Examination of Factors Affecting Driver Injury Severity in Michigan's Single-Vehicle–Deer Crashes

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Michigan is plagued by more than 60,000 deer–vehicle crashes on an annual basis. Although the majority of these crashes result in property damage only, a substantial number lead to significant injuries and fatalities, illustrating the need for a better understanding of the many interrelated factors that affect crash severity. A database of all single-vehicle deer–vehicle crashes (DVC) reported to Michigan law enforcement agencies between January 1, 2004, and December 31, 2005, was used to estimate a multinomial logit model of driver injury severity. Results revealed a number of driver, vehicle, and environmental factors that significantly influenced injury severity. Younger drivers were more likely to be injured as a result of a DVC, a possible indication of a lack of appropriate skills or knowledge on the part of these drivers when they encounter deer on the roadway. Female drivers were found to be at an increased risk of injury, as were drivers who had a passenger in the vehicle at the time of the crash. Seatbelt and airbag usage were found to be the most effective means of reducing the likelihood of severe injuries, although airbags did increase the likelihood of minor injuries. Impacting deer head-on and avoiding run-off-the-road collisions were also found to reduce the propensity of injury. Educational and enforcement initiatives, such as the "Don't Veer for Deer" campaign, may provide a cost-effective means of combating the DVC problem.

It has been estimated that more than 1.5 million deer–vehicle crashes (DVCs) occur each year in the United States, costing the public more than $1 billion (*1*). In Michigan, approximately 60,000 DVCs are reported on an annual basis, as shown in Figure 1. This is a conservative estimate, because many deer-involved crashes are not reported because of minimal injury and property damage (*2*). A recent survey of drivers from southeastern Michigan found DVC reporting rates to be only 46.3% to law enforcement agencies and 52.1% to insurance companies (*3*).

Although the number of police-reported deer-involved crashes decreased by approximately 15% from 1997 to 2006, this decline has been outpaced by the overall decline in motor vehicle crashes in Michigan, as shown by the ratio of deer-related to total crashes in Figure 1. More troubling is the recent increase in fatalities. From 1997 to 2001, Michigan motorists experienced 32 deer-related fatalities. From 2002 to 2006, there were a total of 40 such fatalities in the state, an increase of 25%. These findings mirror national trends as the total number of fatalities resulting from animal-vehicle collisions increased from 136 in 1997 to 220 in 2006 (*4*).

There are potentially many reasons for this observed increase in fatalities. Vehicle miles traveled have climbed significantly over this time period, and deer population estimates have increased substantially, as well. With many factors likely involved in this disturbing upward trend in fatalities, there is a clear need for research to provide some insight into the relative effect of various factors so that appropriate countermeasures can be implemented to save lives.

The majority of prior research on DVCs has focused on the identification of sites with high frequencies of deer–vehicle crashes and the evaluation of the effectiveness of treatments aimed at reducing the number of DVCs. Iverson and Iverson (*5*) analyzed spatial and temporal trends of DVCs, relating these patterns to various characteristics including roadway length and type of land. They concluded that crash frequency is more closely tied to human factors (e.g., urban land and human populations) than to deer or habitat-related factors (e.g., harvested deer, forest land). Knapp et al. (*6*) developed a countywide DVC frequency model that showed increases in DVCs associated with increasing deer population and vehicle travel and decreases associated with increasing wolf population and woodland acreage. The purpose of such models is often to identify areas where countermeasures will be most effective.

These countermeasures may include engineering infrastructure (e.g., fencing, underpasses and overpasses, wildlife reflectors, highway lighting, and warning signs), vehicle accessories (e.g., wildlife warning whistles), and environmental countermeasures (e.g., chemical repellants, herd reduction). Knapp (*7*) conducted a comprehensive evaluation of DVC countermeasures and found that the majority of those countermeasures had rarely or never been properly evaluated from a safety standpoint. Several of the countermeasures that were evaluated produced conflicting results. Meyer (*8*) noted that the most common countermeasure in Kansas is the deer warning sign, even though its effectiveness is suspect. Based on these empirical results and the continual increases in both the deer population and the number of vehicle miles traveled, many of these collisions are likely unavoidable.

An important aspect of the DVC problem that has been overlooked to date is the effect of driver, vehicle, and environmental characteristics on the injury severity resulting from a DVC. In fact, general research incorporating driver- and location-specific factors has been limited (*9*). The purpose of this research is to identify what factors affect the likelihood of injuries and fatalities resulting from DVCs and to identify means of mitigating these factors through engineering, education, and enforcement.

