Comparison of Severity of Motorcyclist Injury by Crash Types

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The purpose of this study was to examine statewide motorcycle crash data from the state of Ohio to identify those factors most strongly associated with the level of injury sustained by motorcyclists involved in crashes. The year 2009 marked the first time since 1997 that Ohio experienced fewer motorcycle fatalities than in the previous year; this result was consistent with national trends over this same period. Since anecdotal evidence suggested that much of this result was due to decreases in motorcycle travel, an investigation of rider, crash, and environmental factors that influenced injury severity was an important step toward sustaining this reduction. The effects of such factors in various types of motorcycle crashes were compared. Multinomial logit models were developed for single-vehicle and multivehicle motorcycle crashes at both intersection and nonintersection locations. The results showed that the impacts of relevant crash factors varied by crash type and location and that severe injuries were more likely when high speed or alcohol was involved. Collisions with fixed objects and high-impact crashes, such as angle and head-on collisions, also produced dramatic increases in injury severity. Helmet use continued to provide the most promising means of reducing severe and fatal injuries in all types of crashes. Helmet use was found to reduce the likelihood of injury by 34.4% in single-vehicle crashes and between 12.4% and 14.1% in multivehicle crashes.

In 1997, the United States experienced a historic low of 2,116 motorcyclist fatalities. However, this promising result was followed by a rapid rise in the annual number of fatalities, which increased in each of the subsequent 11 years to 5,290 in 2008, an increase of 150% (*1*). During this same period, the number of motorcyclist fatalities in the state of Ohio increased from 108 in 1997 to 213 in 2008 (*2*). This increase is in sharp contrast to the trend of overall traffic fatalities, which decreased from 1,439 to 1,191 in Ohio (*2*) and from 42,013 to 37,261 nationwide during the same period (*3*). There are various potential explanations for this result since the number of motorcycle riders and motorcycle vehicle miles of travel increased substantially over this period (*4*, *5*), the characteristics of the riding population changed with an influx of both young and old riders, and several states either repealed or weakened existing helmet laws (*6*). The existing helmet law in Ohio covers only operators who are in their first year of licensure and as such is difficult to enforce. Furthermore, a 2007 study showed that such limited helmet laws are particularly ineffective at increasing helmet use among young riders (*7*).

Numerous studies have been conducted in recent years to determine the primary factors contributing to this traffic safety dilemma. Savolainen and Mannering (*8*) and Daniello et al. (*9*) examined the effects of licensing and training, two critical safety areas for motorcycle safety highlighted in the *National Agenda for Motorcycle Safety* (*10*). Alcohol use and other risky riding behaviors have also been the focus of several recent studies (*11–15*), and alcohol continues to be a serious safety issue as evidenced by the fact that 37% of fatally injured motorcycle riders had alcohol in their system at the time of their crash, 81% of whom were over the legal limit (*1*). At least four studies examined the effects of site-specific factors on the frequency of motorcycle crashes (*16–19*), including a study by Schneider et al. (*19*) that examined the impacts of roadway geometry on the frequency of motorcycle crashes along rural two-lane highways in Ohio. The findings of this study showed that the radius and length of each horizontal curve significantly influenced the likelihood of motorcycle crashes, and so did the location of the road segment relative to the curve, shoulder width, and annual average daily traffic.

To determine avenues for reducing the number of fatalities and serious injuries sustained by motorcyclists, an important area of research is the examination of factors that influence the likelihood of such severe injuries given that a crash has occurred. There are several examples of multivariate investigations of injury severity in the existing literature (*20–23*). Shankar and Mannering conducted a study of injury severity resulting from single-vehicle motorcycle crashes in the state of Washington (*20*), Quddus et al. examined injury severity and the degree of vehicle damage sustained in motorcycle crashes in Singapore (*21*), Savolainen and Mannering conducted separate analyses of single- and multivehicle crashes in the state of Indiana (*22*), and de Lapparent focused on crashes occurring in urban areas of France (*23*). These studies found several recurring factors to increase the likelihood of severe or fatal injuries, including alcohol use and riding without a helmet, and the effects of these and other factors were shown to have substantive differences at different types of locations.

This study involves the development of a series of multinomial logit models to assess the impacts of rider characteristics, roadway geometry, environmental factors, and other crash characteristics on the level of injury sustained by crash-involved motorcyclists in Ohio between 2006 and 2010. Since different factors are found to affect crash outcomes in single- and multivehicle crashes, separate analyses are conducted of each type, and the multivehicle data are disaggregated further to contrast the results of crashes at intersection and nonintersection locations.

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ROADWAY GEOMETRY AND CRASH DATA

Data for this study were developed by using Ohio Department of Public Safety OH-1 crash reports. The OH-1 report provides data related to crash-involved motorcyclists and the second driver; additional information includes the vehicle types and other relevant crash factors such as roadway geometry and environmental conditions at the time of the crash. These data are drawn from January 2006 through June 2010. The injury severity distribution for the injured motorcyclist (according to the KABCO scale) includes 969 cases of no injury and property damage only (O), 656 possible injuries (C), 3,457 nonincapacitating injuries (B), 2,096 incapacitating injuries (A), and 303 fatalities (K). The data for multivehicle motorcycle riders includes 1,762 O-level, 965 C-level, 2,400 B-level, 1,451 A-level, and 255 K-level injuries. A detailed description of these injury severity levels can be found in ANSI D16.1-1996. These injuries are "classified on the basis of conditions at the scene of the accident" except for fatal injuries since a lower reported severity level is changed to a fatality if crash-resultant injuries lead to death within 30 days of the crash.

