Case Study

# Factors Influencing the Severity of Crashes Caused by Motorcyclists: Analysis of Data from Alabama

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**Abstract:** The number of motorcycle crashes in Alabama more than doubled from 1999 to 2008, while the number of fatal motorcycle crashes tripled during the same period. Most work on motorcycle crash severity has been based on analysis of all crashes involving motorcycles. The majority of motorcycle crashes in Alabama are cause by the motorcyclist. An analysis of factors affecting the injury severity outcome of motorcycle causal crashes is presented. The analysis uses a multinomial logit (MNL) regression model to examine 5 years (2006 to 2010) of crash data. The variables affecting motorcycle crashes were grouped by common characteristics into four categories: motorcyclist, crash, environment, and roadway. Average direct pseudoelasticities were obtained to interpret the factors influencing motorcyclist-caused crashes (MCCs) severity. With some 70% of motorcycles crashes in Alabama resulting in some type of injury, there is potential for positive impact on safety from policies and programs that address the behavior-related crashes identified in this study. In addition to reducing behaviors considered as aggressive, it would appear that considerable safety benefit could be derived from efforts to alter motorcyclist behavior in the vicinity of large vehicles, around roadway curves, and in rural areas. **DOI: 10.1061/(ASCE)TE.1943-5436.0000570.** 

**CE Database subject headings:** Vehicles; Traffic accidents; Alabama; Data analysis; Rural areas; Driver behavior.

**Author keywords:** Motorcycle; Crash; Severity; Multinomial logit; Speeding; Driving under the influence (DUI).



## Introduction

The U.S. Census Bureau reports that there were approximately 4.0 million registered motorcycles in the United States in 1999 and 7.7 million in 2008. The number of motorcycle-related fatalities more than doubled over the same period (Fatality Analysis Reporting System 2011). Motorcycle crashes comprise only 1% of the total U.S. crashes but constitute as much as 10% of total fatal crashes. As indicated in Fig. 1, motorcycle crashes in Alabama have more than doubled between 1999 and 2008, while fatal motorcycle crashes have tripled (Critical Accident Reporting Environment 2013).

Analysis of 8,794 motorcycle-related crashes from 2006 to 2010 (Table 1) clearly indicates that motorcyclists are responsible for the majority of the most severe crashes. This paper uses a straightforward multinomial logit (MNL) formulation in conjunction with direct pseudoelasticities to identify the most prevalent factors affecting the severity of motorcyclist-caused crashes (MCCs) in Alabama. Specifically, an attempt is made to isolate factors affecting injury severity that are attributable to motorcyclist driving behavior and other characteristics (e.g., crash type, environment, roadway) related to the crash. Defining crashes as being caused by the motorcyclist is for analytical purposes only and is not intended to imply fault or liability. For example, a single-vehicle, run-off-road motorcycle crash would be designated as caused by the motorcyclist even though the crash may have resulted from evasive action to avoid an animal or other object.

The literature is replete with previous studies of motorcycle crash severity. Most have focused on all motorcycle crash types, including those caused by other motorists [e.g., Preusser et al. (1995), Yuan (2000), Savolainen and Mannering (2007b), Koustana et al. (2008), Pai (2009), Rifatt et al. (2011), Haque et al. (2012), and Schneider et al. (2012)]. Other studies [e.g., Shankar and Mannering (1996)] have focused more on crashes attributable to the motorcyclist. Insight also comes from several survey-based studies (Hurt et al. 1981; Rutter and Quine 1996; Sexton et al. 2004; Elliot et al. 2007; Savolainen and Mannering 2007a).

After a brief justification of the MNL method employed, the data used in the study are described. The MNL model is then estimated to examine the influence of various factors (motorcyclist, roadway, and environmental characteristics) on motorcycle crash severity in Alabama. The direct pseudoelasticities of key variables are calculated and interpreted.

## Methodology

There are numerous analytical methods available for analyzing the frequency and severity of traffic crashes (O'Donnell and Connor 1996; Shankar and Mannering 1996; Al-Ghamdi 2002; Srinivasan 2002; Abdel-Aty 2003; Wang and Kockelman 2005; Savolainen and Mannering 2007a, b; Xie et al. 2009). Crash severity is typically classified into five categories: fatal ($K$), severe ($A$), minor ($B$), possible ($C$), and no injury ($O$). Because crash severity is ordinal in nature, ordered logit or probit models can be used to model the crash injury severities (Quddus et al. 2002). However, previous studies have documented the limitations of using such models (Abdel-Aty 2003; Washington et al. 2003; Savolainen and Mannering 2007a, b). Ordered logit and ordered probit models

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Note. This manuscript was submitted on December 7, 2012; approved on May 2, 2013; published online on May 4, 2013. Discussion period open until February 1, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Transportation Engineering***, Vol. 139, No. 9, September 1, 2013. © ASCE, ISSN 0733-947X/2013/9-949-956/$25.00.