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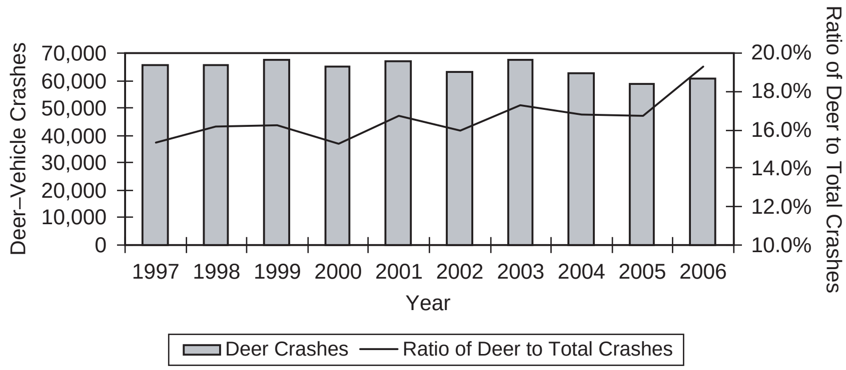

FIGURE 1 Ratio of deer–vehicle crashes to total crashes in Michigan, 1997–2006.

METHODOLOGY

Modeling Framework

The analysis of crash-injury severity data is well suited for discrete outcome modeling because the injury level sustained as a result of a crash may be classified as one of five discrete categories (property damage only, possible injury, nonincapacitating injury, incapacitating injury, or fatality). The two most prominent discrete outcome modeling frameworks used in injury severity analyses are ordered probability models, such as the ordered probit, and unordered probability models, such as the multinomial logit. Because injury levels are inherently ordered (with severity increasing from property damage only to fatality), ordered probability models have frequently been used by researchers (*10–14*).

However, there are two potential drawbacks to using ordered probability models for crash severity analyses. First, ordered probability models constrain variable influence such that they will either increase the likelihood of the lowest severity level and decrease the likelihood of the highest severity level or vice versa (*15*). This precludes the possibility that a variable may increase (or decrease) the likelihood of the interior injury categories relative to the lowest and highest injury severity levels. For example, the results of this study show that airbag deployment increases the likelihood of possible and nonincapacitating injuries while decreasing the likelihood of property damage only and incapacitating or fatal injury. This result would not be apparent in the ordered probability framework. The second problem relates to the fact that crashes of a lower severity level are more likely to be underreported in crash data (*16*). The underreporting rate for DVC has been estimated to be nearly 50% (*3*), although without knowledge of the true rate for this sample, ordered probability models may lead to biased and inconsistent model coefficient estimates. This underreporting does not create the same problem in the unordered probability model framework, except for the severity-specific constant terms (*17*). Because of these issues, this research used unordered probability models, specifically the multinomial logit, to examine driver injury severity as has been done by numerous researchers (*18–21*).

Linear Function

To assess driver injury severity, a linear function was defined to determine driver *n*'s injury severity outcome *i* as follows:

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

where X_{in} is a vector of measurable characteristics (driver, vehicle, and roadway characteristics) that determine the injury severity for driver n, β_i is a vector of estimable coefficients, and ϵ_{in} is an error term accounting for unobserved effects influencing the injury severity of crash n (*15*). If the ϵ_{in} are assumed to be generalized extreme value distributed the standard multinomial logit model results,

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

where $P_n(i)$ is the probability that crash n will result in driver injury outcome i and I is the set of possible crash injury-severity outcomes (*15, 17*). Equation 2 is estimable by standard maximum likelihood techniques.

DATA

The data analyzed in this study were drawn from 122,273 police-reported DVCs involving one vehicle that occurred in Michigan between January 1, 2004, and December 31, 2005. This empirical analysis focused exclusively on crashes involving one motor vehicle because of the substantially different causality mechanisms and factors involved in crashes involving multiple vehicles. Police provide estimates of crash-injury severity at the scene of the crash as one of five categories (no injury, possible injury, nonincapacitating injury, incapacitating injury, and fatality). Because of the relatively small number of fatal injuries sustained in the sample, these crashes were combined with incapacitating injuries for analysis purposes. Only driver injury levels (not passengers) were considered and, of these crashes, 20% resulted in property damage only, 62% in possible injury, 15% in nonincapacitating injury, and 3% in incapacitating or fatal injury. The crash data, provided by the Michigan Office of Highway Safety Planning (OHSP), contains information on the vehicle, driver, and roadway environment. Summary statistics for these characteristics are shown in Tables 1 through 3.

Table 1 provides summary statistics for the drivers involved in the DVCs of this sample. Men were involved in 60.43% of all single-vehicle deer-involved crashes, consistent with previous DVC findings in Michigan and nationwide (*9*). The age distribution is similar to that of national crash statistics, as well, with crash frequencies increasing by age group up to the mid-50s before declining. The safety belt use rate was 97.08% for the entire population of crash-involved drivers, although among those seriously injured it was only 40.22%.