Table 1 provides summary statistics related to the crash-involved motorcycle riders and passenger vehicle drivers (in cases of

TABLE 1 Descriptive Statistics for Crash-Involved Motorcyclists, Drivers, and Vehicles

Variable	Single-Vehicle (N = 7,484)	Multivehicle Intersection (N = 3,311)	Multivehicle Nonintersection (N = 3,522)
Motorcyclist Characteristics			
Male	92.0%	94.9%	95.6%
Female	8.0%	5.1%	4.4%
Wearing a helmet	47.4%	44.9%	44.8%
Not wearing a helmet	52.6%	55.1%	55.2%
No injury, property damage only	12.9%	25.7%	25.9%
Possible injury	8.8%	14.9%	13.4%
Injury, not incapacitating	46.2%	34.1%	36.1%
Incapacitating injury	28.0%	21.6%	20.9%
Fatal injury	4.1%	3.7%	3.8%
Motorcyclist at fault	NA	22.7%	39.6%
Alcohol use by rider	16.9%	3.3%	4.9%
Drug use by rider	0.2%	0.2%	0.22%
Rider age			
25th percentile	28	31	29
50th percentile	41	43	43
75th percentile	51	53	52
Speed, mph			
25th percentile	25	15	15
50th percentile	35	25	30
75th percentile	45	35	37
Driver Characteristics			
Driver alcohol use	NA	2.4%	2.3%
Driver drug use	NA	0.2%	0.2%
Driver age			
25th percentile	NA	24	25
50th percentile	NA	38	39
75th percentile	NA	56	57
Speed, mph			
25th percentile	NA	5	5
50th percentile	NA	10	10
75th percentile	NA	20	25
Vehicle Types			
Passenger car	NA	61.6%	56.7%
Sport utility vehicle	NA	13.9%	15.4%
Pickup truck	NA	10.8%	13.4%
Minivan	NA	7.8%	8.2%
Van	NA	2.0%	2.0%
Semitruck	NA	2.9%	3.4%
Other vehicle	NA	0.7%	0.9%

NOTE: NA means data are not applicable. Single and multivehicle crashes occurred from January 2006 to June 2010.

multivehicle collisions). Table 2 provides similar statistics associated with the circumstances surrounding the crash, including the site-specific geometric conditions and variables related to the environmental and lighting conditions at the time of the crash.

All crash-related information, including the determination of injury severity, is based on the expert judgment of the investigating officer. Farmer conducted an analysis of the reliability of such police-reported crash information with the more rigorous data obtained through the National Automotive Sampling System and found that the severity level for certain types of injuries tended to be overstated or understated by the investigating officer (*24*). Further, certain fields (e.g., speed, crash causal factors) require greater expertise to make an accurate determination than others. Although there is certain to be some inherent error in the data that cannot be identified by the researchers, the police-reported crash database provides the richest source of information available for Ohio motorcycle crashes.

There are a few interesting points when the summary data for the single- and multivehicle crashes in Tables 1 and 2 are compared. The age distribution of crash-involved riders is similar in each of the data sets since the age quartiles fall at 28, 41, and 51 years of age for the single-vehicle data set and 29, 43, and 52 for multivehicle nonintersection-related crashes. Rider gender is also quite similar between the two data sets, although female riders made up approximately 3% more of the single-vehicle crashes. Although precise estimates of the number of male and female riders are unavailable, it is believed that this gender split is likely reflective of the number of active riders.

TABLE 2 Descriptive Statistics for Crash-Related and Environmental Factors

	Type of Motorcycle-Involved Crash		
Variable	Single-Vehicle (%) (*N* = 7,484)	Multivehicle Intersection (%) (*N* = 3,311)	Multivehicle Nonintersection (%) (*N* = 3,522)
Crash Geometry			
Noncollision	100.0	10.5	1.0
Rear-end	N/A	20.6	33.6
Head-on	N/A	4.7	5.9
Rear-to-rear	N/A	0.3	0.2
Backing	N/A	1.6	2.7
Angle	N/A	55.2	36.2
Sideswipe, same direction	N/A	4.2	7.1
Sideswipe, opposite direction	N/A	2.2	3.4
Unknown	0.0	0.8	0.9
Roadway Geometry			
Roadway curve	43.0	4.3	11.0
Driveway related	1.4	N/A	24.9
Two lane	52.9	40.6	37.1
Dry roadway pavement	92.6	96.4	95.8
Time of Year			
January	0.7	0.7	0.8
February	0.5	0.4	0.5
March	3.9	4.9	3.5
April	9.5	9.5	9.9
May	14.8	14.9	15.8
June	16.7	15.8	15.1
July	16.1	15.4	14.9
August	15.0	15.1	15.3
September	11.7	12.1	12.7
October	7.3	7.1	7.5
November	3.2	3.4	3.2
December	0.6	0.7	0.7
Lighting Condition			
Daylight	66.6	79.5	82.5
Dawn or dusk	4.8	4.1	3.4
Dark	27.8	12.2	13.1
Other	0.8	4.2	1.0

NOTE: NA = data not applicable in single-vehicle data set. Single- and multivehicle crashes occur from January 2006 to June 2010.

There are various substantial differences between the two data sets as well. First, alcohol use by the motorcyclist was associated with 16.9% of single-vehicle crashes, 3.3% of multivehicle intersection-related, and 4.9% of multivehicle non-intersection-related crashes. This finding is likely a factor of the types of collisions occurring at each type of location: the single-vehicle crashes generally involved errors by the motorcyclists, particularly in relation to speed selection and curve negotiation, whereas the multivehicle crashes were frequently due to errors on the part of the other driver involved in the crash. The single-vehicle crashes were also more likely to occur along two-lane roads and under dry pavement conditions but also resulted in a larger percentage of severe injuries. One of the most substantial differences is in relation to the effects of horizontal curves. Approximately 43% of single-vehicle crashes occurred on horizontal curves in comparison with 7.7% of multivehicle crashes. These percentages are quite similar to those found by Savolainen and Mannering (*22*) in a study of motorcyclist injury in Indiana, which included 39.3% and 8.3% single- and multivehicle curve-related crashes, respectively.

The estimated precrash vehicle speeds warrant particular attention. In comparison with previous research, these speeds are significantly higher than those reported by Hurt et al. (*25*) or in the recent Motorcycle Accidents in Depth Study (*26*). This finding is likely reflective of the difficulty in determining the speed of the crash. When the Ohio speed data are examined, there are substantial differences between the single- and multivehicle crashes. In a comparison of the speed quartiles, the speeds of the crash-involved motorcyclists in single-vehicle crashes (25, 35, and 45 mph) are significantly higher than those in multivehicle crashes (15, 25, and 35 mph), a finding that may be indicative of both rider behavior and the types of locations at which these crashes occurred.