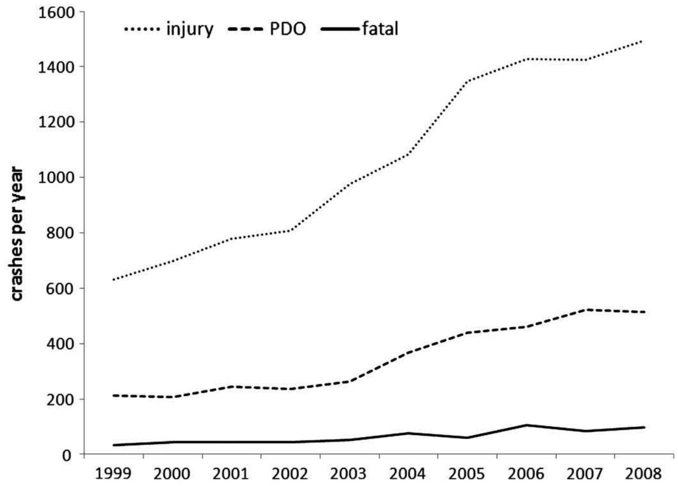


**Fig. 1.** Ten-year trend of motorcycle crashes in Alabama

**Table 1.** Relationship between Crashes Caused by Motorcyclists and Other Motorcycle-Related Crashes

| Severity | Number of crashes caused by motorcyclists | Number of other motorcycle crashes |
|---|---|---|
| Fatal (*K*) | 310 | 112 |
| Severe injury (*A*) | 3,015 | 989 |
| Minor injury (*B*) | 1,042 | 326 |
| Possible injury (*C*) and no-injury property damage only (*O*) | 1,881 | 1,119 |
| Total | 6,248 | 2,546 |

are biased when outcomes are underreported, which is often the case with lower injury severities (Hauer and Hakkert 1988), and the assumption that crash severities are determined by a single continuous propensity measure may be incorrect (Bhat and Pulugurta 1998), preventing a variable from increasing or decreasing the probability of low- and high-injury severities simultaneously (Malyshkina and Mannering 2008). Multinomial models provide consistent estimation despite underreporting of crashes, and they can relax parameter restrictions imposed by ordered probability models (Malyshkina and Mannering 2008; Geedipally et al. 2011).

Nested and mixed logit models were considered because they are typically cited as useful in crash severity modeling due to the possibility the MNL may violate the independence of irrelevant alternatives (IIA) assumption (Savolainen et al. 2011). However, MNL was chosen due to (1) the structure of the Alabama crash data, (2) their relative simplicity (Greene 2007) and efficiency, (3) the extent of their previous successful applications [e.g., Islam and Mannering (2006), Savolainen and Mannering (2007a, b), Malyshkina and Mannering (2008), and Geedipally et al. (2011)], and (4) the determined of lack of IIA violation evidence for this study. Further, many statistical packages provide an efficient and flexible way of model development and testing for MNL models (Kim and Boski 2001).

To formulate a MNL model, a linear function of covariates that determine the probability of the crash severity outcome is given as follows:

$$S_{ni} = x_n\beta_i + \varepsilon_{ni}, \qquad n \in \{1, 2, \ldots, N\}, \qquad i \in 1, 2, \ldots, I \tag{1}$$

where $S_{ni}$ = function determining the probability of crash severity outcome $i$ for accident $n$; $x_n$ = vector of measurable characteristics for crash $n$ that determine outcome $i$; $\beta_i$ = vector of estimable coefficients for injury outcome $i$; and $\varepsilon_{ni}$ = error term that explains unobserved influences on injury severity.

By assuming the error term as a generalized extreme-value distribution, the MNL model is obtained (McFadden 1981) as

$$P_n(i) = \frac{\exp(\beta_i x_n)}{\sum_I \exp(\beta_i x_n)} \tag{2}$$

where $Pn(i)$ = probability that the crash severity for accident $n$ is $i$.

Relative-risk ratios (RRRs) are a common way to express how modeled outcomes vary with the explanatory variables. A RRR can be difficult to interpret (Greene 2007), but its interpretation is relatively simple for binary variables. Essentially, a RRR is a relative measure and does not inform whether the probability of an outcome is more likely, only whether that outcome becomes more likely compared to the baseline outcome. A RRR greater than 1 suggests the variable increases the outcome of interest, $i$, more than the baseline outcome, $b$; a RRR of 1 suggests the variable increases $i$ and $b$ equally; and a RRR less than 1 suggests the variable increases $b$ more than $i$.