TABLE 1 Summary Statistics for Driver Characteristics

Variable	Property Damage Only	Possible Injury	Nonincapacitating Injury	Incapacitating or Fatal Injury
Gender				
Male	70,668 (60.68%)	607 (44.15%)	343 (53.59%)	39 (45.88%)
Female	45,794 (39.32%)	768 (55.85%)	297 (46.41%)	46 (54.12%)
Age				
Younger than 25 years of age	19,585 (16.83%)	378 (27.49%)	195 (30.47%)	33 (38.82%)
25 to 34 year of age	21,766 (18.71%)	257 (18.69%)	111 (17.34%)	17 (20.00%)
35 to 44 years of age	26,697 (22.94%)	302 (21.96%)	117 (18.28%)	16 (18.82%)
45 to 54 years of age	26,065 (22.40%)	253 (18.40%)	118 (18.44%)	13 (15.29%)
55 to 64 years of age	14,555 (12.51%)	124 (9.02%)	55 (8.59%)	3 (3.53%)
Age 65 or older	7,694 (6.61%)	61 (4.44%)	44 (6.88%)	3 (3.53%)
Safety Equipment				
Safety belt usage	114,378 (97.97%)	1,323 (88.32%)	612 (75.37%)	74 (40.22%)
Airbag deployment	2,849 (2.44%)	432 (31.40%)	193 (30.16%)	24 (28.24%)
Other Factors				
Passenger present	26,279 (22.53%)	353 (25.65%)	206 (32.19%)	27 (31.76%)
Alcohol involved	213 (0.18%)	30 (2.18%)	26 (4.06%)	13 (15.29%)

Airbag deployment occurred in 3,498 of the crashes (2.95% of all crashes) and was significantly underrepresented in the property damage only category. Alcohol involvement was nearly absent from the DVCs, as has been reported previously (*22*).

As shown in the vehicle summary statistics in Table 2, approximately 64.81% of all crashes involved automobiles, followed by pickup trucks (7.50%), vans and SUVs (23.70%), and semi trucks (3.99%). The most frequent impact area was the front of the vehicle (73.05%) or the passenger side (26.38%), whereas a minimal number of crashes involved drivers running over deer (0.30%) or collisions on the driver's side (0.27%).

Table 3 provides summary statistics for the environmental factors related to the DVCs. Collisions occurred much more frequently during the fall season (42.87%), followed by winter (21.91%), spring (20.31%), and summer (14.91%). Most deer–vehicle crashes occurred in the period from October to December, especially in November, which signals the beginning of both the mating and hunting seasons for deer (*2*). Only 11.69% of crashes occurred under adverse weather conditions with rain (5.41%) and snow (4.21%) constituting the majority of such crashes. Similarly, the pavement condition was found to be dry in 77.86% of crashes and wet in 14.07% of crashes, with wintry effects present in 7.90% of crashes. More than 86% of DVCs occurred on high-speed roads (speed limit of 55 miles per hour or higher) and a similar percentage occurred during nighttime conditions. These findings were all consistent with previous research (*3, 9, 22*).

MODEL RESULTS AND DISCUSSION OF RESULTS

Determining the impact of driver, vehicle, and environmental characteristics on driver injury-severity outcomes was the principal motivation for this research. Using the previously described crash data, models were developed to estimate the probability of the four discrete

TABLE 2 Summary Statistics for Vehicle Characteristics

Nonvariable	Property Damage Only	Possible Injury	Incapacitating Injury	Incapacitating or Fatal Injury
Vehicle Type				
Car	75,307 (64.60%)	1,055 (76.67%)	498 (77.81%)	61 (71.76%)
Van	8,738 (7.50%)	124 (9.01%)	34 (5.31%)	3 (3.53%)
Pickup	27,858 (23.90%)	162 (11.77%)	91 (14.22%)	15 (17.65%)
Semi trucks	4,676 (4.01%)	35 (2.54%)	17 (2.66%)	6 (7.06%)
Damage Area				
Bottom	335 (0.30%)	3 (0.26%)	1 (0.20%)	0 (0.00%)
Front	83,208 (73.59%)	474 (40.44%)	168 (33.14%)	13 (21.67%)
Driver's side	210 (0.19%)	39 (3.33%)	45 (8.88%)	17 (28.33%)
Passenger's side	29,311 (25.92%)	656 (55.97%)	293 (57.79%)	30 (50.00%)