Some differences are particularly pronounced between the intersection and nonintersection multivehicle crashes as well. The motorcycle rider was determined to be at fault in only 22.7% of intersection-related crashes but in 39.6% of nonintersection crashes. One potential explanation for this difference is driver difficulty in identifying motorcycles, as documented by previous research (*22*). The types of crashes occurring at these locations were also significantly different: rear-end collisions were surprisingly underrepresented at intersection locations (20.6% of intersection and 33.6% of nonintersection crashes). As expected, angle crashes were substantially more likely at intersections (55.2% versus 36.2%), although this difference is not as pronounced as it was initially suspected to be because Ohio classifies driveway crashes as nonintersection related. Some clarification is also required as to the noncollision crash category. The Ohio crash report form defines a noncollision as any crash in which two vehicles are involved but do not actually strike one another. For example, when another driver cuts off a motorcyclist, causing the motorcyclist to fall, this event is coded as a noncollision crash if the two vehicles do not actually strike one another. By definition, all single-vehicle crashes are noncollisions.

STATISTICAL METHODOLOGY

As discussed previously, the investigating officer classifies the degree of injury sustained by crash-involved motorcyclists into one of five discrete categories: property damage only (O) as well as possible injury (C), nonincapacitating injury (B), incapacitating injury (A), and fatal injury (K). Such data are ideally suited for analysis with discrete outcome models, and this approach has been utilized in several motorcycle safety studies during the past 15 years (*20–23*) as well as in various studies examining other focus areas of traffic safety (*27–31*).

One of the most widely applied analytical frameworks used to investigate injury severity resulting from traffic crashes is the multinomial logit (MNL) model. MNL models allow for a determination of those factors that significantly affect the degree of injury sustained in a crash, conditioned on the fact that a crash has occurred. Specifically, given that a motorcycle crash has occurred and is police reported, MNL models can be used to quantify how various factors increase or decrease the likelihood that the rider will sustain an injury of a specific severity level. The MNL model is an appropriate modeling framework as long as the underlying data do not violate the independence of irrelevant alternatives (IIA) assumption. A violation of the IIA assumption occurs when there is correlation in the error terms of a subset (but not all) of the injury severity outcomes. Failing to account for such correlation may result in biased parameter estimates and incorrect inferences, although this issue may be addressed by generalizing the MNL model as a nested logit (*23*) or mixed logit (*32, 33*) model. Further details on alternative approaches to injury severity analysis may be found elsewhere (*34*). As a part of this research, various model formulations were examined, and since the data were not found to violate the IIA assumption, the MNL model provides an appropriate framework.

The MNL model used to assess the injury severity sustained by the motorcyclist involved in the crash is

$$S_{in} = \beta_i X_{in} + \epsilon_{in} \tag{1}$$

where S_{in} determines injury severity outcome i for motorcyclist n, and β_i is the vector of coefficient estimates. The vector of parameters, X_{in}, is associated with the operator, Driver 2; the roadway; and the environment that influence the injury severity for the motorcyclist; ϵ_{in} is an independently and identically distributed generalized extreme value error term. Each motorcyclist injury has the same set of potential injury severity outcomes and the resulting probability for any particular outcome is

$$P_n(i) = \frac{\exp(\beta_i X_{in})}{\sum_{\forall I}(\beta_i X_{in})} \tag{2}$$

where $P_n(i)$ is the probability that motorcyclist n will sustain a particular injury severity level I within the entire set of injury severity outcomes. In this study, to be included in the final model all the variables are required to be statistically significant at the 95% confidence level. In some cases, variables may be treated as either continuous or a series of discrete variables. With these variables, multiple specifications are examined in order to precisely determine their individual effects on injury severity. Such specifications include aggregating vehicle speeds into discrete categories such as low, medium, and high or rider age into young, middle, and old age groups. In cases in which the discrete trends were consistently increasing or decreasing, continuous variables were found to provide a superior fit.

Three distinct MNL models are developed as a part of this study: one for single-vehicle crashes and two for separate multivehicle intersection and nonintersection crashes. The rationale behind developing separate multivehicle models is that the impacts of relevant factors are likely to vary between intersection and nonintersection locations. After a preliminary multivehicle model is developed that includes both intersection and nonintersection crashes, the model is then separated into two submodels, one for those crashes occurring at intersection locations and the other for those crashes occurring at nonintersection locations. A likelihood ratio test is used to determine whether those factors affecting the degree of motorcycle injury have similar impacts among crashes occurring at both intersection and non-intersection locations. The likelihood ratio test statistic follows the chi-squared distribution:

$$\chi^2 = 2\left[LL(\beta_R) - LL(\beta_U)\right] \quad (3)$$

where $LL(\beta_R)$ is the non-location-specific model log likelihood value at convergence and $LL(\beta_U)$ is defined as the sum of the two location-specific log likelihood values at convergence (*35*). The results at the 95% confidence level indicate that location-specific intersection and nonintersection multivehicle models provide an enhanced model in comparison with the non-location-specific model of all multivehicle motorcycle crashes. The likelihood ratio test is explained in further detail by Washington et al. (*35*). The year during which the crash occurred was also assessed through likelihood ratio tests to determine whether, when the effects of all other factors are accounted for, severities tended to be generally increasing or decreasing over time. However, no time-related effects were found to be statistically significant.

The magnitude of the individual parameters for the likelihood of the five injury severity outcomes is defined by their elasticities. In the case of elasticities for continuous variables, such as motorcyclist age or vehicle speed, each variable is calculated as follows:

$$E_{X_{in}}^{P_n(i)} = \left[1 - \sum_{I=I_n} P(i)\right]\beta_i X_{in} \quad (4)$$

In Equation 4, the subset of injury severity levels (I_n) includes the variable X_{in} in the severity function. The estimated coefficient (β_i) is associated with X_{in}. It is incorrect to calculate elasticities for indicator variables by using Equation 4 where variable values are either 0 or 1. In the case of binary indicator variables, it is suitable to quantify their effects by using pseudoelasticities (*20*):

$$E_{X_{in}}^{P_n(i)} = \frac{\exp\left[\Delta(\beta_i X_{in})\right]\sum_{\forall I}\exp(\beta_i X_{in})}{\exp\left[\Delta(\beta_i X_{in})\right]\sum_{I=I_n}\exp(\beta_i X_{in}) + \sum_{I\neq I_n}\exp(\beta_i X_{in})} - 1 \quad (5)$$

The calculated pseudoelasticity values for each variable represent the average change in the likelihood of a particular severity level if the conditions corresponding to the variable of interest occur during the crash. In this study, for example, when the passenger variable is changed from 0 to 1, the likelihood of severe injury for the motorcyclist decreases by 47.1%. The calculated elasticity (and pseudoelasticity) values for all parameters are shown in Tables 3 and 4. The effects of these parameters are discussed in detail in the following section.

