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Are SUVs "Supremely Unsafe Vehicles"?

Analysis of Rollovers and Injuries with Sport Utility Vehicles

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With increasing speed limits and more light trucks penetrating the market, concern over their rollover risk is growing. In particular, the general public and automobile manufacturers would like to know if the increasingly popular sport utility vehicles (SUVs) are indeed safer than other vehicle platforms. The influences of various vehicle platforms on rollovers and driver injuries were investigated. Specifically, (*a*) the rollover intensities of SUVs vis-à-vis those of other vehicle types in single-vehicle crashes and (*b*) the severity of the resulting driver injury were explored. Data from a good-quality federally maintained database were used for crash analysis. The database contains a relatively clean stratified sample of police-reported tow-away crashes nationwide, and it contains detailed information about vehicle rollovers. Rollover intensity, captured by the number of quarter turns, was investigated by using weighted negative binomial models; injury severity, measured on the abbreviated injury scale, was examined by using weighted ordered logit models. New insights emerged about the factors that increase rollover intensity and injury severity. As expected, SUVs are more likely to roll over and therefore injure their occupant drivers more severely. However, SUVs also protect their drivers during collisions because of their greater crashworthiness. In fact, the SUV crashworthiness effect exceeds the rollover effect, on average. The implications of these findings are discussed.

In the United States, about 10,000 deaths and 27,000 serious injuries per year are attributed to light-vehicle rollovers (*1*). Particularly vulnerable to rollovers are sport utility vehicles (SUVs), which are becoming increasingly popular. Originally meant for mountain trails and logging roads, SUVs are typically higher and narrower than passenger cars, which increases their propensity to roll over. They are increasingly being used on urban and rural highways, where the potential for rollovers is often higher because of higher speed limits. The popular press has referred to SUVs as "supremely unsafe vehicles" mainly because they are more likely to roll over than passenger cars (*2*). Alternatively, some in the automobile industry defend SUVs' safety record, claiming that "you can roll over any vehicle if you turn fast enough and abruptly enough," and that a majority of SUV injuries and deaths are due to younger drivers, who are more likely to drive them at higher speeds and who are more likely to be using alcohol. Given the magnitude of the rollover problem, the differences in opinion, and the scarcity of rigorous analysis on this topic, the question of whether these light trucks are more likely to roll over and injure occupant drivers needs further investigation.

According to the NHTSA rollover rating system, SUVs receive between 1 and 3 stars, pickup trucks receive between 1 and 4 stars, vans receive between 2 and 3 stars, and passenger cars receive between 4 and 5 stars. These ratings are based on a simple measure called the static stability factor (SSF), which is 0.5 · (wheelbase/vehicle height), where the vehicle height is measured from the ground to the center of gravity of the vehicle. The SSF typically ranges between 1.05 and 1.20 for SUVs and between 1.35 and 1.45 for passenger cars. The relationship between SSF and real-life rollover crash data has been investigated in a recent TRB report that finds that SSF correlates significantly with a vehicle's involvement in single-vehicle rollovers (treated as a binary outcome), although driver and roadway factors also contribute significantly (*3*). The present research does not directly investigate the effect of SSF, partly because the center-of-gravity data were not available in the data set analyzed. Instead, the study described here focuses on understanding the role of SUVs on rollover intensity, taking full advantage of the rollover data. Going a step further, the study explores how vehicle platforms and rollovers are associated with driver injury and combines the rollover and injury severity results by using path analysis. Fundamental questions about SUV safety in collisions are answered by identifying the direct and indirect effects of vehicle platforms on injury severity. The analysis is based on a 3-year sample of crash and inventory data from the Crashworthiness Data System (CDS).

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LITERATURE

Several studies identify the main factors that influence rollover crashes. Using National Automotive Sampling System (NASS) data from 1988 to 1996, Parenteau et al. identified parameters that increase the likelihood of rollovers, suggesting that rollovers most often occurred in good weather and in daylight conditions and that more than 55% of the drivers were distracted or fell asleep at the time of the crash (*4*). Given a rollover, driver injuries increased with rollover intensity, as measured by the number of quarter turns. While insightful, the study did not control for other factors when investigating the effect of rollover on injury severity.