TABLE 3 Summary Statistics for Environmental Characteristics

Variable	Property Damage Only	Possible Injury	Nonincapacitating Injury	Incapacitating or Fatal Injury
Season				
Spring	23,602 (20.24%)	315 (22.89%)	181 (28.28%)	18 (21.18%)
Summer	17,238 (14.78%)	278 (20.20%)	156 (24.38%)	25 (29.41%)
Fall	50,069 (42.93%)	555 (40.33%)	236 (36.88%)	38 (44.71%)
Winter	25,710 (22.05%)	228 (16.57%)	67 (10.47%)	4 (4.71%)
Lighting Conditions				
Daylight	23,329 (20.24%)	428 (28.65%)	313 (38.59%)	65 (35.71%)
Dawn	9,677 (8.40%)	136 (9.10%)	65 (8.01%)	13 (7.14%)
Dusk	6,023 (5.23%)	68 (4.55%)	54 (6.66%)	11 (6.04%)
Dark (lighted)	3,547 (3.08%)	34 (2.28%)	11 (1.36%)	1 (0.55%)
Dark (unlighted)	72,687 (63.06%)	828 (55.42%)	368 (45.38%)	92 (50.55%)
Weather				
Clear	62,288 (54.50%)	726 (53.07%)	357 (56.04%)	38 (45.24%)
Cloudy	38,691 (33.85%)	442 (32.31%)	200 (31.40%)	31 (36.90%)
Fog	2,003 (1.75%)	33 (2.41%)	15 (2.35%)	3 (3.57%)
Rain	6,145 (5.38%)	100 (7.31%)	37 (5.81%)	10 (11.90%)
Snow	4,812 (4.21%)	60 (4.39%)	23 (3.61%)	2 (2.38%)
Severe wind	235 (0.21%)	4 (0.29%)	4 (0.63%)	0 (0.00%)
Sleet or hail	116 (0.10%)	3 (0.22%)	1 (0.16%)	0 (0.00%)
Pavement Condition				
Dry	87,141 (77.86%)	1,024 (76.82%)	504 (80.90%)	63 (77.78%)
Wet	15,738 (14.06%)	203 (15.23%)	81 (13.00%)	13 (16.05%)
Icy	2,127 (1.90%)	42 (3.15%)	7 (1.12%)	1 (1.23%)
Snowy	6,360 (5.68%)	51 (3.83%)	21 (3.37%)	1 (1.23%)
Muddy	154 (0.14%)	7 (0.53%)	7 (1.12%)	2 (2.47%)
Slushy	385 (0.34%)	3 (0.23%)	2 (0.32%)	1 (1.23%)
Debris	18 (0.02%)	3 (0.23%)	1 (0.16%)	0 (0.00%)
Geometry Related				
Speed limit under 35 mph	3,173 (2.72%)	47 (3.14%)	26 (3.20%)	2 (1.09%)
Speed limit 35 to 40 mph	3,292 (2.82%)	49 (3.28%)	23 (2.83%)	2 (1.09%)
Speed limit 45 to 50 mph	9,534 (8.18%)	131 (8.76%)	74 (9.11%)	8 (4.35%)
Speed limit over 50 mph	100,507 (86.27%)	1,269 (84.83%)	689 (84.85%)	172 (93.48%)
Run off the road	6,073 (5.21%)	330 (23.98%)	174 (27.19%)	46 (54.12%)
Two-lane horizontal curve	2,353 (2.02%)	75 (5.45%)	42 (6.56%)	8 (9.41%)

driver-injury severity outcomes conditioned on a crash having occurred and having been reported to police. The selection of the variables incorporated into the final model was determined by likelihood ratio tests. Likelihood ratio tests also were conducted to determine whether the effects of specific variables were constant across several injury severity categories (e.g., the female variable) or whether several related variables had common impacts on severity (e.g., dawn and dusk). The likelihood ratio test statistic is as follows:

$$L_R = -2\left(L_R - \sum_{\forall U} L_U\right) \tag{3}$$

where L_R is the log likelihood at convergence for the restricted model and L_U is the log likelihood at convergence for the unrestricted model. For example, in the case of the "dawn or dusk" variable, a restricted model is estimated by constraining the coefficient for both the "dawn" and "dusk" variables to be equal and the unrestricted model is estimated without such a restriction. The resulting L_R statistic is χ^2 distributed with J degrees of freedom, where J is equal to the difference in the total number of parameters between the restricted and unrestricted models. The null hypothesis for the likelihood ratio test is that the restricted model does not have a significantly lower log likelihood than the unrestricted models (which would indicate a significant difference between the two models). A likelihood ratio test statistic larger than the critical χ^2 value with J degrees of freedom at a 95% confidence level would allow one to reject the null hypothesis. For additional information on the specifics of the log likelihood ratio test, please refer to Washington et al. (*15*).

Results of the final multinomial logit model are included in Table 4. Parameter coefficient estimates are presented (with stan-

TABLE 4 Multinomial Logit Crash Severity Model Results

Variable	Property Damage Only	Possible Injury	Nonincapacitating Injury	Incapacitating or Fatal Injury
Alternative-specific constant	8.676 (1.060)	4.975 (1.060)	4.210 (1.007)	
Driver Characteristics				
Age	0.012 (0.003)			
Female		0.233 (0.078)	0.233 (0.078)	0.233 (0.078)
Passenger	0.410 (0.082)			
Vehicle Characteristics				
Damage to front of vehicle	1.837 (0.090)			
Damage to passenger side of vehicle	1.088 (0.234)	1.088 (0.234)		
Safety belt usage	1.712 (0.333)	1.045 (0.381)		
Airbag deployment (passenger car)			1.489 (0.166)	
Airbag deployment (other vehicle type)		1.489 (0.166)	1.489 (0.166)	
Vehicle other than passenger car	0.578 (0.096)			0.578 (0.096)
Environmental Characteristics				
Dawn or dusk	0.266 (0.118)			
Dark, lighted	1.190 (0.342)			
Dark, not lighted	0.643 (0.087)			
Horizontal curvature		0.513 (0.159)	0.513 (0.159)	0.513 (0.159)
Run off the road		1.575 (0.087)	1.575 (0.087)	1.575 (0.087)
Spring or summer		0.820 (0.134)	0.820 (0.134)	0.820 (0.134)
Fall		0.495 (0.135)	0.495 (0.135)	0.495 (0.135)
Speed limit over 55 mph				2.880 (1.225)
Initial log likelihood	−164,076			
Log likelihood with constants only	−4,692			
Log likelihood at convergence	−3,998			
ρ^2 (compared to start values)	0.976			
ρ^2 (compared to model with constants only)	0.148			

NOTE: Values under each severity column indicate coefficient estimates with standard errors in parentheses.

dard errors in parentheses) for those variables that were statistically significant at a 95% confidence level.