MODELING RESULTS

The model estimation results are provided in Tables 5 through 7, and the elasticities and pseudoelasticities for each model are shown in Tables 3 and 4. The results from the base multivehicle motorcycle model are not included in these results since the log likelihood ratio test suggests splitting the data set by location.

TABLE 3 Elasticities for Single-Vehicle Motorcycle Crashes

Variable	Elasticity (%)
Operator Characteristics	
Wearing helmet (O)	34.4
Wearing helmet (C)	50.7
Wearing helmet (B)	0.1
Speed (B)[a]	0.2
Speed (A)[a]	0.8
Speed (K)[a]	2.0
Age (A)[a]	0.4
Age (K)[a]	1.1
Female (B, C)	–2.1
Female (K, A)	33.6
Presence of alcohol (A)	32.1
Presence of alcohol (K)	226.5
Passenger on motorcycle (O)	47.1
Operator is making lane change (K, A, B)	10.0
Object Struck by Motorcycle	
Guardrail (B)	–10.7
Guardrail (A)	72.4
Guardrail (K)	158.0
Post (B)	–13.5
Post (A)	80.6
Post (K)	296.6
Tree (A)	45.3
Tree (K)	112.3
Fence (A)	40.9
Fence (K)	252.6
Curb (A)	53.7
Curb (K)	196.0
Rollover (B)	14.5
Rollover (K, A)	24.2
Intersection related (C)	32.8
Horizontal curve (K, A, B, C)	3.9
Two lane (K, A)	11.9
Adverse weather (O)	62.2
Adverse weather (C)	28.5
Adverse weather (B)	–0.8
Daylight (K, A, B)	7.9

NOTE: O = property damage only; C = possible injury; B = not incapacitating injury; A = incapacitating injury; K = fatal injury.
[a]Continuous variable.

Motorcyclist Characteristics

It is well established that helmet use is the single most effective means of reducing the likelihood of fatal or severe injury when a motorcyclist is involved in a crash. At each of the three types of locations where injury severity was examined, helmet use was found to significantly reduce the likelihood of being injured, and this reduction was most pronounced in the case of single-vehicle crashes. In such crashes, helmet use reduced the likelihood of nonincapacitating

TABLE 4 Comparison of Elasticities in Multivehicle Crashes

Variable	Elasticities by Location Type (%) Intersection	Nonintersection
Operator Characteristics		
Wearing helmet (O)	14.1	12.4
Wearing helmet (B, C)	5.5	4.8
Speed (C)[a]	0.4	0.3
Speed (B)[a]	0.7	0.6
Speed (A)[a]	1.4	1.1
Speed (K)[a]	2.9	2.2
Age (K, A)[a]	0.5	0.4
Presence of alcohol (K)	284.2	336.4
No insurance (K, A, B, C)	10.4	NA
Passenger on motorcycle (O)	34.2	NA
Female (K, A, B)	14.8	NA
Driver Characteristics		
Vehicle 2 speed (A, B)[a]	0.3	NA
Vehicle 2 speed (K)[a]	1.0	0.4
Driver 2 failure to yield (K, A, B)	17.5	NA
Driver 2 ran red light (B)	4.6	NA
Driver 2 ran red light (K, A)	45.2	NA
Driver 2 is wearing seat belt (C, O)	NA	31.2
Driver 2 is male (K, A)	NA	21.3
Driver 2 presence of alcohol (K, A)	NA	58.9
Vehicle Type: Semitrailer–Truck (K)	260.7	253.7
Crash Geometry		
Motorcycle rollover (K, A, B)	NA	34.3
Head-on (B, C)	–7.7	–6.6
Head-on (A)	81.4	81.7
Head-on (K)	91.8	279.8
Motorcycle front, Vehicle 2 side (K, A)	37.2	55.6
Motorcycle under struck (B)	13.7	37.3
Motorcycle under struck (K, A)	58.5	21.4
Roadway Geometry		
Curve on grade (K)	NA	146.7
Two lane (K, A, B)	NA	11.6
Driveway related (B)	NA	18.2
Driveway related (A)	NA	25.6
Driveway related (K)	NA	161.4
Environmental: March–April (O)	43.6	

NOTE: NA = not applicable.
[a]Continuous variable.

and fatal injuries and increased the probability of that no injury will be sustained by 34.4%. Helmet use was also found to reduce injury severity sustained in multivehicle crashes, although the impacts were more subtle since the likelihood of the occurrence of property-damage-only crashes (i.e., no injury) was increased by 14.1% at intersection locations, and a 5.5% increase was shown relative to possible and nonincapacitating injuries. At nonintersection locations, similar increases of 12.4% and 4.8% were experienced for property-damage-only crashes and minor injuries. These results are consistent with previous research (*8*) that shows helmets to be most effective in single-vehicle crashes.

The improvements exhibited in this study are likely to be conservative, potentially underestimating the safety benefit provided by helmet use. One of the primary reasons for this underestimate is the fact that Ohio is not a helmet law state. Observational surveys collected by the authors show preliminary results suggesting that approximately 2% to 4% of riders in Ohio wear novelty helmets. Many such helmets do not meet the requirements of FMVSS 218. The crash data also generally tend to indicate whether the helmet was in use at the time of the crash, which means that cases in which the helmet is used improperly or is dislodged during the crash are likely to be included in the resulting estimate of effectiveness.

The speed of the motorcycle at the time of the crash was also shown to be a strong predictor of injury severity in multivehicle and particularly in single-vehicle crashes. In the case of single-vehicle crashes, the likelihood of a fatal injury increased by nearly 2% for every 1% increase in speed. Among multivehicle crashes, fatalities were 2.9% and 2.2% more likely for similar increases in speed at intersection and nonintersection locations, respectively. Smaller increases were also observed relative to incapacitating and nonincapacitating injuries for each crash type. Higher speeds at impact have also been demonstrated to result in more severe injuries by several previous motorcycle safety studies (*20, 36, 37*). These effects might be overstated given the higher-than-expected speeds shown in the Ohio crash data. It is possible that some of these differences may be attributable to a tendency of investigating officers to estimate higher speeds for more-severe crashes.