Using Illinois crash and roadway data, Viner found that slopes and hitting fixed objects were the major tripping mechanisms for all rollovers outside the roadway (*5*). Moreover, higher speed limits were associated with higher rates of rollover occurrence. Using Fatality Analysis Reporting System and New Mexico crash data, Viner examined rollovers that resulted from tripping on side slopes and ditches and found that such rollovers lead to a substantial amount of fatalities in run-off-the-road crashes (*6*). Furthermore, rural run-off-the-road crashes were more likely to result in rollovers than similar urban crashes. Richardson et al. analyzed Hawaii crash data and found that pickups were 86% more likely than passenger cars to be involved in rollovers and that young drivers were more likely to experience rollovers (*7*).

Several studies have found that light trucks are more likely to roll over than passenger cars (*3–10*). A TRB report on rollovers found that such events are more likely when SSF is lower, which implies that SUVs are more likely to roll over than passenger cars (*3*). Furthermore, rollovers were more likely to occur on hills or curves and if the driver was young, drunk, or female. Bligh and Mak report that given a rollover crash, injury rates are higher for those in passenger cars than for those in light trucks (*8*). A study by Viner et al. disagreed slightly, reporting no difference between vehicle platforms in fatal and severe injuries (*9*).

Krull et al. analyzed Highway Safety Information Service data for Illinois and Michigan in an exploration of single-vehicle run-off-the-road crashes and found that the probability of severe injury increased with rollover involvement, passenger cars as opposed to pickups and vans, failure to use a seat belt, alcohol use, daylight, rural roads, higher speed limits, and dry pavement conditions (*11*). Donelson et al. concluded that high-risk conditions for light trucks include an unbelted, drinking driver, higher-speed roads, occupant ejection, and nonelderly occupant (*12*). McGinnis et al. reported that rollovers, SUVs, younger and older drivers, male drivers, and alcohol use pose special challenges for crash reduction efforts (*13*).

A behavioral study has found that on average light trucks are used over longer distances with more people aboard and are purchased by wealthier households living in lower-density neighborhoods (*14*). SUV occupancies and total annual mileage are higher for SUVs than for passenger cars, and SUVs are relatively popular for weekend travel.

HYPOTHESIS

When the reviewed research is taken as a whole, it suggests that risk analysis should include both rollovers and injury severity. Indeed, both rollovers and injury occurrence are complex phenomena that are influenced by many driver, vehicle, and roadway factors. While some of these factors have been explored, there remains a need to comprehensively and rigorously analyze the roles of light trucks in rollovers and in driver injury severity.

Most studies treat rollovers as a binary outcome variable and often ignore the intensity of rollovers. Rollover intensity is of interest because more intense rollovers are likely to increase injury severity. Furthermore, the intensity effect might be nonlinear; that is, more vehicular turns might increase occupant driver injury, but at an increasing or decreasing rate. While several studies have separately analyzed the relationship between rollovers and injuries, they have not examined the joint effects of vehicle platforms and rollovers on injury and integrated the results. Through path analysis, this study provides such integration.

It is expected that SUVs and pickups are more likely than passenger cars to roll over. This could be largely due to their higher SSFs (*3*). However, many other driver, vehicle, and roadway factors are likely to play a role; the research question is whether the SUV effect will still be significant after other factors are controlled for. For instance, certain precrash conditions, such as a loss of vehicle control or avoidance of collisions with other vehicles, can be correlated with certain vehicle platforms and more directly result in high overturning forces, increasing rollover intensity. Such variables must be controlled for before it can be inferred that SUVs are significantly and substantially more likely to roll over than other vehicles.

It is expected that rollovers increase occupant driver injury severity, so in comparison with rollovers in passenger cars, rollovers in SUVs will indirectly increase injury severity. However, in a crash these larger and sturdier vehicles might be harder to penetrate, protecting occupant drivers and passengers more than passenger cars do. The interesting issue is to be able to quantify the two competing effects and identify the net effect. For example, do the negative and positive effects of SUVs cancel each other? To answer these research questions, it is necessary to control for many obvious factors that correlate with injury severity. Such factors include the use of restraints and the presence of airbags, which are likely to reduce injury severity, whereas alcohol use (associated with slower reaction times and impaired judgment), higher speeds, curves and ramps, darkness, and old age might increase driver injury.

METHOD

NASS Data

NHTSA created NASS to produce a national traffic accident database for use in the development of highway and vehicle safety standards and the identification of highway safety needs. The system consists of 24 teams of accident researchers situated throughout the country. They investigate a probability sample of police-reported tow-away crashes involving passenger cars, light trucks, and vans. This system has been termed CDS. For analysis purposes, the NASS-CDS database contains 11 files that describe the accident scene, although this study used variables from two of the files: (*a*) the general vehicle file, which contains information about vehicles, roadway and environmental conditions, and rollovers, and (*b*) the occupant assessment file, which contains data related to drivers and driver behavior, such as seat belt use.