Elasticities and Pseudoelasticities

The parameter coefficient estimates for multinomial logit models can be misinterpreted because a positive coefficient does not necessarily indicate an increase in the likelihood of that particular severity level. To properly assess the vector of estimated coefficients (β_i), parameter-specific elasticities were used to measure the impact of individual parameters on the five severity-outcome probabilities. In this study, the only continuous variable was the age of the crash-involved driver. The elasticity of a continuous variable may be calculated as shown in the following formula for driver *n:*

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

where I_n is the subset of injury severity levels that have variable x_n (age) in the severity function (property damage only) and β_i is the estimated coefficient that is associated with x_n (*15*). The elasticity value obtained from Equation 4 reports the change in the likelihood of a particular severity outcome given a 1% change in the corresponding independent variable.

With the exception of age, all other variables in the model are coded as categorical binary indicator variables. Because these indicator variables may have a value of only zero or one, it is inappropriate to use Equation 4 to determine the elasticities. To appropriately quantify the effects of such indicator variables, a pseudoelasticity should be calculated as follows (*15*):

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

In this case, the calculated pseudoelasticity reports the change in probability of a particular severity level given the presence (or absence) of a particular variable in a crash. For example, our results show that when the driver of the crash-involved vehicle is female (i.e., the female variable is changed from 0 to 1), the likelihood of an injury increases by 26% in comparison to when the driver is male. Table 5 presents the elasticity values for each variable in the model and the interpretation of these results is presented in the following section.

Driver Characteristics

Age

Younger drivers were found to be more likely to be injured as a result of a deer-related crash, with the likelihood of injury decreasing by 0.49% for a corresponding 1% increase in age. This finding confirms the result of previous work that found that the age distribution of those injured in large animal crashes was different from those injured during all other types of traffic-related crashes (*23*). This finding is likely because of the inexperience of younger drivers, who have been found to take excessive risks and are overrepresented in crashes involving higher speed limits and unfavorable road conditions. Laflamme and Vaez warned that young drivers need to be sensitized to the risk factors involved with traffic crashes (*24*). Further illustrating this point, Riley and Marcoux (*3*) found that drivers who had previously been involved in a DVC demonstrated a greater knowledge of appropriate actions to avoid a DVC, a likely effect of experiential learning. On the basis of these findings, it may be appropriate to introduce a greater emphasis on interactions with deer as a part of Michigan's driver education programs.

Gender

Female drivers were more likely to be injured than male drivers, a result consistent with previous findings (*25, 26*) that may be caused by physiological or behavioral differences. Physiological differences

TABLE 5 Multinomial Crash Severity Elasticities

Variable	Property Damage Only	Possible Injury	Nonincapacitating Injury	Incapacitating or Fatal Injury
Driver characteristics				
Age[a]	0.002	−0.490	−0.490	−0.490
Female	−0.126	26.205	26.205	26.205
Passenger	−0.266	50.281	50.281	50.281
Vehicle characteristics				
Damage to front of vehicle	1.067	−84.077	−84.077	−84.077
Damage to passenger side of vehicle	0.065	0.065	−66.457	−66.457
Seatbelt	0.680	−48.223	−82.044	−82.044
Airbag (passenger car)	−0.166	−0.166	348.320	−0.166
Airbag (vehicle other than passenger car)	−1.683	341.509	341.509	−1.683
Vehicle other than passenger car	0.280	−44.356	−44.356	0.280
Environmental characteristics				
Dawn	0.139	−24.694	−24.694	−24.694
Dusk	0.139	−24.694	−24.694	−24.694
Dark, lighted	0.387	−69.029	−69.029	−69.029
Dark, not lighted	0.363	−46.921	−46.921	−46.921
Horizontal curvature	−0.334	64.816	64.816	64.816
Run off the road	−1.647	373.694	373.694	373.694
Spring	−0.479	128.919	128.919	128.919
Summer	−0.479	128.919	128.919	128.919
Fall	−0.288	63.740	63.740	63.740
Speed limit over 55 mph	−0.014	−0.014	−0.014	1,757.576

[a]This is a continuous variable and elasticities are not reported in percentages. See Equation 4 and its accompanying discussion.

can arise from differences in the body to withstand impacts or from the relationship between driver body type and vehicle characteristics, such as how airbags and seatbelts affect average males and females differently. Behavioral differences may arise from driving more aggressively (*25*).