Elasticities can be useful in assessing the impact of variables on severity probabilities. However, elasticities are not applicable to binary variables (Washington et al. 2003), so the direct pseudoelasticity was calculated for each observation. Pseudoelasticity is a measure of how the probability of an outcome varies with an explanatory variable, but unlike RRR, pseudoelasticity does not require direct comparison to the probability of another outcome. The equation for direct pseudoelasticity is given in Kim et al. (2010) as

$$E_{x_{nk}}^{P_{ni}} = \frac{P_{ni}[\text{given} x_{nk} = 1] - P_{ni}[\text{given} x_{nk} = 0]}{P_{ni}[\text{given} x_{nk} = 0]} \tag{3}$$

where $E_{x_{nk}}^{P_{ni}}$ = direct pseudoelasticity of the $k$th variable for injury severity $i$, crash $n$.

This direct pseudoelasticity value represents the percent change in the probability of severity category $i$ for crash $n$ when the $k$th variable is changed from 0 to 1 (Washington et al. 2003). Because the direct pseudoelasticity is the percentage change in probability for each observation $n$, an average value for all observations has been used in this study. A pseudoelasticity of 0.5 for variable $x_k$ in the fatal injury category means that fatalities are on average 50% more likely when $x_k$ is 1 than when it is 0, all else being equal.

## Data Description

The Alabama Department of Public Safety (DPS) maintains a comprehensive crash database and analysis system via its CARE. CARE is a data-mining tool that interfaces with the state crash-reporting database. CARE can retrieve data from the entire database or a user-specified subset. MCC data were extracted from CARE for the period 2006 to 2010 by filtering crashes with the causal unit type set equal to "motorcycle." Of the MCC identified, some 2% were found to be attributable to defective equipment and removed from analysis so that only crashes caused by the motorcyclist were considered. Single-vehicle MCCs (e.g., run-off road) were included and treated as all other crashes with the causal unit type designated as a motorcycle. Further exploratory data analysis revealed an unusual pattern in motorcyclist ages. Specifically, there were 118 crashes that listed a motorcyclist age greater than 100. Because there is no way to verify these suspicious ages, all crashes with a listed motorcyclist age over 100 were removed the analyses.





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The data set includes 188 explanatory variables for each crash record. Crash severity, which is the dependent variable for the proposed model, reduced to four categories by combining the possible injury ($C$) and property damage only ($O$) categories. This is consistent with previous research (Savolainen and Mannering 2007b) and necessary because it is often difficult to distinguish between the possible injury and property damage only categories due to reporting variations.

Numerous variables affecting motorcycle crashes were identified in the literature (Preusser et al. 1995; Lardelli-Claret et al. 2005; Chimba et al. 2006; Savolainen and Mannering 2007b; Eustace et al. 2011; Geedipally et al. 2011; Rifaat et al. 2011; Shaheed and Dissanayake 2011). Descriptive statistics for the independent variables extracted from CARE are summarized in Table 2. Most variables exhibit a binary form [e.g., driving under the influence (DUI) versus non-DUI, speeding versus nonspeeding]. There are five age categories (<18, 18–25, 26–45, 46–65, and over 65) in lieu of a continuous age variable because 13 crashes reported in CARE involve motorcyclists over 79 years old. When analyzed as a continuous variable, age was found to be a statistically significant factor contributing to fatalities when including the few crashes involving riders 80 years and older but not when those motorcyclists were excluded from the analysis. Another set of four variables (small vehicle, passenger car, large vehicle, and none/other) was specified to describe opponent vehicles involved in multivehicle crashes. Small vehicle includes motorcycles, mopeds, all-terrain vehicles (ATVs), and snowmobiles; passenger car includes passenger cars, station wagons, vans, passenger vans, minivans, and sport utility vehicles (SUVs); and large vehicle includes trucks, tractors, and recreational vehicles (RVs). There is little evidence of multicollinearity in the MCC data. No correlation exceeded 0.45 and the condition number is 12.4, well below the threshold of 30 proposed by Kennedy (2008).