This study also reinforces previous findings regarding increases in injury severity with age (*20–22*). Age was initially examined as a series of binary indicator variables in order to investigate whether a bathtub effect was present as has been shown in some passenger vehicle studies that find both younger and older drivers to be more prone to severe injuries. However, since injuries tended to increase consistently across each subsequent age group, age was treated as a continuous variable. Rider age was found to have the greatest impact in single-vehicle crashes: a 1% increase in age resulted in a 1.1% increase in fatalities. Incapacitating and fatal injuries were also more pronounced in multivehicle crashes. There are various potential explanations for this finding, such as degradations in riding abilities or reaction time with age as well as physiological differences that may make older riders more susceptible to injuries.

Alcohol use continues to be a significant problem for all types of motorcycle crashes. Alcohol use by the crash-involved motorcyclist more than doubled the chance of fatalities in single-vehicle crashes as well as in intersection- and non-intersection-related multivehicle crashes. The consumption of alcohol degrades the rider's ability to process information, increases perception–reaction time, and inhibits the rider's ability to safely navigate the motorcycle. These findings are consistent with the existing literature (*13, 15, 20, 22*).

Female riders in single-vehicle crashes are found to increase the likelihood for an incapacitating or fatal injury by 33.6%. Female ridership was still significant in multivehicle crashes: a 14.8% increase in nonincapacitating, incapacitating, and fatal injuries was associated with intersection-related crashes. One potential explanation for this result may be associated with the physiological differences between men and women. Another variable of interest is the presence of a passenger on the motorcycle. The likelihood of injury is reduced by 47.1% in single-vehicle crashes and 34.2% in multivehicle crashes at intersections when passengers were present on the motorcycle. Although the added passenger increases the overall weight

TABLE 5 Estimates of Coefficients for Single-Vehicle Crashes

Variable	Injury Severity	Coeff.	SE	*t*-Ratio	*p*-Value
Alternative-Specific Constant					
Property damage only	O	6.724	0.468	14.364	.000
Possible injury	C	6.136	0.470	13.042	.000
Not incapacitating injury	B	7.092	0.460	15.403	.000
Incapacitating injury	A	5.042	0.458	10.999	.000
Operator Characteristics					
Wearing helmet	O	0.679	0.090	7.559	.000
	C	0.791	0.101	7.817	.000
	B	0.435	0.065	6.693	.000
Speed	B	0.012	0.002	5.786	.000
	A	0.032	0.003	12.697	.000
	K	0.063	0.005	12.365	.000
Age	A	0.012	0.002	5.547	.000
	K	0.029	0.007	4.054	.000
Female	B, C	0.664	0.171	3.882	.000
	K, A	0.975	0.185	5.260	.000
Presence of alcohol	A	0.435	0.085	5.136	.000
	K	1.340	0.191	7.033	.000
Passenger on motorcycle	O	0.459	0.099	4.651	.000
Operator is making lane change	K, A, B	0.472	0.158	2.993	.003
Crash Characteristics and Object Struck by Motorcycle					
Rollover	B	0.696	0.068	10.255	.000
	K, A	0.777	0.080	9.725	.000
Struck guardrail	B	0.698	0.192	3.636	.000
	A	1.356	0.201	6.761	.000
	K	1.759	0.347	5.069	.000
Struck post	B	0.880	0.238	3.702	.000
	A	1.616	0.242	6.679	.000
	K	2.403	0.336	7.146	.000
Struck tree	A	0.568	0.191	2.979	.003
	K	0.947	0.430	2.203	.028
Struck fence	A	0.559	0.257	2.171	.030
	K	1.476	0.477	3.094	.002
Struck curb	A	0.673	0.133	5.073	.000
	K	1.328	0.307	4.323	.000
Roadway and Environmental Conditions					
Intersection related	B	0.316	0.109	2.899	.004
Horizontal curve	K, A, B, C	0.279	0.079	3.519	.000
Two lane	K, A	0.155	0.060	2.608	.009
Adverse weather (fog, rain, snow, etc.)	O	0.924	0.219	4.212	.000
	C	0.691	0.251	2.754	.006
	B	0.432	0.192	2.254	.024
Daylight	K, A, B	0.310	0.067	4.657	.000

NOTE: Log likelihood = −7,721.24; restricted log likelihood = −8,187.64; chi-squared = 932.79; coeff. = coefficient; SE = standard error.

and alters the center of gravity of the motorcycle, potentially decreasing its maneuverability, the operator may be less likely to take added risks when a passenger is on board. A second potential explanation may be the fact that in Ohio an operator is not allowed legally to have a passenger until full endorsement status has been achieved. In Ohio a full endorsement requires 1 year after the operator reaches novice status. Simply put, the operator has been riding longer and should have more experience as well as training.

Driver Characteristics

When the speed of the other vehicle involved in the crash increases, so does the likelihood of nonincapacitating and incapacitating injuries for intersection-related crashes. In the case of non-intersection-related crashes, the likelihood of fatality increases by 0.4% for each 1% increase in speed. In general these results are to be expected. As the speed of the other vehicle increases, so

TABLE 6 Estimates of Coefficients for Crashes at Intersections

Variable	Injury Severity	Coeff.	SE	*t*-Ratio	*p*-Value
Alternative-Specific Constant					
Property damage only	O	7.550	0.554	13.631	.000
Possible injury	C	7.046	0.553	12.736	.000
Not incapacitating injury	B	6.639	0.548	12.105	.000
Incapacitating injury	A	4.438	0.514	8.631	.000
Operator Characteristics					
Wearing helmet	O	0.337	0.134	2.518	.012
	B, C	0.259	0.106	2.436	.015
Speed[a]	C	0.016	0.005	3.240	.001
	B	0.043	0.005	9.515	.000
	A	0.074	0.005	14.020	.000
	K	0.115	0.012	10.013	.000
Age[a]	K, A	0.014	0.004	3.679	.000
Female	K, A, B	0.440	0.205	2.146	.032
Presence of alcohol	K	1.416	0.448	3.158	.002
No insurance	K, A, B, C	0.602	0.290	2.075	.038
Driver Characteristics					
Vehicle 2 speed	B	0.027	0.005	5.916	.000
	A	0.029	0.006	5.272	.000
	K	0.067	0.010	6.373	.000
Driver 2 failure to yield	K, A, B	0.457	0.102	4.495	.000
Driver 2 ran red light	B	0.463	0.221	2.098	.036
Driver 2 ran red light	K, A	0.791	0.245	3.224	.001
Vehicle Type: Semitrailer–Truck	K	1.349	0.531	2.541	.011
Crash Geometry					
Motorcycle rollover	K, A, B	0.956	0.175	5.472	.000
Head-on	B, C	0.754	0.311	2.421	.016
	A	1.420	0.337	4.218	.000
	K	2.157	0.516	4.181	.000
Motorcycle front, Vehicle 2 side	K, A	0.583	0.114	5.097	.000
Motorcycle under struck	B	0.944	0.282	3.348	.001
	K, A	0.821	0.334	2.457	.014

NOTE: Log likelihood = −3,064.29; restricted log likelihood = −3,346.58; chi-squared = 564.58.
[a]Continuous variable.

should the severity of the crash. One additional finding of interest is that the effect of the speed of the other vehicle is more pronounced in the intersection model compared with the nonintersection model, which is likely reflective of the types of crashes that occur more frequently at intersections (e.g., angle and left turn or head-on).