Safety Equipment

Safety belt use decreased the likelihood of moderate or severe injuries by 82.0% and possible injury by 48.2%, a finding that is consistent with numerous other traffic safety studies (*25*, *27*, *28*). Boontob et al. found that the significant influencing factors of seatbelt use included gender, age, education, income, vehicle type, average travel time (*29*). Increased enforcement, such as the National Highway Traffic Safety Administration' Click-It-or-Ticket, has been shown to be effective in combating this problem.

Air bag usage decreased the likelihood of property damage only and incapacitating or fatal injury, but increased the likelihood of moderate injury by more than 340%. This finding is likely because of the force of impact exerted on the driver when the airbag inflates. There is also evidence that drivers tend to be more aggressive when their vehicles are equipped with airbags, which may lead to more severe, if not fatal, injuries (*30*).

Passenger Present

If a passenger was present in the crash-involved vehicle, the likelihood of injury increased by 50%. This may be because of driver distraction issues or to the physical impact occurring between drivers and passengers in crash-involved vehicles. Huelke and Compton (*31*) found the presence of an unrestrained front seat passenger to increase driver injury severity in driver's side crashes in particular.

Vehicle Characteristics

Vehicle Type

Vehicles other than passenger cars were more likely to result in either property damage only or severe injuries. This dichotomous result is likely picking up on two separate factors. Wang and Kockelman (*26*) found that heavier vehicles increased both a vehicle's crashworthiness, which may lead to the increase in property damage only likelihood, and driver aggressiveness, which may lead to the increased probability of severe injuries.

Damage Area

If the deer collisions resulted in damage to the passenger side of the vehicle, the probability of a moderate or severe injury decreased by 66.5%, and if the damage occurred to the front of the vehicle, there was an 84.1% decrease in the likelihood of all injuries. Injuries were more likely if the damage occurred to the bottom of the vehicle, a situation whereby drivers would have less control of the vehicle, or if the damage occurred to the driver side, in which case the driver was more likely to feel the force of the impact or come into contact with a shattered window.

Environmental Characteristics

Lighting Conditions

Crashes were most likely to result in injuries during daylight conditions. Injuries were least likely during dark conditions when lighting was present, a 69.0% decrease relative to daylight conditions. Dark, unlighted conditions were 46.9% less likely to result in driver injuries and dawn or dusk conditions decreased the likelihood of injury by 24.7%. These findings are in contrast to the effect of lighting on crash frequency as dark or unlighted conditions have been found to increase crash risk by more than 17 times (*3*, *32*) that of daylight conditions. Previous research has shown drivers to decrease their travel speeds under dark conditions (*33*). Consequently, these lower speeds may explain the reduction in injury severity for collisions occurring under darkness.

Horizontal Curvature on Two-Lane Roads

Horizontal curvature increased the likelihood of injury by 64.8%. This effect can be explained by the fact that vehicle handling is more difficult under such conditions as reported by several researchers (*34*).

Run off the Road

Run-off-the-road crashes were substantially more likely to increase the probability of injury (373.7%). By running off the road, drivers are more likely to strike roadside objects and to lose control of their vehicles. In addition, run-off-the-road crashes may be a proxy for poor driving abilities. Running off the road has also been shown to be highly correlated with various high risk groups, including young drivers, drunk drivers, and people who speed and do not wear their safety belts (*35*).

Season

Surrounded by the Great Lakes, Michigan is subject to severe inclement weather conditions throughout the winter months. Annual snowfall in the state ranges up to 170 in. per year along the coasts of Lake Michigan and Lake Superior (*36*). These areas tend to be primarily rural and inhabited by a large proportion of the state's deer population. Surprisingly, crashes tended to be least severe during the winter months, which may indicate increased caution on the part of motorists because of potentially hazardous road conditions. Drivers generally tend to drive slower and exercise greater caution in such situations (*33*). In the fall, when deer collisions are most prevalent, there is a 63.7% increase in the likelihood of injury. In the spring and summer, injury likelihood increase by 128.9%. Further research may be warranted to confirm the reasons for such seasonal effects.

Speed Limit

High-speed roads appear to be especially problematic for DVCs as they have been shown to increase the frequency of DVCs, as well as the severity (*3*). Crashes occurring on roads with speed limits greater than 55 mph led to enormous increases in the likelihood of severe injuries (1,757.6%). At higher speeds, the impact forces between a vehicle and any object with which it collides are greater, and consequent injuries would be expected to be more severe. In addition, the reaction time available to drivers is reduced at higher speeds, which may further compound this problem.

SUMMARY AND CONCLUSIONS

Michigan is plagued by the same DVC problems as many other states throughout the Midwest. The crash-injury severity analysis presented in this paper revealed various driver, vehicle, and environmental factors that contribute to injuries. Summarizing the results of the study, in contrast to other types of crashes, older drivers were found to be less likely to sustain an injury as a result of a DVC and younger drivers were more likely to be injured. This may be evidence of a lack of appropriate skills or knowledge on the part of younger drivers when they encounter deer on the roadway. Consequently, it is recommended that the DVC issue be addressed to a greater extent in Michigan driver training programs. Female drivers were found to be at an increased risk of injury, which may be because of either physiological or behavioral differences between men and women. The presence of passengers in the crash-involved vehicle was found to increase the likelihood of injury, although it was not determinable if this was because of driver distraction, impact between the driver and passenger, or some other factors. Seatbelt and airbag usage were both found to reduce the likelihood of severe injuries, although airbags were actually found to increase the likelihood of minor injuries.