## Results

The results of the MNL estimation are presented in Table 3. The table includes the coefficient estimates, standard errors, and

**Table 2.** Descriptive Statistics for Motorcycle Causal Crashes in Alabama

| Variables | Fatal injury ($K$) | Severe injury ($A$) | Minor injury ($B$) | Possible or no injury ($C$ and $O$) | Total |
|---|---|---|---|---|---|
| Motorcyclist characteristics | | | | | |
| 1a. DUI | 30 (9.7) | 147 (4.9) | 49 (4.7) | 53 (2.8) | 279 (4.5) |
| 1b. Non-DUI | 280 (90.3) | 2,868 (95.1) | 993 (95.3) | 1,828 (97.2) | 5,969 (95.5) |
| 2a. Speeding | 105 (33.9) | 580 (19.2) | 120 (11.5) | 145 (7.7) | 950 (15.2) |
| 2b. No speeding | 205 (66.1) | 2,435 (80.8) | 922 (88.5) | 1,736 (92.3) | 5,298 (84.8) |
| 3a. Aggressive driving | 7 (2.3) | 33 (1.1) | 34 (3.3) | 15 (0.8) | 89 (1.4) |
| 3b. No aggressive driving | 303 (97.7) | 2,982 (98.9) | 1,008 (96.7) | 1,866 (99.2) | 6,159 (98.6) |
| 4a. Failed to yield right-of-way (ROW) | 2 (0.6) | 61 (2.0) | 17 (1.6) | 88 (4.7) | 168 (2.7) |
| 4b. Not failed to yield ROW | 308 (99.4) | 2,954 (98.0) | 1,025 (98.4) | 1,793 (95.3) | 6,080 (97.3) |
| 5a. Followed too close | 2 (0.6) | 133 (4.4) | 61 (5.9) | 198 (10.5) | 394 (6.3) |
| 5b. Not follow too close | 308 (99.4) | 2,882 (95.6) | 981 (94.2) | 1,683 (89.5) | 5,854 (93.7) |
| 6a. Age < 18 | 3 (1.0) | 79 (2.6) | 39 (3.7) | 56 (3.0) | 177 (2.8) |
| 6b. 18 ≤ Age ≤ 25 | 63 (20.3) | 580 (19.2) | 225 (21.6) | 379 (20.2) | 1,247 (20.0) |
| 6c. 26 ≤ Age ≤ 45 | 146 (47.1) | 1,307 (43.4) | 417 (40.0) | 809 (43.0) | 2,679 (42.9) |
| 6d. 46 ≤ Age ≤ 65 | 59 (19.0) | 627 (20.8) | 219 (21.0) | 354 (18.8) | 1,259 (20.2) |
| 6e. Age > 65 | 8 (2.6) | 115 (3.8) | 39 (3.7) | 75 (4.0) | 237 (3.8) |
| 7a. Female | 6 (1.9) | 195 (6.5) | 59 (5.7) | 71 (3.8) | 331 (5.3) |
| 7b. Male | 304 (98.1) | 2,820 (93.5) | 983 (94.3) | 1,810 (96.2) | 5,917 (94.7) |
| 8a. Weekend | 153 (49.4) | 1,465 (48.6) | 451 (43.3) | 787 (41.8) | 2,856 (45.7) |
| 8b. Weekday | 157 (50.7) | 1,550 (51.4) | 591 (56.7) | 1,094 (58.2) | 3,392 (54.3) |
| Crash-type characteristics | | | | | |
| 9a. Run off road | 8 (2.6) | 45 (1.5) | 36 (3.5) | 24 (1.3) | 113 (1.8) |
| 9b. Not run off road | 302 (97.4) | 2,970 (98.5) | 1,006 (96.7) | 1,857 (98.7) | 6,135 (98.2) |
| 10a. Intersection related | 6 (1.9) | 89 (2.9) | 63 (6.1) | 114 (6.1) | 272 (4.4) |
| 10b. Nonintersection related | 304 (98.1) | 2,926 (97.1) | 979 (94.0) | 1,767 (94.0) | 5,976 (95.7) |
| 11a. Small vehicle | 3 (1.0) | 75 (2.5) | 28 (2.7) | 61 (3.2) | 167 (2.7) |
| 11b. Passenger car | 83 (26.8) | 559 (18.5) | 212 (20.4) | 669 (35.6) | 1,523 (24.4) |
| 11c. Large vehicle | 21 (6.8) | 63 (2.1) | 16 (1.5) | 47 (2.5) | 147 (2.4) |
| 11d. None/other | 203 (65.5) | 2,318 (76.9) | 786 (75.4) | 1,104 (58.7) | 4,411 (70.6) |
| Environmental characteristics | | | | | |
| 12a. Clear weather | 257 (82.9) | 2,377 (78.6) | 857 (82.2) | 1,586 (79.8) | 5,077 (79.8) |
| 12b. Adverse weather | 53 (17.1) | 648 (21.4) | 186 (17.8) | 402 (20.2) | 1,289 (20.2) |
| 13a. Lighting: Day, dawn, and dusk | 176 (56.8) | 2,092 (69.4) | 731 (70.2) | 1,376 (73.2) | 4,375 (70.0) |
| 13b. Dark condition | 134 (43.2) | 923 (30.6) | 311 (29.9) | 505 (26.9) | 1,873 (30.0) |
| Roadway characteristics | | | | | |
| 14a. Curvature | 162 (52.3) | 1,186 (39.3) | 307 (29.5) | 467 (24.8) | 2,122 (34.0) |
| 14b. Straight | 148 (47.7) | 1,829 (60.7) | 735 (70.5) | 1,414 (75.2) | 4,126 (66.0) |
| 15a. Two-lane roads | 209 (67.4) | 2,091 (69.4) | 670 (64.3) | 1,105 (58.8) | 4,075 (65.2) |
| 15b. Other roads | 101 (32.6) | 924 (30.7) | 372 (35.7) | 776 (41.3) | 2,173 (34.8) |
| 16a. Rural locale | 188 (60.6) | 1,712 (56.8) | 431 (41.4) | 683 (36.3) | 3,014 (48.2) |
| 16b. Urban locale | 122 (39.4) | 1,303 (43.2) | 611 (58.6) | 1,198 (63.7) | 3,234 (51.8) |