The files were first merged for each year (1997, 1998, and 1999) and then combined to create a file that contains a sample of 4,552 single-vehicle crashes involving SUVs, pickups, vans, and passenger cars. A driver was present in all cases. To analyze single-vehicle crashes, cases that represented the crash types shown in Figure 1 were selected. The values for some variables were missing from the final data set.

Because the crashes selected in NASS-CDS are a probability sample of all crashes occurring in the survey year, the data from these crashes are weighted to produce national estimates. Thus, the data were analyzed by using the weight variable provided in the NASS-CDS data set; that is, all the statistics and models presented in the paper account for sampling weights.

Analysis of Crash Data

The vehicles and situations that increase the likelihood of SUV rollovers were identified by using frequency analysis, contingency tables, and count regression models. Specifically, Poisson and negative binomial models were estimated to investigate the number of quarter turns experienced by vehicles in rollover crashes. Additionally, whether or not a rollover occurred was analyzed by using the binary logit model. For these crashes, injuries are recorded by using a seven-point ordinal scale known as the Abbreviated Injury Scale (AIS): maximum, critical, severe, serious, moderate, minor, and no injuries. These data are ordinal and categorical, obviating the use of ordered probability models for estimation (*15, 16*).

Variables representing driver, vehicle, and environmental and roadway factors were extracted from the original data set, including

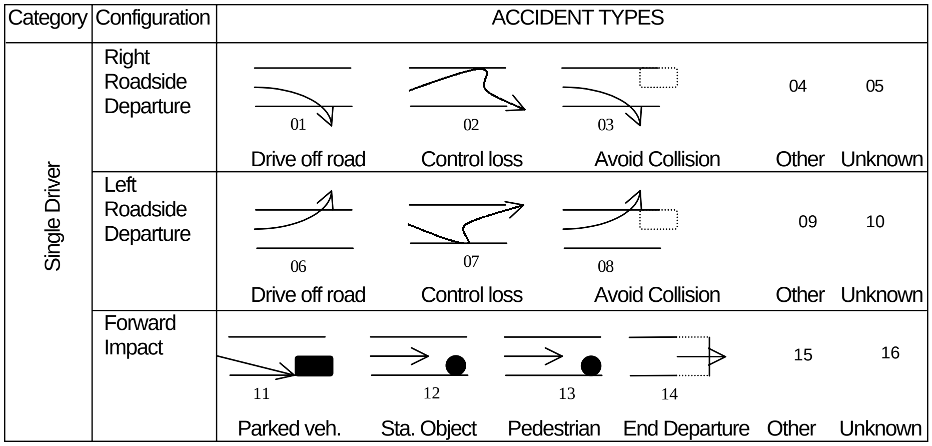

FIGURE 1 Various single-vehicle crash types included in the analysis (source: NASS code book; veh. = vehicle; Sta. = stationary).

the two dependent variables: rollover and injury severity. The independent variables were chosen on the basis of the hypotheses or for use as controls. Some of the variables that had been intended to be included in the analysis and models revealed problems and had to be dropped. Examples include driver distraction before the crash (for which a large number of values were missing) and the presence of drugs and cargo weight (neither showed a correlation with rollover or injury). The model specifications were developed over several iterations on the basis of theory and empirical evidence.

Modeling Structure

Models were estimated to test specific hypotheses, control for the effects of several factors, and account for interdependencies among explanatory variables. The effects of vehicle platform on rollover propensity were investigated by using binary logit, which is similar to the ordered logit discussed below. Rollover intensity, captured by the number of quarter turns in a collision, was investigated by using Poisson and negative binomial regression models, both of which are appropriate for the modeling of count data, that is, the frequency of quarter turns experienced by a vehicle. While the Poisson model requires mean–variance equality, the negative binomial regression relaxes this assumption. The negative binomial model is discussed below.

Let Y_i denote the number of quarter turns for the ith of N vehicles; Y_i can theoretically attain different integer values equaling 0, 1, 2, ... The number of quarter-turn rollover occurrences can have a negative binomial distribution. Suppose λ_i is vehicle i's expected quarter-turn frequency; y_i equal to 0, 1, 2, . . . is the realized or actual value of the quarter turns; and i is 1, 2, . . . , N. The mean of Y_i equals λ_i. To incorporate explanatory variables $\mathbf{x}_i$, the parameter λ_i is specified to be

$$\lambda_i = \exp(\gamma' \mathbf{x}_i + \epsilon_i) \tag{1}$$

where

γ' = vector of estimated parameters;
$\mathbf{x}_i$ = vehicle i's explanatory variables (e.g., vehicle platform and make), and
$\exp(\epsilon_i)$ = a gamma-distributed error term.