Injury likelihood was substantially reduced if the front of the crash-involved vehicle was the area that sustained the greatest damage. Since 2005, the Michigan Deer Crash Coalition (MDCC) and the Michigan Department of Transportation (MDOT) have promoted a "Don't Veer for Deer!" campaign, discouraging motorists from swerving in an attempt to avoid a deer collision. By striking the deer directly, drivers are more likely to maintain control of their vehicles than if they were to take evasive actions. If drivers do not swerve to avoid deer, the number of run-off-the-road crashes would decrease and result in further reductions in injuries and fatalities. Consequently, the continuation of this campaign may further reinforce this positive behavior moving forward.

In addition to educating the driving public, providing targeted enforcement to combat the problems of speeding and driving without a safety belt are other areas of opportunity. Michigan annually conducts a "Click-It-Or-Ticket" campaign, which has resulted in the second highest safety belt usage rate in the country (*37*). In addition, various speed enforcement programs have proven effective and may provide incremental benefits at locations experiencing frequent DVCs. Encouragingly, crashes were found to be less severe under nighttime conditions and during winter months, possible indications that drivers are more cautious under such situations, driving slower, and consequently suffering less severe injuries when crashes occur. On the basis of this finding, an examination of the injury severity of crashes occurring at locations near deer warning signs is recommended to determine their effect on driver behavior as sufficient information was not available to examine this issue as a part of this study.

Because this study is the first to address the DVC injury severity issue, further research is warranted to confirm these findings. In addition, determining how these impacts may vary across other states would be of value to both practitioners and researchers. Although engineering efforts have been the primary focus of DVC prevention to date, supplementing these infrastructure improvements with education and enforcement efforts may provide a promising avenue for addressing the DVC severity issue.

REFERENCES

1. Hedlund, J. H., P. D. Curtis, G. Curtis, and A. F. Williams. Methods to Reduce Traffic Crashes Involving Deer: What Works and What Does Not. *Traffic Injury Prevention,* Vol. 5, 2004, pp. 122–131.
2. Perrin, J., and R. Disegni. *Animal-Vehicle Accident Analysis.* Report No. UT-03.31. Utah Department of Transportation Research and Development Division, Salt Lake City, 2003.
3. Riley, S., and A. Marcoux. *Deer-Vehicle Collisions: An Understanding of Accident Characteristics and Drivers' Attitudes, Awareness, and Involvement.* Final Report. Department of Fisheries and Wildlife, Michigan State University, East Lansing, 2006.
4. U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis. Fatality Analysis Reporting System (FARS) Web-based encyclopedia. http://www-fars.nhtsa.dot.gov. Accessed November 14, 2007.
5. Iverson, A. L., and L. R. Iverson. Spatial and Temporal Trends of Deer Harvest and Deer-Vehicle Accidents in Ohio. *The Ohio Journal of Science,* Vol. 99, No. 4, 1999, pp. 84–94.
6. Knapp, K. K., A. Khattak, and T. Oakasa. Development of a Countywide Deer-Vehicle Crash Frequency Model. Presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C., 2005.
7. Knapp, K. K. Crash Reduction Factors for Deer-Vehicle Crash Countermeasures: State of the Knowledge and Suggested Safety Research Needs. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1908,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 172–179.
8. Meyer, E. Assessing the Effectiveness of Deer Warning Signs. Final Report, Kansas Department of Transportation, University of Kansas, Lawrence, 2006.
9. Marcoux, A. Deer-Vehicle Collisions: An Understanding of Accidents Characteristics and Drivers' Attitude, Awareness and Involvement. MS thesis, Department of Fisheries and Wildlife, Michigan State University, East Lansing, 2005.
10. O'Donnell, C., and D. Connor. Predicting the Severity of Motor Vehicle Accident Injuries Using Models of Ordered Multiple Choice. *Accident Analysis and Prevention,* Vol. 28, No. 6, 1996, pp. 739–753.
11. Khattak, A., D. Pawlovich, R. Souleyrette, and S. Hallmark. Factors Related to More Severe Older Driver Traffic Crash Injuries. *Journal of Transportation Engineering,* Vol. 128, No. 3, 2002, pp. 243–249.
12. Kweon, Y.-J., and K. Kockelman. Overall Injury Risk to Different Drivers: Combining Exposure, Frequency, and Severity Models. *Accident Analysis and Prevention,* Vol. 35, No. 3, 2003, pp. 414–450.
13. Abdel-Aty, M. A. Analysis of Driver Injury Severity Levels at Multiple Locations Using Ordered Probit Models. *Journal of Safety Research,* Vol. 34, No. 5, 2003, pp. 597–603.
14. Deng, Z., J. N. Ivan, and P. Garder. Analysis of Factors Affecting the Severity of Head-On Crashes: Two-Lane Rural Highways in Connecticut. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1953,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 137–146.
15. Washington, S., M. Karlaftis, and F. Mannering. *Statistical and Econometric Methods for Transportation Data Analysis.* Chapman and Hall/CRC, Boca Raton, Fla., 2003.
16. Hauer, E. The Frequency-Severity Indeterminacy. *Accident Analysis and Prevention,* Vol. 38, No. 1, 2006, pp. 78–83.
17. McFadden, D. Econometric Models of Probabilistic Choice. In *Structural Analysis of Discrete Data with Econometric Applications* (C. F. Manski and D. McFadden, eds.), MIT Press, Cambridge, Mass., 1981, pp. 198–272.
18. Shankar, V., F. Mannering, and W. Barfield. Statistical Analysis of Accident Severity on Rural Freeways. *Accident Analysis and Prevention,* Vol. 28, No. 3, 1996, pp. 391–401.
19. Al-Ghamdi, A. S. Using Logistic Regression to Estimate the Influence of Accident Factors on Accident Severity. *Accident Analysis and Prevention,* Vol. 34, 2002, pp. 729–741.