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**Table 3.** Multinomial Logit Motorcycle Causal Crashes Severity Model Estimation Results

| Variables | Fatal ($K$) | | Severe injury ($A$) | | Minor injury ($B$) | |
|---|---|---|---|---|---|---|
| | Coefficient | Relative risk ratio | Coefficient | Relative risk ratio | Coefficient | Relative risk ratio |
| Motorcyclist characteristics | | | | | | |
| DUI | 1.218 (0.257) | 3.382 | 0.384 (0.170) | 1.468 | 0.507 (0.210) | 1.661 |
| Speeding | 1.552 (0.164) | 4.721 | 0.761 (0.104) | 2.141 | 0.435 (0.137) | 1.545 |
| Aggressive operation | 1.253 (0.479) | 3.501 | | 1.516 | 1.528 (0.317) | 4.611 |
| Failed to yield right-of-way | −1.677 (0.729) | 0.187 | | 0.795 | −0.588 (0.279) | 0.556 |
| Followed too close | −2.467 (0.722) | 0.085 | −0.388 (0.128) | 0.678 | | 0.810 |
| $18 \leq \text{Age} \leq 25$ | | 0.905 | | 0.984 | | 1.006 |
| $26 \leq \text{Age} \leq 45$ | | 1.008 | | 0.990 | | 0.823 |
| $46 \leq \text{Age} \leq 65$ | | 1.084 | | 1.088 | | 1.024 |
| $65 < \text{Age}$ | | 1.009 | | 1.133 | | 0.941 |
| Female | | 0.598 | 0.588 (0.147) | 1.800 | 0.434 (0.185) | 1.543 |
| Weekend | | 1.162 | 0.127 (0.062) | 1.136 | | 0.969 |
| Crash characteristics | | | | | | |
| Run off road | 0.935 (0.430) | 2.547 | | 0.861 | 0.853 (0.273) | 2.346 |
| Intersection related | −0.884 (0.432) | 0.413 | −0.461 (0.150) | 0.631 | | 1.135 |
| Small vehicle | | 0.626 | | 0.762 | | 0.712 |
| Passenger car | 0.587(0.159) | 1.799 | −0.531 (0.078) | 0.588 | −0.687 (0.104) | 0.503 |
| Large vehicle | 1.884 (0.302) | 6.579 | | 0.919 | −0.598 (0.298) | 0.550 |
| Environmental characteristics | | | | | | |
| Clear weather | | 1.263 | | 0.950 | 0.193 (0.101) | 1.212 |
| Lighting: daylight | −0.595 (0.135) | 0.551 | | 0.923 | | 0.992 |
| Roadway characteristics | | | | | | |
| Curvature | 0.878 (0.145) | 2.405 | 0.249 (0.072) | 1.283 | | 0.912 |
| Two-lane roads | −0.349 (0.150) | 0.706 | | 0.995 | | 1.048 |
| Rural locale | 0.716 (0.144) | 2.047 | 0.560 (0.068) | 1.751 | | 1.008 |

Note: Standard errors are in parentheses; coefficients that were not significant at the 90% level were restricted to zero and omitted from the table; possible or no injury is the base case, with coefficients restricted at zero; number of oberservations = 6,248; log-likelihood for contants only = −7,252; log-likelihood at convergence = −6,837; chi-square = 831; $df = 63$; significance <0.001.

relative-risk ratios for all the variables for each severity category. The coefficients of variables with less than 90% significance were removed from the model. The fourth severity category, $C$ and $O$, was taken as the reference case with coefficients restricted at zero.

