Analyzing the Severity of Motorcycle Crashes in North Carolina using Highway Safety Information Systems Data

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According to the National Highway Traffic Safety Association (NHTSA), in 2013, compared to passenger car occupants, mile for mile, motorcyclists are 26 times more at a fatality risk in crashes.[1] More specifically, North Carolina was ranked 4th in the United States with respect to the total motorcycle fatalities. Due to the different nature of crashes and their causes, several previous studies affirmed to distinguish single-vehicle motorcycle crashes from crashes involving other vehicles.[2,3,4] Notably, the severity of motorcycle crashes is highly associated with the number of vehicles involved. Shaheed and Gkritza as well as Savolainen and Mannering demonstrated that single-vehicle motorcycle crashes tend to be more severe than multi-vehicle ones.[5,6] Moreover, other pillion passengers of the motorcycles are expected to influence injury severity. Given these facts, this paper provides useful insight into single-vehicle, single-rider motorcycle crash injury severity in an effort to develop effective strategies and countermeasures. To do so, this paper, as the first of its kind, takes advantage of the partial proportional odds (PPO) model to analyze Highway Safety Information Systems (HSIS) data in North Carolina and provide specific recommendations based on the obtained results.

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Data and Method

The Federal Highway Administration's (FHWA) HSIS database from 2009 to 2013 was used to extract single-vehicle motorcycle crashes without any riders other than the operator in North Carolina for final analysis. After identifying these crashes and filtering out overly incomplete crash records, 6,545 crashes remained for model development. These crashes were composed of 234 (3.6 percent) fatal, 562 (8.6 percent) incapacitating injury, 3,451 (52.7 percent) non-incapacitating injury, 1,545 (23.6 percent) possible injury, and 753 (11.5 percent) no injury crashes. Ascertaining enough number of observations in each severity category and given that distinguishing between no injury and possible injury is often difficult, three severity categories were suggested by merging fatal and incapacitating injuries as "severe injury" category and possible injury and property damage only as "no/possible injury" category. Non-incapacitating injuries were also labeled as "minor injury" category.

In this paper, the dependent variable, i.e., the severity sustained by the rider given a motorcycle crash has happened, is modeled by considering the ordered nature of crash severity and using the PPO model. This model, which has previously been used by other studies showing promising results, has the capability of handling parallel line assumption among other ordered-response models appropriately.[7] According to this assumption, the effect of the explanatory variables entered into the model is assumed to be constant across each ordinal category, and the only difference between the regression lines is the cut-off point for the threshold. The adoption of this assumption oversimplifies the model and may yield unrealistic results while the violation of this assumption for all parameters may result in an unnecessary increase in the number of estimated parameters, as not all the explanatory variables in the model will violate the parallel line assumption. PPO model lies in between these two situations. In other words, this model holds and violates this assumption wherever necessary and based on some specific tests (e.g., Brant test). As previously mentioned, crash severity, as the dependent variable, is categorized into three groups. Given this, let j denote the crash severity level (1=no/possible injury; 2=minor injury; 3=severe injury) and let J represent the number of severity levels (here J=3) where j= 1,2, … , J–1. Accordingly, the PPO model can be formulated as follows:

$$Pr(Y_i > j) = \frac{exp(X_{1i}\beta_1 + X_{2i}\beta_2 - \alpha_j)}{1 + [exp(X_{1i}\beta_1 + X_{2i}\beta_2 - \alpha_j)]}$$

where X_{1i} is the vector of explanatory variables in PPO model holding parallel line assumption, X_{2i} is the vector of explanatory variables in PPO model relaxing parallel line assumption, β_1 is the vector of parameter estimations in PPO model holding parallel line assumption, β_2 is the vector of parameter estimations in PPO model relaxing parallel line assumption, and α_j is the cut-off term for the threshold in the model.