Thus, the negative binomial distribution is given by

$$P[Y_i = y_i] = \frac{\Gamma[(1/\alpha) + y_i]}{\Gamma(1/\alpha) y_i!} \left[\frac{1/\alpha}{(1/\alpha) + \lambda_i}\right]^{1/\alpha} \left[\frac{\lambda_i}{(1/\alpha) + \lambda_i}\right]^{y_i} \tag{2}$$

where y_i! denotes the factorial of y_i. The specifications for α (the dispersion parameter) and Γ (the gamma function) have been provided by Long (*17*). If α is equal to 0, then the model reduces to a Poisson model. The change in the expected count, referred to as "factor change," gives a straightforward interpretation and a good indication of the relative importance of variables. The factor change in the expected count for a change of δ in x_k (the kth explanatory variable) equals

$$\frac{E(y_i | \mathbf{x}, x_k + \delta)}{E(y_i | \mathbf{x}, x_k)} = \exp(\gamma_k \cdot \delta) \tag{3}$$

It means that for a change of δ in x_k, the expected count increases by a factor of $\exp(\gamma_k \cdot \delta)$, where γ_k is the parameter estimate for the kth variable, when all other variables are held constant. However, for noncontinuous variables (e.g., indicator variables) this measure is not very informative, so the discrete change must be used.

To model injury severity, ordered probability models are appropriate because the injury data are ordinal and categorical (*14*). The ordered logit model can capture the qualitative differences between different injury categories, for example, the effect of SUVs on the likelihood of a fatality differently from its influence on the likelihood of a minor or incapacitating injury. The ordered logit uses the following form:

$$y_i^* = \gamma' \mathbf{x}_i + \zeta_i \tag{4}$$

where

y_i^* = dependent variable, the propensity of injury severity, coded as 0, 1, 2, . . . for AIS;
γ' = vector of estimated parameters;
$\mathbf{x}_i$ = crash i's explanatory variables (e.g., vehicle platform or driver age and gender); and
ζ_i = a logistically distributed error term.

The observed counterpart to y_i^* is y_i, and they are related to each other through estimable thresholds as follows:

$$y_i = m \qquad \text{if } \mu_{m-1} \le y_i^* \le \mu_m \tag{5}$$

where m's are the ordinal categories and μ's are thresholds. Computation of marginal effects is particularly meaningful for the ordered logit model, in which the effects of variables $\mathbf{x}_i$ on the intermediate categories are ambiguous if only the parameter estimates are available.

Path analysis, shown in Figure 2, allows the calculation of direct and indirect effects. The following equations describe the path analysis structure:

$$Y_1 = \boldsymbol{\gamma}_{11}\mathbf{X}_1 + \boldsymbol{\gamma}_{12}\mathbf{X}_2 + \boldsymbol{\gamma}_{13}\mathbf{X}_3 + \boldsymbol{\gamma}_{14}\mathbf{X}_4 + \zeta_1$$

$$Y_2^* = \boldsymbol{\gamma}_{21}\mathbf{X}_1 + \boldsymbol{\gamma}_{22}\mathbf{X}_2 + \boldsymbol{\gamma}_{23}\mathbf{X}_3 + \boldsymbol{\gamma}_{24}\mathbf{X}_4 + \boldsymbol{\gamma}_{25}\mathbf{X}_5 + \beta_{21}Y_1 + \zeta_2 \tag{6}$$

where

Y_1 = whether or not a vehicle rolled over;
Y_2^* = injury severity;
γ_{ij} = vectors of estimated parameters for each set of variables $\mathbf{X}_j$;
β_{21} = effect of rollover on injury severity; and
ζ_i = error terms, which are assumed to be uncorrelated.