### IIA Assumption

The MNL model assumes IIA. Both the Hausman-McFadden (HM) and Small-Hsiao (SH) tests were applied to the current model to test for IIA violations (Hausman and McFadden 1984; Small and Hsiao 1985). The estimated HM and SH tests produced conflicting evidence about whether the MCC data violate the IIA assumption. Because the SH test uses two randomly generated subsamples, it provides different estimates each time it is used, leading to a situation in which not only do the HM and SH results sometimes conflict with each other, but also the SH results conflict with one another (Fry and Harris 1998). HM (Table 4) failed to find adequate evidence to reject the null hypothesis, while SH (Table 5) rejected the null hypothesis 86% of the time. These results are consistent with research showing that when some cells contain a small percentage of the total observations, HM and SH often reject the null hypothesis even when it is valid (Cheng and Long 2007). Of the 148 cells in Table 3, 43 (29%) contain fewer than 112 (1.8%) observations, and there are two cells with only 2 (0.03%) observations each. The SH estimates in Table 5 provide further evidence of the unreliability of the results: the interquartile range of three of the four sets of estimates approximately lies between 40 and 160, which for a chi-squared distribution with 44 degrees of freedom gives a $p$ value between 0.000 and 0.644. Based on these findings, there is not enough evidence to conclude the IIA assumption is violated.

### Pseudoelasticity

The average pseudoelasticity (the average percentage change in probability of an injury severity category when a variable switches from 0 to 1 or 1 to 0) for each variable in the model is provided in Fig. 2. The arrows indicate whether the probability of the respective injury severity increases or decreases with an increase in the variable given in the left column.

**Table 4.** Hausman-McFadden Independence of Irrelevant Alternatives Test Results

| Models tested | Test statistic (chi-square value) | $p$ value | Hypothesis results |
|---|---|---|---|
| Full model and model with no injury excluded | 46.771 | 0.359 | Cannot reject $H_0$ |
| Full model and model with minor injury excluded | 0.728 | 1.000 | Cannot reject $H_0$ |
| Full model and model with severe injury excluded | 0.451 | 1.000 | Cannot reject $H_0$ |
| Full model and model with fatality excluded | −2.802[a] | — | Cannot reject $H_0$ |

[a]Hausman and McFadden (1984) note that a negative test statistic is also evidence that IIA holds.



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**Table 5.** Summary of 200 Small-Hsiao IIA Chi-Squared Statistics

| Models tested | Minimum | 25th percentile | Median | 75th percentile | Maximum | Proportion rejecting $H_0$ |
|---|---|---|---|---|---|---|
| Full model and model with no injury excluded | 22.17 | 38.44 | 45.81 | 51.23 | 88.10 | 0.11 |
| Full model and model with minor injury excluded | 21.68 | 40.79 | 120.30 | 159.80 | 800.90 | 0.51 |
| Full model and model with severe injury excluded | 23.72 | 40.45 | 120.80 | 164.60 | 803.90 | 0.53 |
| Full model and model with fatality excluded | 23.08 | 40.01 | 120.10 | 165.00 | 651.60 | 0.51 |



### Motorcyclist Characteristics

Examination of Fig. 2 indicates that risky behaviors, exhibited by DUI, speeding, and aggressive operation, clearly contribute to fatal MCCs. The results are intuitive and are well supported by previous research. DUI is a well-documented contributor to fatal motorcycle crashes (Shankar and Mannering 1996; Clarke et al. 2004; Lardelli-Claret et al. 2005; Savolainen and Mannering 2007b; Geedipally et al. 2011; Schneider et al. 2012; Eustace et al. 2011). The RRRs (Table 3) show that speeding has an increasing effect from least severe crashes to most severe crashes. The pseudoelasticities in Fig. 2 show that fatalities are 1.7 times more likely when the motorcyclist is speeding. Both results are supported in the literature (Chimba et al. 2006; Savolainen and Mannering 2007b; Eustace et al. 2011; Rifaat et al. 2011). Moreover, the literature suggest that these two risky behaviors, DUI and speeding, are both common to risk-taking motorcyclists (Elliott et al. 2007; Haque et al. 2009; Schneider et al. 2012). Finally, while not as strong of a contributor as the other two, aggressive driving on the part of motorcyclists increases the risk of fatality. Interestingly, aggressive driving is an even stronger contributor to minor injury crashes and perhaps reflects the effects of aggressive behavior such as excessive lane changing that can lead to crashes not necessarily involving or