To interpret the results, direct pseudo-elasticities, as the change in the percentage of crash severity probability when the dummy variable is switched from 0 to 1, or vice versa, will be used for each injury severity and each crash as follows:

$$E_{x_{jnk}}^{Pr(Y_i>j)} = \frac{Pr(Y_i > j)[Given\ x_{jnk} = 1] - Pr(Y_i > j)[Given\ x_{jnk} = 0]}{Pr(Y_i > j)[Given\ x_{jnk} = 0]}$$

where $Pr(Y_i>j)$ is defined previously and x_{jnk} is the k-th explanatory variable associated with the injury severity j for the individual crash n. The average direct pseudo-elasticities can then be calculated for each injury severity to represent the whole dataset.

Results and Discussion

A Brant test was conducted for both the entire model as well as for every single parameter separately, and a PPO model was developed. According to this test and the developed model, 17 categories of explanatory variables were found to significantly affect the injury severity of studied crashes, among which 6 violated parallel line assumption, showing a varying effect on different levels of severity (Table 1). The Wald chi-square statistic of 468.97 with 23 degrees of freedom, which is substantially larger than the respective chi-square values at any reasonable confidence level, demonstrates that the presence of exogenous variables significantly improves the quality of the model's estimation.

About HSIS

HSIS is a safety database that contains crash, roadway inventory, and traffic volume data for a select group of U.S. states and cities. The participating agencies were selected based on the quality and quantity of data available, and their ability to merge data from various files. FHWA uses the HSIS to support the FHWA safety research program and provides input for program policy decisions.

FHWA has used HSIS data to analyze a large number of safety problems. These safety problems can range from the more basic "problem identification" issues to identifying the size and extent of a safety problem to modeling efforts that attempt to predict future crashes from roadway characteristics and traffic factors. FHWA also provides HSIS data to professionals conducting research under the National Cooperative Highway Research Program, universities, and others studying highway safety. Results from many of the studies have been used to develop new safety policies and establish improved safety practices.

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Table 1. Parameter Estimates and Elasticities

Explanatory Variable	Parameter Estimates		Average Direct Pseudo-Elasticities		
	Threshold 1	Threshold 2	Severe Injury	Minor Injury	No/Possible Injury
Motorcyclist Characteristics					
Age					
Younger Rider (Less than 24)	-0.110*	-0.110*	-9.6%	-2.5%	7.1%
Older Rider (65 and over)	0.381***	0.381***	33.4%	8.7%	-24.7%
DUI Driving?					
Yes	0.835***	0.835***	73.3%	19.1%	-54.2%
Helmet Used?					
No	0.213**	0.213**	18.7%	4.9%	-13.8%
Temporal Variables					
Season					
Summer	0.253***	0.253***	22.3%	5.8%	-16.5%
Winter	-0.228***	-0.228***	-20.0%	-5.2%	14.8%
Day of Week					
Weekend	0.130***	0.130***	11.4%	3.0%	-8.4%
Crash Variables					
Type of Setting					
Rural †	0.541***	-0.024	47.5%	-11.5%	1.5%
Weather Condition					
Adverse	-0.312*	-0.312*	-27.4%	-7.1%	20.3%
Surface Condition					
Wet	-0.290**	-0.290**	-25.5%	-6.6%	18.8%
Lighting Condition					
Dark – Lit †	0.314***	-0.006	27.6%	-6.4%	0.4%
Dark – Not Lit †	0.633***	-0.068	55.6%	-15.2%	4.4%
Accident Type					
Fixed-Object †	0.682***	0.206***	59.9%	-4.5%	-13.4%
Overturn/Rollover	0.195***	0.195***	17.1%	4.5%	-12.7%
Contributing Factor					
Reckless	0.303***	0.303***	26.6%	6.9%	-19.7%
Speeding †	0.480***	0.203***	42.1%	-0.7%	-13.2%
Roadway Characteristic					
Curve †	0.431***	0.097	37.9%	-4.3%	-6.3%
Constant	-3.572***	0.158**			
Number of Observations		6,545			
Wald chi2 (23)		468.97			
Log likelihood at Constant		-6,291.06			
Log likelihood at Convergence		-6,038.13			
AIC		12,126.26			
BIC		12,295.92			