20. Khorashadi, A., D. Niemeier, V. Shankar, and F. Mannering. Differences in Rural and Urban Driver-Injury Severities in Accidents Involving Large Trucks: An Exploratory Analysis. *Accident Analysis and Prevention,* Vol. 37, No. 5, 2005, pp. 910–921.
21. Savolainen, P., and F. Mannering. Probabilistic Models of Motorcyclists' Injury Severities in Single- and Multi-Vehicle Crashes. *Accident Analysis and Prevention,* Vol. 39, No. 5, 2007, pp. 955–963.
22. Centers for Disease Control and Prevention. Effectiveness in Disease and Injury Prevention Injuries from Motor-Vehicle Collisions with Deer–Kentucky, 1987–1989. *Morbidity and Mortality Weekly Report,* Vol. 40, 1991, pp. 717–719.
23. Centers for Disease Control and Prevention. Nonfatal Motor-Vehicle Animal Crash-Related Injuries—United States, 2001–2002. *Morbidity and Mortality Weekly Report,* Vol. 53, No. 30, 2004, pp. 675–678.
24. Laflamme, L., and M. Vaez. Car Crash and Injury Among Young Drivers: Contribution of Social, Circumstantial and Car Attributes. *International Journal of Injury Control and Safety Promotion,* Vol. 14, No. 1, 2007, pp. 5–10.
25. Islam, S., and F. Mannering. Driver Aging and its Effect on Male and Female Single-Vehicle Accident Injuries: Some Additional Evidence. *Journal of Safety Research,* Vol. 37, No. 3, 2006, pp. 267–276.
26. Wang, X., and K. M. Kockelman. Use of Heteroscedastic Ordered Logit Model to Study Severity of Occupant Injury: Distinguishing Effects of Vehicle Weight and Type. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1908,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 195–204.
27. Lassarre, S. The Introduction of the Variables 'Traffic Volume,' 'Speed' and 'Beltwearing' into a Predictive Model of the Severity of Accidents. *Accident Analysis and Prevention,* Vol. 18, 1986, pp. 129–134.
28. Cooper, P. J., and P. Salzberg. Safety Restraint Usage in Fatal Motor Vehicle Crashes. *Accident Analysis and Prevention,* Vol. 25, 1993, pp. 67–75.
29. Boontob, N., Y. Tanaboriboon, K. Kanitpong, and P. Suriyawongpaisal. Impact of Seat Belt Use on Road Accidents in Thailand. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
30. 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 and Uncertainty,* Vol. 32, No. 2, 2006, pp. 83–99.
31. Huelke, D. F., and C. P. Compton. *Analysis of Passenger Car Side Impacts—Crash Location, Injuries, AIS and Contacts.* SAE Technical Paper Series. Society of Automotive Engineers, Troy, Mich., 2000.
32. Haikonen, H., and H. Summala. Deer-Vehicle Crashes Extensive Peak at 1 Hour after Sunset. *American Journal of Preventive Medicine,* Vol. 21, No. 3, 2001, pp. 209–213.
33. Kilpeläinen, M., and H. Summala. Effects of Weather and Weather Forecasts on Driver Behaviour. *Transportation Research Part F,* Vol. 10, 2007, pp. 288–299.
34. Savolainen, P. T., and A. P. Tarko. Safety Impacts at Intersections on Curved Segments. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1908,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 130–140.
35. Dissanayake, S. Young Drivers and Run-off-the-Road Crashes. *Proceedings of the Mid-Continent Transportation Research Symposium,* 2003. www.ctre.iastate.edu/PUBS/midcon2003/dissanayakeyoung.pdf. Accessed July 4, 2008.
36. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center. National Environmental Satellite, Data and Information Service. www.ncdc.noaa.gov/oa/ncdc.html. Accessed November 14, 2007.
37. U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis. Seat Belt Use in 2006—Use Rates in the States and Territories. *Traffic Safety Facts, Research Note,* DOT-HS-810-690, 2007.

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