Person type	Passenger = 0; Rider (operator) = 1
Alcohol-related	No = 0; Yes = 1
Drug-related	No = 0; Yes = 1
Helmet use	No = 0; Yes = 1
Roadway class	Major road = 0; Local road = 1
Horizontal alignment	Curved = 0; Straight = 1
Vertical alignment	Graded = 0; Level = 1
Work zone-related	No = 0; Yes = 1
Intersection-related	Yes = 0; No = 1
Crash type	Multi-vehicle = 0; Single-vehicle =1
Light condition	Dark = 0; Day light = 1
Weather condition	Bad = 0; Good = 1
Time of crash	06:00-20:00 = 0; 20:01-05:59 = 1
Day type	Weekend = 0; Weekday = 1
Season of the year	Winter = 1; Spring = 2; Summer = 3; Fall = 4.

Table 2. Summary of the characteristics of risk factors to motorcyclists

Risk factor	Category	1*(%)	2*(%)	3*(%)	4* (%)	5* (%)	Total
Motorcyclist characteristics							
Age group	<25	155 (3.4)	890 (19.8)	1997 (44.4)	608 (13.5)	851 (18.9)	4501
	25+	602 (3.5)	4244 (**24.4**)	6698 (30.6)	2240 (12.9)	3629 (20.9)	17413
Person type	Rider	695 (**3.6**)	4458 (23.1)	7636 (39.6)	2515 (13.0)	3993 (20.7)	19297
	Passenger	62 (2.4)	676 (**25.8**)	1054 (40.5)	333 (12.7)	487 (18.6)	2617
Gender	Male	676 (**3.7**)	4236 (23.0)	7225 (39.2)	2400 (13.0)	3898 (21.1)	18435
	Female	81 (2.3)	898 (**25.8**)	1470 (42.3)	448 (12.9)	582 (16.7)	3479
Alcohol involved	Yes	337 (**13.8**)	917 (**37.6**)	724 (29.7)	173 (7.1)	290 (11.9)	2441
	No	420 (2.2)	4217 (21.7)	7971 (40.9)	2675 (13.7)	4190 (21.5)	19473
Speeding	Yes	243 (**6.2**)	1268 (**32.5**)	1634 (41.8)	353 (9.0)	407 (10.4)	3905
	No	514 (2.9)	3866 (21.5)	7061 (39.2)	2495 (13.9)	4073 (22.6)	18009
Drug involved	Yes	47 (**15.7**)	117 (**39.1**)	81 (27.1)	22 (7.4)	32 (10.7)	299
	No	710 (3.3)	5017 (23.2)	8617 (39.9)	2826 (13.1)	4448 (20.6)	21615
Helmet use	Yes	209 (2.5)	1634 (19.5)	3594 (43.0)	1133 (13.5)	1793 (21.4)	8363
	No	548 (**4.0**)	3500 (**25.8**)	5101 (37.6)	1715 (12.7)	2687 (19.8)	13551
Roadway characteristics							
Roadway class	Local	274 (2.6)	2182 (21.0)	3971 (38.3)	1577 (15.2)	2370 (22.8)	10374
	Major	483 (**4.2**)	2952 (**25.6**)	4724 (40.9)	1271 (11.0)	2110 (18.3)	11540
Horizontal alignment	Straight	470 (2.8)	3471 (21.0)	6428 (39.8)	2316 (14.0)	3846 (23.3)	16531
	Curved	287 (**5.3**)	1663 (**30.9**)	2267 (42.1)	532 (9.9)	634 (11.8)	5383
Vertical alignment	Level	473 (3.0)	3545 (22.2)	6189 (38.8)	2235 (14.0)	3496 (21.9)	15938
	Graded	284 (**4.8**)	1589 (**26.6**)	2506 (41.9)	613 (10.3)	984 (16.5)	5976
Work zone related	Yes	11 (2.9)	98 (**26.0**)	136 (36.1)	52 (13.8)	80 (21.2)	377
	No	746 (3.5)	5036 (23.4)	8559 (39.7)	2796 (13.0)	4400 (20.4)	21537
Intersection -related	Yes	276 (2.9)	2002 (21.3)	3500 (37.2)	1415 (15.0)	2215 (23.5)	9408
	No	481 (**3.8**)	3132 (**25.0**)	5195 (41.5)	1433 (11.5)	2265 (18.1)	12506
Environmental characteristics							
Time of crash	6 AM-8 PM	484 (3.0)	3592 (22.1)	6538 (40.2)	2221 (13.7)	3436 (21.1)	16271
	8:01 PM-5.59AM	273 (**4.8**)	1542 (**27.3**)	2157 (38.2)	627 (11.1)	1044 (18.5)	5643
Light condition	Daylight	465 (2.9)	3514 (22.1)	6427 (40.4)	2142 (13.5)	3349 (21.1)	15897
	Dark	292 (**4.9**)	1620 (**26.9**)	2268 (37.7)	706 (11.7)	1131 (18.8)	6017
Weather	Good	563 (3.3)	4085 (**23.8**)	6763 (39.3)	2237 (13.0)	3551 (20.6)	17199