RESULTS

Descriptive Analysis

Tables 1 and 2 provide the descriptive statistics. Passenger cars, SUVs, pickups, and vans constitute 63%, 16%, 17%, and 4% of the total single-vehicle tow-away crashes in the CDS database, respectively (N = 4,552 crashes that occurred between 1997 and 1999). This distribution is similar to the distribution of passenger cars versus light trucks in the United States: there are about 135 million passenger car registrations and 70 million light truck (SUV, van, and pickup) registrations. Close to 22% of the vehicles in the sample rolled over. Further analysis showed that 49.8% of the SUVs rolled over, whereas 18.7% of passenger cars rolled over, which implies that the incidence of SUV rollovers is higher by about 1.66 [(0.498 – 0.187)/0.187]. In terms of rollover inten-

TABLE 1 Summary Statistics for Dependent Variables

Variable	N	Mean	Std. Dev.	Min	Max
Rollover					
Roll-Yes	4,343	0.2198	0.4142	0	1
Roll-none	4,343	0.7802	0.4142	0	1
Roll 0.25 turns	4,343	0.0390	0.1937	0	1
Roll 0.50 turns	4,343	0.0941	0.2920	0	1
Roll 0.75 turns	4,343	0.0084	0.0911	0	1
Roll 1.00 turns	4,343	0.0481	0.2141	0	1
Roll 1.25 turns	4,343	0.0019	0.0435	0	1
Roll 1.50 turns	4,343	0.0154	0.1233	0	1
Roll 1.75 turns	4,343	0.0007	0.0270	0	1
Roll 2.00 turns	4,343	0.0063	0.0792	0	1
Roll 2.25 turns	4,343	0.0012	0.0348	0	1
Roll 2.50 turns	4,343	0.0035	0.0590	0	1
Roll 2.75 turns	4,343	0.0002	0.0134	0	1
Roll 3.00 turns	4,343	0.0006	0.0242	0	1
Roll 3.25 turns	4,343	0.0000	0.0000	0	0
Roll 3.50 turns	4,343	0.0002	0.0139	0	1
Roll 3.75 turns	4,343	0.0000	0.0000	0	0
Roll 4.00 turns	4,343	0.0000	0.0070	0	1
Roll 4.25 turns	4,343	0.0000	0.0052	0	1
Injury-Abbreviated Injury Scale					
No injury	4,186	0.5517	0.4974	0	1
Minor injury	4,186	0.3271	0.4692	0	1
Moderate injury	4,186	0.0800	0.2713	0	1
Serious injury	4,186	0.0275	0.1634	0	1
Severe injury	4,186	0.0073	0.0850	0	1
Critical injury	4,186	0.0052	0.0719	0	1
Max injury	4,186	0.0014	0.0369	0	1

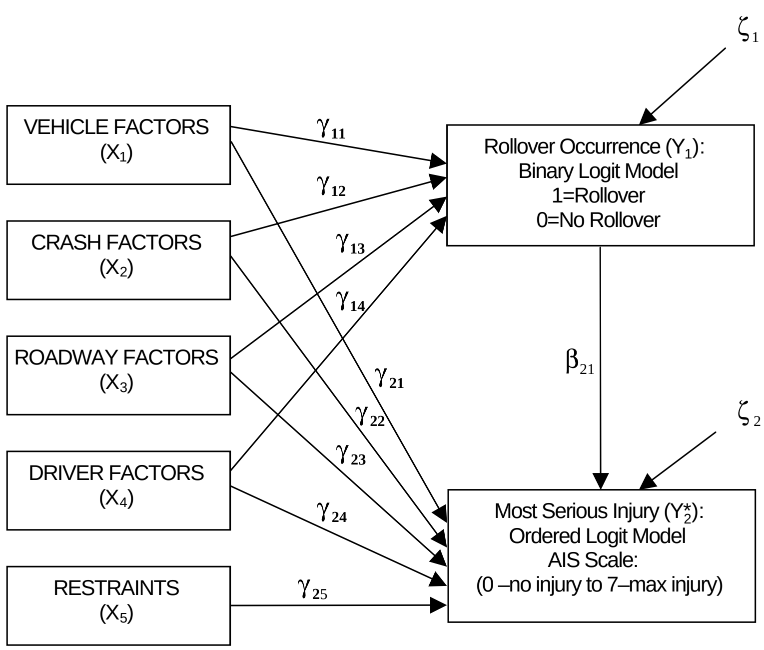

FIGURE 2 Path diagram showing estimation of rollover and injury severity.