Failing to yield and running red lights are both found to increase severe injuries in the intersection model. These results seem to support a general belief in the motorcycle community that drivers are unaware of motorcycles on the road and are more likely to enter the roadway without seeing the motorcycle (*38*). In the case of the intersection location, the motorcycle may be hidden behind other vehicles and unseen by the oncoming traffic.

The final findings of interest are related to risky behavior associated with the driver of the other vehicle. In non-intersection-related crashes, if the other driver is male, incapacitating or fatal injuries increase by 21.3% and 58.9% if the other driver has been drinking. When the other driver is wearing a seat belt, less-severe injuries are likely to be sustained by the motorcyclist as shown by a 31.2% reduction in the likelihood of property-damage-only or possible injuries.

Vehicle Type

Collisions with various types of other vehicles were examined during the model development process. However, in the final models, the only vehicles that were found to influence the level of rider injury severity were semitrailer-trucks. Consistent with previous findings (*22*), the likelihood of a fatality was increased by 260% at intersection locations and 253% at nonintersection locations. The overall size and impact forces generated by semitrailer-trucks provide little forgiveness for the motorcyclist in the event of a crash, and in addition, it is likely that semitrailer-truck drivers may find it

TABLE 7 Estimates of Coefficients for Crashes at Nonintersections

Variable	Injury Severity	Coeff.	SE	*t*-Ratio	*p*-Value
Alternative-Specific Constant					
Property damage only	O	6.974	0.578	12.070	.000
Possible injury	C	6.187	0.580	10.665	.000
Not incapacitating injury	B	6.706	0.550	12.196	.000
Incapacitating injury	A	4.669	0.521	8.959	.000
Operator Characteristics					
Wearing helmet	O	0.352	0.127	2.769	.006
	B, C	0.282	0.105	2.695	.007
Speed[a]	C	0.013	0.004	3.028	.003
	B	0.034	0.004	9.707	.000
	A	0.054	0.004	12.883	.000
	K	0.081	0.010	7.955	.000
Age[a]	K, A	0.011	0.004	3.120	.002
Presence of alcohol	K	1.525	0.374	4.079	.000
Passenger on motorcycle	O	0.342	0.139	2.465	.014
Driver Characteristics					
Vehicle 2 speed	K	0.022	0.009	2.431	.015
Driver 2 wearing seat belt	C, O	0.410	0.178	2.306	.021
	K	NA	NA	NA	NA
Driver 2 presence of alcohol	K, A	0.634	0.294	2.159	.031
Driver 2 is male	K, A	0.247	0.102	2.420	.016
Vehicle Type: Semitrailer–Truck	K	1.306	0.464	2.812	.005
Crash Geometry					
Motorcycle rollover	K, A, B	0.956	0.175	5.472	.000
Head-on	B, C	0.754	0.311	2.421	.016
	A	1.420	0.337	4.218	.000
	K	2.157	0.516	4.181	.000
Motorcycle front, Vehicle 2 side	K, A	0.583	0.114	5.097	.000
Motorcycle under struck	B	0.944	0.282	3.348	.001
	K, A	0.821	0.334	2.457	.014
Roadway Geometry					
Curve on grade	K	0.928	0.442	2.099	.036
Two lane	K, A, B	0.294	0.091	3.221	.001
Driveway related	B	0.555	0.109	5.079	.000
	A	0.616	0.133	4.641	.000
	K	1.349	0.396	3.410	.001

NOTE: Log likelihood = −3,313.96; restricted log likelihood = −3,579.27; chi-squared = 530.60; NA = not applicable.
[a]Continuous variable.

particularly difficult to identify motorcyclists, which could further contribute to this result.

Crash Geometry

In the case of single-vehicle crashes, one of the primary determinants of the level of injury sustained is whether the rider strikes a fixed object during the crash and whether the bike goes down during the occurrence of the crash. Fixed objects increasing the more-severe injuries include guardrails, posts, trees, fences, and curbs. Guardrails, posts, and trees increase the likelihood of fatalities by 158%, 296.6%, and 112.3%, respectively, and impacts with fences and curbs also increase the risk of fatal injury. In each of these cases, such fixed objects are often unforgiving and create severe trauma on impact, as illustrated by previous findings (*16*, *20*, *22*).

In single-vehicle crashes when the rider either voluntarily or inadvertently lays down or rolls the motorcycle, such as when traveling at high speed through a horizontal curve along the wrong entry line, motorcyclists are also more likely to be injured. In such crashes, there is a 14.5% increase in the chance of minor injuries and a 24.2% increase in severe injuries. In multivehicle crashes, motorcycle rollovers increase the likelihood for moderate to fatal injuries by 34%, similar to the results for single-vehicle crashes.

Roadway Geometry

Two-lane roads increase the propensity for severe injuries for both single-vehicle and non-intersection-related multivehicle crashes. Other cases of interest include crashes that occur on horizontal curves or near driveways. Among non-intersection-related multivehicle crashes, a horizontal curve on a grade increases the likelihood of a fatality by 146%, and the presence of a driveway results in a 161% increase in the chances of a fatal outcome. These crashes may be the result of limited sight distance or of the driver's pulling out of a driveway and not seeing the motorcycle.

Environmental Factors

The environmental factors that were significant include adverse weather resulting in less-severe single-vehicle crashes. One possible explanation for this condition is that riders may be more careful when caught out in bad weather. Daylight in single-vehicle crashes increases the likelihood for a nonincapacitating, incapacitating, or fatal injury by 7.9%. The final environmental condition of interest is the time of the year. When the crash occurred early in the season, in March or April, the operator in a intersection-related crash was 43.6% more likely to be uninjured, providing a potential indication of increased caution on the part of motorcyclists.