| Variables | Fatal (K) | | Severe Injury | | Minor Injury | | No Injury(CO) | |
|---|---|---|---|---|---|---|---|---|
| **Motorcyclist Characteristics** | | | | | | | | |
| DUI | 135% | ⇧ | 2% | ⇧ | 15% | ⇧ | -30% | ⇩ |
| Speeding | 168% | ⇧ | 22% | ⇧ | -12% | ⇩ | -43% | ⇩ |
| Aggressive operation | 80% | ⇧ | -22% | ⇩ | 136% | ⇧ | -49% | ⇩ |
| Failed to yield R.O.W. | -76% | ⇩ | 2% | ⇧ | -29% | ⇩ | 28% | ⇧ |
| Followed too close | -89% | ⇩ | -11% | ⇩ | 7% | ⇧ | 32% | ⇧ |
| 18 = Age = 25 | -8% | ⇩ | 0% | - | 2% | ⇧ | 1% | ⇧ |
| 26 = Age = 45 | 5% | ⇧ | 3% | ⇧ | -15% | ⇩ | 4% | ⇧ |
| 46 = Age = 65 | 3% | ⇧ | 4% | ⇧ | -3% | ⇩ | -5% | ⇩ |
| 65 < Age | -4% | ⇩ | 7% | ⇧ | -11% | ⇩ | -5% | ⇩ |
| Female | -59% | ⇩ | 24% | ⇧ | 7% | ⇧ | -31% | ⇩ |
| Weekend | 9% | ⇧ | 7% | ⇧ | -9% | ⇩ | -6% | ⇩ |
| **Crash Type Characteristics** | | | | | | | | |
| Run off road | 108% | ⇧ | -30% | ⇩ | 92% | ⇧ | -18% | ⇩ |
| Intersection related | -49% | ⇩ | -22% | ⇩ | 40% | ⇧ | 24% | ⇧ |
| Small vehicle | -23% | ⇩ | -7% | ⇩ | -13% | ⇩ | 22% | ⇧ |
| Passenger vehicle | 145% | ⇧ | -20% | ⇩ | -31% | ⇩ | 36% | ⇧ |
| Large vehicle | 494% | ⇧ | -17% | ⇩ | -50% | ⇩ | -10% | ⇩ |
| **Environmental Characteristics** | | | | | | | | |
| Clear weather | 24% | ⇧ | -7% | ⇩ | 19% | ⇧ | -2% | ⇩ |
| Lighting – Daylight | -41% | ⇩ | -1% | ⇩ | 6% | ⇧ | 7% | ⇧ |
| **Roadway Characteristics** | | | | | | | | |
| Curvature | 107% | ⇧ | 10% | ⇧ | -22% | ⇩ | -14% | ⇩ |
| Two lane roads | -28% | ⇩ | 1% | ⇧ | 6% | ⇧ | 1% | ⇧ |
| Rural locale | 51% | ⇧ | 29% | ⇧ | -26% | ⇩ | -26% | ⇩ |

**Fig. 2.** Average direct pseudoelasticity of variables



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exacerbated by speed. Following too close is a behavior often considered aggressive. The RRRs indicate that following too close increases lower severity MCCs the most and Fig. 2 reaffirms that this behavior is more associated with lower severity crashes. Both results likely reflect the fact that this behavior is typically exhibited at lower speeds.

With regard to motorcyclist demographics, the results indicate no discernible relationship between age and crash injury severity. This is an interesting result in that other researchers [e.g., Rutter and Quine (1996)] have shown substantially increased severity risks associated with younger riders. Female motorcyclists were shown to be more likely to be in severe injury and minor injury crashes than fatal crashes. While no data were available for this study, other researchers have shown that women make up relatively low percentages of motorcyclists. Furthermore, women are less likely to engage in risky driving behavior associated with fatalities but are nonetheless at risk for severe injury crashes. This may be a result of lack of experience linked to women not riding motorcycles as much or as often as their male counterparts (Savolainen and Mannering 2007b; Eustace et al. 2011; Geedipally et al. 2011).

Weekend motorcycle crashes are slightly more likely to result in fatalities or severe injuries. Weekend crashes are more likely to involve drinking (Shaheed and Dissanayake 2011; Pai 2009) and speeding (Pai 2009). Riders may be less cautious on the weekend or a different, less experienced type of motorcyclist may be more likely to ride on weekends.

### Crash Characteristics

Run-off-road crashes contribute heavily to both fatal and minor injury crashes. Even though fatal run-off-road crashes are often related to DUI and speeding (Preusser et al. 1995; Shaheed and Dissanayake 2011), running off the road appears to have a significant effect on crash injury severity beyond dangerous motorcyclist behaviors. The relationship between run-off-road crashes and minor injuries likely reflects operator errors or other factors (e.g., evasive maneuvers) at speeds low enough to not cause serious injuries. The results indicate that intersection-related crashes have higher rates of no injuries and minor injuries than fatalities or severe injuries. The lower injury severity MCCs at intersections is likely attributable to relatively low-speed rear-end and turning-maneuver collisions as suggested by Savolainen and Mannering (2007b), Eustace et al. (2011), and Geedipally et al. (2011).