**** Statistically significant at α=0.01*
*** Statistically significant at α=0.05*
** Statistically significant at α=0.10*
† Explanatory variable violating parallel line assumption

As for the motorcyclist's characteristics and considering the specific results presented in Table 1, motorcycle rider's age, categorized in three groups of younger (less than 24), middle-aged (between 25 and 64), and older rider (65 and over), was found significant. The calculated elasticities demonstrated a 7.1 percent increase in no/possible injury and 9.6 percent decrease in severe injury for younger riders and a 24.7 percent decrease in no/possible injury and 33.4 percent increase in severe injury for older riders. The physiological differences due to the aging process can justify the change in the injury severity in various age groups. Furthermore, this aging process can cause longer perception/reaction time for older riders, which consequently results in delayed driving behaviors and a higher likelihood of getting involved in a more severe crash. Intoxication is also found as a significant factor with the highest effect on injury severity among other variables. Specifically, it was determined that riding while intoxicated increases the probability of severe injuries by 73.3 percent, minor injuries by 19.1 percent, and decreases the probability of no/possible injuries by 54.2 percent. Liu et al. also highlighted varying characteristics and body injury patterns of intoxicated drivers compared to others.[8] As for the helmet usage, the obtained results demonstrate that not wearing a helmet significantly affects the injury severity outcome, resulting in a 13.8 percent decrease in no/possible injury and an 18.7 percent increase in the severe injury probability. A recent study also indicated that using a helmet can significantly reduce the possibility of head injury and fatality.[9]

In terms of the temporal characteristics of crashes, the analysis of the results showed that having a crash during the summer season is associated with higher likelihood of severe injuries (22.3 percent) and, conversely, in winter is associated with lower likelihood of severe injuries (20.0 percent). This variation in the severity of crashes can be attributed to the motorcycle traffic volume fluctuation during various seasons. The lower probability of severe injuries during adverse weather condition also implies the same result. Furthermore, drivers are known by more risk-compensating behaviors (e.g., speed reduction) during inclement weather conditions. As for the day of the week, crashes that happened during the weekend are attributed to a higher likelihood of severe injuries (11.4 percent) and lower likelihood of no/possible injuries (8.4 percent). Two factors might explain this finding: first, motorcycle riding is more prevalent during weekends, and second, weekend motorcycle riders are less likely to wear standard helmets, with the latter found to be the most pronounced factor in this study.

As for the type of setting, the analysis results indicated that the crashes occurred in rural areas, compared to those that happened in urban areas, and are more severe, with an increase in the likelihood of severe crashes by 47.5 percent. This result is in line with another study reporting motorcycle single-vehicle crashes in rural areas are more likely to have a higher likelihood of fatality compared to motorcycle crashes in urban areas.[10] Moreover, emergency medical services (EMS) are more accessible and faster in urban areas, and the faster response equates to less severe injury outcomes.[11,12] Driving under adverse weather conditions reduces the likelihood of severe crashes by 27.4 percent and increases the possibility of no/possible injuries crashes by 20.3 percent. For wet roadway surface conditions, these numbers dropped to 25.5 percent and 18.8 percent, respectively. This finding is justifiable as the state of North Carolina ranks 9th in the nation in terms of the average total yearly precipitation. The calculated average direct pseudo-elasticities for darkness indicate an increase in the likelihoods of severe and no/possible injury crashes. Note that darkness is the third strongest factor among the identified significant variables in the model increasing the severity of injuries by 55.6 percent. A study conducted by Bella et al. demonstrated that the acuity, glare, and dark adaptation during the nighttime conditions reduce the visibility of signs and roadway pavement markings, resulting in crashes with more severe outcomes.[13] According to Table 1, there is a strong relationship between the crash type and severe crash injury outcome. More specifically, a collision with a fixed object significantly increases the likelihood of severe crashes by 59.9 percent. This result is in good agreement with the findings by Shaheed and Gkritza.[5] Similarly, overturn/rollover increases the probability of severe injuries by 17.1 percent and decreases the probability of no/possible injuries by 12.7 percent. As for reckless riders, the crash injuries tend to be more severe, with an increase of likelihood of severe injuries by 26.6 percent. The results also indicate that speeding increases the probability of severe injuries by 42.1 percent and decreases the probability of no/possible injuries by 13.2 percent. These findings are reasonable, as higher speeds increase the chance of losing vehicle control and striking fixed objects, all of which increase the likelihood of more severe injuries. This result is consistent with the findings of Roque et al. and Abegaz et al.[14,15] Compared to a straight section of road, motorcycle crashes that typically occurred at curves tend to be more severe, with the probability of increasing severe injuries by 37.9 percent. This finding is in line with Schneider IV et al. who found a significant increase in the frequency of single-vehicle motorcycle crashes on horizontal curves on rural two-lane highways.[16]