CONCLUSIONS

From 1997 to 2008, the number of motorcyclist fatalities in the state of Ohio increased from 108 to 213 as statewide traffic fatalities decreased from 1,439 to 1,191 (*2*). In order to more clearly understand the reasons for this drastic increase, Ohio police-reported crash data for 2006 to 2010 were used to conduct an investigation of the level of injury sustained by crash-involved motorcycle riders. The year 2009 marked a significant shift; preliminary data indicate that the number of motorcyclist fatalities decreased by approximately 16% in comparison with the previous year (*39*). This improvement was substantially more pronounced in Ohio, in which there was a decrease of 23% (*40*). It is suspected that this finding, although consistent with national trends, may be due in part to reduced exposure since anecdotal evidence suggests that motorcycle travel was down substantially during this period. In fact, short-term estimates from 2010 indicate this trend to have reversed. As such, it is imperative that a continued focus be maintained on reducing the opportunity for motorcycle crashes and fatalities. This comparison of motorcyclist injuries among various crash types is an important step in that direction.

The results of this study show that the factors contributing to motorcycle rider injuries may be substantially different between single- and multivehicle crashes as well as at intersection and nonintersection locations. Helmet use continues to provide the most promising means of reducing severe and fatal injuries in all types of crashes. Helmet use reduced the likelihood of injury by 34.4% in single-vehicle crashes and between 12.4% and 14.1% in multivehicle crashes. This finding is consistent with national trends: NHTSA has estimated that helmets saved the lives of 1,829 motorcyclists in 2008 and that 100% helmet use would have saved an additional 823 lives (*1*). Alcohol use continues to be a serious problem among motorcycle riders, increasing the likelihood of fatality by over 200% among various types of crashes. Higher-impact collisions, including angle crashes, head-on crashes, and collisions in which either vehicle was traveling at a high speed, also had dramatic negative impacts on injury severity. Crashes involving horizontal curves, those in which the bike goes down or rolls over, and those in which a motorcyclist strikes a tree, post, or other fixed object were also shown to result in more-severe injuries.

High-risk behaviors on the part of the other driver were also detrimental. If the other driver had been drinking, ran a red light, or otherwise failed to yield, the risk of fatality was increased by 58.9%, 45.2%, and 17.5%, respectively. On a more promising note, when the other drivers were wearing a seat belt, crashes tended to be less severe, a finding that may point to either increased caution or greater safety awareness on the part of such drivers. There were also some promising findings regarding risk management by motorcyclists: injuries were found to be less likely under complete darkness as well as during adverse weather conditions. These results may be indicative of risk compensation effects as alluded to by Winston et al. (*41*).

Collectively, the findings of this study show that there are numerous factors that are contributing to the continuing public safety problems posed by motorcycle crashes. In Ohio, there are some avenues available for improvement. These include providing additional targeted education and enforcement campaigns focused on reducing the frequency of hazardous actions such as driving while distracted or under the influence of alcohol since the other driver was found to be at fault a significant majority of the time in multivehicle crashes. However, much of the solution must come on the part of motorcyclists, who were shown to be much more likely to be under the influence in fatal and severe injury crashes and more prone to such injuries in other high-risk situations such as navigating a horizontal curve.

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REFERENCES

1. *Traffic Safety Facts: Motorcycles.* Report DOT HS 811 159. NHTSA, U.S. Department of Transportation, 2009.
2. Ohio Department of Public Safety. *Ohio Traffic Crash Facts 2008.* Columbus, 2009. http://www.publicsafety.ohio.gov/links/HSY7606-2008.pdf. Accessed July 29, 2010.
3. NHTSA, U.S. Department of Transportation. *Fatality Analysis Reporting System: Query FARS Data.* 2010. http://www-fars.nhtsa.dot.gov/QueryTool/QuerySection/SelectYear.aspx. Accessed July 29, 2010.
4. *2008 Motorcycle Industry Council Owner Survey.* Motorcycle Industry Council, Irvine, Calif., 2009.
5. NHTSA, U.S. Department of Transportation. Table 10. In *Traffic Safety Facts, Final Edition: 1975–2007* (annual issues). March 2009. http://www-nrd.nhtsa.dot.gov.
6. Insurance Institute for Highway Safety. *Current US Motorcycle and Bicycle Helmet Laws.* Washington, D.C., 2010. http://www.iihs.org/laws/helmetusecurrent.aspx. Accessed July 30, 2010.
7. Houston, D. J. Are Helmet Laws Protecting Young Motorcyclists? *Journal of Safety Research,* Vol. 38, No. 3, 2007, pp. 329–336.