condition	Bad	193 (**4.1**)	1041 (22.3)	1909 (41.0)	604 (13.0)	912 (19.6)	4659
Day of week	Weekend	337 (**3.7**)	2291 (**25.0**)	3659 (39.9)	1074 (11.7)	1818 (19.8)	9179
	Weekday	420 (3.3)	2843 (22.3)	5036 (39.5)	1774 (13.9)	2662 (20.9)	12735
Season of the year	Winter	25 (2.5)	270 (**27.1**)	382 (38.4)	118 (11.8)	201 (20.2)	996
	Spring	280 (3.5)	1876 (23.2)	3195 (39.5)	1067 (13.2)	1665 (20.6)	8083
	Summer	361 (**3.6**)	2361 (23.3)	4124 (40.7)	1274 (12.6)	2004 (19.8)	10124
	Fall	91 (3.4)	627 (23.1)	994 (36.7)	389 (14.3)	610 (22.5)	2711
Crash type characteristics							
Collision type	Single-vehicle	386 (3.4)	2832 (**25.3**)	5165 (46.1)	1252 (11.2)	1570 (14.0)	11205
	Multi-vehicle	371 (3.5)	2302 (21.5)	3530 (33.0)	1596 (14.9)	2910 (27.2)	10709
Total		757 (3.5)	5134 (23.4)	8695 (39.7)	2848 (13.0)	4480 (20.4)	21914

*1 = fatal injuries, 2 = incapacitating injuries, 3 = Non-incapacitating injuries, 4 = possible injuries, 5 = no injuries

Table 3. Estimated parameters and marginal effects of the multinomial probit regression model

Variable	Parameter estimate				Marginal Effects	
		95% C.I.				
	Coefficient	Lower	Upper	z-value	dP/dx	SE
Possible +Non-incapacitating						
Age group 25+years=0; <25=1	0.209	0.118	0.299	4.51	0.053	0.009
Horizontal alignment Curved=0; Straight=1	-0.260	-0.366	-0.155	-4.83	0.024	0.009
Collision type Multi=0; Single=1	0.740	0.660	0.820	18.08	0.128	0.008
Roadway class Major=0; Minor=1	-0.124	-0.195	-0.052	-3.39	0.022	0.007
Intersection-related Yes=0; No=1	-0.084	-0.160	-0.008	-2.16	-0020	0.008
Person type Rider=0; Passenger=1	0.260	0.088	0.432	2.96	0.020	0.016
Helmet use No=0; Yes=1	-0.080	-0.153	-0.006	-2.11	0.030	0.007
Gender Male=0; Female=1	0.465	0.309	0.622	5.82	0.035	0.014
Speed-related No=0; Yes=1	0.492	0.374	0.610	8.19	-0.019	0.010
Light condition Dark=0; Daylight=1	0.092	0.008	0.176	2.14	0.024	0.008
Day type Weekend=0; Weekday=0	-0.083	-0.156	-0.011	-2.25	-0.015	0.007
Constant	0.572	0.344	0.800	4.92		
Incapacitating + Fatality						
Horizontal alignment	-0.582	-0.697	-0.467	-9.92	-0.078	0.009
Vertical alignment	-0.188	-0.285	-0.091	-3.8	-0.027	0.007
Collision type	0.389	0.296	0.481	8.24	-0.030	0.007
Roadway class	-0.369	-0.452	-0.287	-8.8	-0.054	0.006
Person type	0.329	0.132	0.525	3.28	0.027	0.014
Helmet use	-0.356	-0.443	-0.270	-8.06	-0.057	0.006
Gender	0.520	0.342	0.697	5.74	0.032	0.013
Speed-related No=0; Yes=1	0.885	0.760	1.009	13.93	0.105	0.009
alcohol/drug related No=0; Yes=1	1.039	0.893	1.184	13.99	0.223	0.012
Constant	0.382	0.125	0.639	2.91		