Conclusions and Recommendations

This study identifies several issues that can be addressed to relieve the severity of single-vehicle, single-rider motorcycle crashes in North Carolina. The method outlined in this study and the calculated elasticities provide an opportunity for state departments of transportation, facing financial constraints to identify and prioritize the critical issues that need additional attention. According to the obtained results, older motorcycle riders, DUI riders, speeders, reckless riders, and non-helmeted riders are more likely to have increased injury severity. Given that North Carolina currently has several active educational programs to increase awareness for safety among motorcycle riders, these efforts need to invest and capitalize more on the abovementioned groups. North Carolina has also seen a 27.35 percent increase in the population of people 65 years and older in the 2000s, according to Census.gov. This age group of road users shows a longer response time to events while driving, which in turn can affect their critical driving behaviors such as steering and breaking. Strategies such as counseling by healthcare providers or self-assessment tools can help older riders to examine their capabilities to ride safely. As for the DUI riding, the effect of alcohol in motorcycle crashes is more noticeable than in vehicle crashes, as riding a motorcycle is much more complex than driving a car. For North Carolina, DUI driving prevention campaigns, associated with stricter enforcement rules and fines, are recommended to be established for motorcycle riders. Based on the analysis results, not wearing a helmet increases the likelihood of severe injuries slightly. This can be justifiable as DUI riding and speeding can offset the benefit of wearing a helmet as proved by Barrette et al.[17] Given the fact that roadway curvatures increase the severity of motorcycle crashes, the implementation of low-cost safety countermeasures such as chevron and advanced curve warning signs at crash-prone locations is highly recommended. Additionally, a field survey of these locations might be necessary to ascertain the signs are clearly conveying the intended message as confusing signs might be contributing to crashes inherently.[18] High friction surface treatment, as another effective safety countermeasure, is also suggested for high-crash locations for a state with such a high precipitation level. The

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The Highway Safety Information Systems (HSIS) Research Paper Contest is designed to encourage university students to use HSIS data to investigate a topic that advances highway safety and to develop a paper to document the original research. The competition introduces potential future highway safety professionals to good quality safety data, the application of appropriate research methods to derive recommendations, and the practice of using data to make decisions. The competition is jointly administered by the Federal Highway Administration (FHWA) and the Institute of Transportation Engineers.

Application information for the 2017 competition is now available. For details, visit www.hsisinfo.org/contest.cfm.

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presence of factors such as weekend and striking fixed object in the final model can be explained as motorcyclist tend to use their motorcycles for recreational purposes over the weekend, which increase the likelihood of being involved in fixed-object crashes. Lighting condition is also found to have a significant impact on crash severity. Consequently, increasing the level of lighting at the crash-prone locations can help reduce the number of severe crashes.

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