8. Savolainen, P. T., and F. L. Mannering. Effectiveness of Motorcycle Training and Motorcyclists' Risk-Taking Behavior. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2031,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 52–58.
9. Daniello, A., H. C. Gabler, and Y. A. Mehta. Effectiveness of Motorcycle Training and Licensing. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2140,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 206–213.
10. Motorcycle Safety Foundation. *National Agenda for Motorcycle Safety.* Irvine, Calif., 2000. http://www.nhtsa.gov/people/injury/pedbimot/motorcycle/00-NHT-212-motorcycle/toc.html. Accessed July 30, 2010.
11. Mannering, F. L., and L. L. Grodsky. Statistical Analysis of Motorcyclists' Perceived Accident Risk. *Accident Analysis and Prevention,* Vol. 27, No. 1, 1995, pp. 21–31.
12. Heger, R., and A. Zehn. Road Design and Human Factors Associated to Motorcycle Accidents—A Contribution to Safer Roads. *3rd International Symposium on Highway Geometric Design* (CD-ROM), Transportation Research Board of the National Academies, Washington, D.C., 2005.
13. Creaser, J. I., N. J. Ward, M. E. Rakauskas, E. Boer, C. Shankwitz, and F. Nardi. *Effects of Alcohol on Motorcycle Riding Skills.* Report DOT HS 810 877. NHTSA, U.S. Department of Transportation, 2007.
14. Haworth, N., K. Greig, and A. Nielson. Comparison of Risk Taking in Moped and Motorcycle Crashes. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2140,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 182–187.
15. McKnight, A. S., L. R. Becker, A. S. Tippetts, and R. L. Hohn. Impaired Motorcycle Operation: Evaluation of Riders Helping Riders Program. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2140,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 188–194.
16. Quddus, M. A., H. C. Chin, and J. Wang. Motorcycle Crash Prediction Model for Signalized Intersections. In *Urban Transport VII: Urban Transport and the Environment in the 21st Century* (L. J. Sucharov and C. A. Brebbia, eds.), Wessex Institute of Technology, Ashurst, United Kingdom, 2001, pp. 609–716.
17. Harnen, S., R. S. Radin Umar, S. V. Wong, and W. I. Wan Hashim. Motorcycle Accident Prediction Model for Junctions on Urban Roads in Malasia. *Advances in Transportation Studies: An International Journal,* Section A8, 2006, pp. 31–40.
18. Haque, M. M., H. C. Chin, and H. Huang. Factors Affecting Motorcycle Crashes at Signalized Intersections. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
19. Schneider, W. H., IV, P. T. Savolainen, and D. N. Moore. Effects of Horizontal Curvature on Single-Vehicle Motorcycle Crashes Along Rural Two-Lane Highways. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2194,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 91–98.
20. Shankar, V., and F. Mannering. An Exploratory Multinomial Logit Analysis of Single-Vehicle Motorcycle Accident Severity. *Journal of Safety Research,* Vol. 27, No. 3, 1996, pp. 183–194.
21. Quddus, M., R. Noland, and H. Chin. An Analysis of Motorcycle Injury and Vehicle Damage Severity Using Ordered Probit Models. *Journal of Safety Research,* Vol. 33, No. 4, 2002, pp. 445–462.
22. Savolainen, P., and F. Mannering. Probabilistic Models of Motorcyclists' Injury Severities in Single- and Multivehicle Crashes. *Accident Analysis and Prevention,* Vol. 39, 2007, pp. 955–963.
23. de Lapparent, M. Empirical Bayesian Analysis of Accident Severity for Motorcyclists in Large French Urban Areas. *Accident Analysis and Prevention,* Vol. 38, No. 2, 2006, pp. 260–268.
24. Farmer, C. M. Reliability of Police-Reported Information for Determining Crash and Injury Severity. *Traffic Injury Prevention,* Vol. 4, No. 1, 2003, pp. 38–44.
25. Hurt, H. H., J. V. Ouellet, and D. R. Thom. *Motorcycle Accident Cause Factors and Identification of Countermeasures,* Vol. 1: *Technical Report.* Final report. Traffic Safety Center, University of Southern California, Los Angeles, Jan. 1981.
26. *Motorcycle Accidents in Depth Study: In-Depth Investigations of Accidents Involving Powered Two Wheelers.* Version 2.0. European Association of Motorcycle Manufacturers, Brussels, Belgium, 2009.
27. Carson, J., and F. L. Mannering. The Effect of Ice Warning Signs on Ice-Accident Frequencies and Severities. *Accident Analysis and Prevention,* Vol. 33, No. 1, 2001, pp. 99–109.
28. Lee, J., and F. L. Mannering. Impact of Roadside Features on the Frequency and Severity of Run-off-Roadway Accidents: An Empirical Analysis. *Accident Analysis and Prevention,* Vol. 34, No. 2, 2002, pp. 149–161.
29. Ulfarsson, G., and F. L. Mannering. Differences in Male and Female Injury Severities in Sport-Utility Vehicle, Minivan, Pickup and Passenger Car Accidents. *Accident Analysis and Prevention,* Vol. 36, No. 2, 2004, pp. 135–147.
30. Savolainen, P. T., and I. Ghosh. Examination of Factors Affecting Driver Injury Severity in Michigan's Single-Vehicle–Deer Crashes. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2078,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 17–25.
31. Schneider, W. H., IV, P. T. Savolainen, and K. H. Zimmerman. Driver Injury Severity Resulting from Single-Vehicle Crashes Along Horizontal Curves on Rural Two-Lane Highways. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2102,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 85–92.
32. Schneider, W. H., IV, and P. T. Savolainen. Mixed Logit Analysis of Bicyclist Injury Severity Resulting from Motor Vehicle Crashes at Intersection and Non-Intersection Locations. *Accident Analysis and Prevention,* Vol. 43, No. 3, 2010, pp. 621–630.
33. Milton, J. C., V. N. Shankar, and F. L. Mannering. Highway Accident Severities and the Mixed Logit Model: An Exploratory Empirical Analysis. *Accident Analysis and Prevention,* Vol. 40, No. 1, 2008, pp. 260–266.
34. Savolainen, P. T., F. L. Mannering, D. Lord, and M. A. Quddus. The Statistical Analysis of Highway Crash-Injury Severities: A Review and Assessment of Methodological Alternatives. *Accident Analysis and Prevention,* Vol. 43, No. 5, 2010, pp. 1879–2057.
35. Washington, S., M. Karlaftis, and F. Mannering. *Statistical and Econometric Methods for Transportation Data Analysis.* CRC Press, Boca Raton, Fla., 2003.
36. Shibata, A., and K. Fukuda. Risk Factors of Fatality in Motor Vehicle Traffic Accidents. *Accident Analysis and Prevention,* Vol. 26, No. 3, 1994, pp. 391–397.
37. Lin, M. R., S. H. Chang, W. Huang, H. F. Huang, and L. Pai. Factors Associated with Severity of Motorcycle Injuries Among Young Adult Riders. *Annals of Emergency Medicine,* Vol. 41, 2003, pp. 783–791.
38. Clarke, D., P. Ward, C. Bartle, and W. Truman. The Role of Motorcyclist and Other Driver Behavior in Two Types of Serious Accident in the UK. *Accident Analysis and Prevention,* Vol. 29, 2007, pp. 974–981.
39. Hedlund, J. *Motorcyclist Traffic Fatalities by State.* Governors' Highway Safety Association, 2010. http://www.ghsa.org/html/publications/spotlight/pdf/spotlight_motorcycles.pdf. Accessed July 29, 2010.
40. Ohio Department of Transportation. *Ohio Traffic Fatalities Reach Historic Low in 2009.* Columbus, 2010. http://www.dot.state.oh.us/news/Pages/OhioTrafficFatalitiesReachHistoricLowIn2009.aspx. Accessed July 29, 2010.
41. Winston, C., V. Maheshri, and F. Mannering. An Exploration of the Offset Hypothesis Using Disaggregate Data: The Case of Airbags and Antilock Brakes. *Journal of Risk Uncertainty,* Vol. 32, No. 2, 2006, pp. 83–99.

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