As suggested by Dupont et al. (2010), the type of vehicle with which a motorcycle collides is perhaps the most important contributor to crash injury severity. Fig. 2 indicates fatalities are approximately 1.5 times more likely in collisions with passenger vehicles and 5 times more likely in collisions with large vehicles. The RRRs (Table 3) show similar increased severity risks with larger opponent vehicles.

### Environmental Characteristics

No strong indicators were identified among the environmental characteristics. Both the RRRs and pseudoelasticities suggest that clear weather somewhat increases the probability that a crash is fatal. This is likely due to motorcycling being predominantly a leisure activity that occurs during times (days and seasons) with better weather (Shaheed and Dissanayake 2011). However, if they do ride in adverse weather conditions, motorcyclists are expected to ride more carefully (Kim et al. 2002; Haque et al. 2012). The results in Fig. 2 also show a negative relationship between fatal crashes and the daytime lighting conditions. These results agree with previous studies (Chimba et al. 2006; Savolainen and Mannering 2007b; Eustace et al. 2011) and suggest that nighttime riding in itself is not a major factor contributing to crash severity.

### Roadway Characteristics

Roadway curvature doubles the probability that a crash is fatal and also increases the likelihood of severe injuries. While this result is consistent with previous research (Kim et al. 2002; Chimba et al. 2006; Savolainen and Mannering 2007b; Eustace et al. 2011; Geedipally et al. 2011; Shaheed and Dissanayake 2011), the Alabama results are particularly pronounced. Fatalities are almost 30% less likely on two-lane roads in Alabama.

Injury severities are higher for rural MCCs. These results concur with previous research (Kim and Boski 2001; Kim et al. 2002; Clarke et al. 2004; Geedipally et al. 2011). This may be because motorcyclists drive less carefully when there are fewer vehicles around. Indeed, they are more likely to be at fault for crashes at rural nonintersection locations (Kim and Boski 2001). Other contributing factors may include higher speed limits than nonrural locations with otherwise similar characteristics (Geedipally et al. 2011).

## Summary and Conclusions

The analysis has identified several factors influencing the severity of MCCs in Alabama. The most important factors include motorcyclist behavior, opponent vehicle, and roadway geometry. Motorcyclists face greater risk when they speed, drive aggressively, or operate under the influence. Motorcyclists who run off the road or hit another vehicle, especially large vehicles, are much more likely to be killed. Injury severity increases slightly on weekends and was shown to be greater for MCCs occurring in roadway curves and on rural roads.

The results suggest that the primary factors influencing severity of crashes caused by motorcyclists are related to motorcyclist behavior. In addition to reducing behaviors generally considered as aggressive, it would appear that considerable safety benefit could be derived from efforts to alter motorcyclist behavior (or awareness) in the vicinity of large vehicles, around roadway curves, and in rural areas. With some 70% of motorcycle crashes in Alabama resulting in injury or death, there is considerable potential for positive impact on motorcycle safety from policies and programs that address the behavior-related crashes identified in this study.

There are three general categories of tools available to influence motorcyclist behavior: enforcement, signage, and education and outreach. It is well documented that enforcement reduces the frequency (Makowsky and Stratmann 2011; Corsaro et al. 2012) and severity (Corsaro et al. 2012) of crashes. The results of this study indicate that targeted enforcement of aggressive motorcyclist behavior could improve safety. While development of a detailed enforcement plan is beyond the scope of this paper, one effective way to reduce these behaviors may be to increase the incentives officers face to enforce motorcycle laws (Tsebelis 1989). With regard to signage, Section 2C.33 of the *Manual on Uniform Control Devices* (MUTCD) provides for signage targeted specifically for motorcyclists (e.g., W8-15P) in the context of grooved pavement (W8-15) and metal bridge decks (W8-16) as well as other conditions affecting overall roadway surface conditions as set out in Section 2C.32 (U.S. Dept. of Transportation 2009). Use of the W8-15P sign should be encouraged where applicable and where engineering judgment deems appropriate, especially in curved roadway sections and rural areas. Finally, motorcycle education and outreach programs can be updated and improved to reflect these findings. For example, motorcyclist training in Alabama is largely based on the Basic Rider Course, *Rider Handbook* published by the national Motorcycle Safety Foundation (2007). While it is an excellent source of information, it does not explicitly address the increased danger associated with large vehicles reported in this study.

The proposed MNL model was shown to be useful and appropriate for modeling motorcycle crash severity for the Alabama data. Specifically, it identified the significant variables affecting the severity of MCCs. It is recommended that a separate study be conducted on motorcycle crashes caused by vehicles other than motorcycles (i.e., cars, trucks) to identify any interesting influencing factors in Alabama.

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