TABLE 2 Summary Statistics for Independent Variables

Variable	N	Mean	Std. Dev.	Min	Max
Vehicle Factors					
SUV	4,552	0.1573	0.3641	0	1
Van	4,552	0.0364	0.1874	0	1
Pickup	4,552	0.1676	0.3736	0	1
Chrysler	4,552	0.0953	0.2937	0	1
Ford	4,552	0.2227	0.4161	0	1
General Motors	4,552	0.3491	0.4767	0	1
Honda	4,552	0.0538	0.2257	0	1
Toyota	4,552	0.0737	0.2613	0	1
Crash Factors					
Blowout/flat tire	4,378	0.0305	0.1718	0	1
Drive off road	4,552	0.3439	0.4751	0	1
Control/traction loss	4,552	0.4343	0.4957	0	1
Avoid collision	4,552	0.0919	0.2890	0	1
End departure	4,552	0.0239	0.1527	0	1
Speed limit <40 km/h	4,509	0.0140	0.1177	0	1
Speed limit >80 km/h	4,509	0.3124	0.4635	0	1
Roadway Factors					
Curve	4,552	0.4168	0.4931	0	1
Uphill	4,537	0.1500	0.3571	0	1
Downhill	4,537	0.2544	0.4356	0	1
Asphalt road	4,552	0.8730	0.3330	0	1
Gravel road	4,552	0.0077	0.0875	0	1
Dirt road	4,552	0.0382	0.1916	0	1
Wet roadway condition	4,546	0.2271	0.4190	0	1
Snow roadway condition	4,546	0.0572	0.2323	0	1
Ice roadway condition	4,546	0.0641	0.2449	0	1
Sand roadway condition	4,546	0.0003	0.0167	0	1
Dark	4,542	0.3124	0.4635	0	1
Darklight	4,542	0.2130	0.4095	0	1
Dawn	4,542	0.0193	0.1376	0	1
Dusk	4,542	0.0174	0.1308	0	1
Driver Factors					
Alcohol presence	4,552	0.1584	0.3651	0	1
Alcohol presence missing	4,552	0.1147	0.3187	0	1
Youth (< 30yrs)	4,475	0.5515	0.4974	0	1
Senior (> 60yrs)	4,475	0.0473	0.2123	0	1
Female	4,501	0.3595	0.4799	0	1
Driver Restraint Factors					
Airbag	4,552	0.4251	0.4944	0	1
Airbag missing	4,552	0.0422	0.2010	0	1
Seat Belt	4,552	0.5529	0.4973	0	1
Seat Belt missing	4,552	0.2244	0.4173	0	1
Ejection	4,464	0.0223	0.1475	0	1

sity, 19% rolled over up to one complete turn, 2.4% took from one-plus to two compete turns, and 0.6% took more than two complete turns. Among the major vehicle manufacturers, General Motors (Buick, Cadillac, Chevrolet, Oldsmobile, Pontiac, GMC, Saturn) had the most vehicles in the sample, followed by Ford (Ford, Lincoln, Mercury), Chrysler (Chrysler, Jeep, Dodge), Toyota, and Honda (Acura, Honda). This ordering is in line with the market share of vehicle manufacturers in the United States. Although the data set used may be biased toward the more severe crashes, given that these are all tow-away crashes, the distribution of injury severity variables seems reasonable, with 55% of the crashes involving no injury and 0.7% involving severe or maximum injuries.

Rollover Propensity and Intensity Models

Table 3 presents the results for rollover propensity and intensity, given a rollover. The goodness of fit for the binary model seems reasonable, and the parameter signs are as expected. The negative binomial model was found to be preferable to the Poisson model, as indicated by the significance of the overdispersion parameter, α (p-value < .05). The goodness of fit for the negative binomial model is reasonable, and the parameters have the expected signs. In the following discussion, p-values below .10 are considered marginally significant, and p-values below .05 are considered statistically significant.

The two models show largely similar results, although they capture slightly different aspects of rollovers. Given a crash, SUVs and

TABLE 3 Models for Rollover Propensity and Intensity in Crashes

	Binary Logit Regression				Negative Binomial Regression			
Independent Variable	**Beta**		**P-value**	**Marginal**	**Beta**		**P-value**	**Factor Change**
Constant	-6.8210	***	0.0000		-4.7667	***	0.0000	
Vehicle Factors								
SUV	1.6332	***	0.0000	0.2900	0.9346	***	0.0000	2.5461
Van	0.2013		0.6850	0.0271	-0.1874		0.5670	0.8291
Pickup	0.5113	*	0.0710	0.0723	0.4139	**	0.0400	1.5126
Chrysler	0.4369		0.3140	0.0622	0.1430		0.6530	1.1537
Ford	-0.3145		0.3690	-0.0374	-0.4070		0.1130	0.6657
General Motors	0.5553		0.1280	0.0744	0.1905		0.4430	1.2098
Honda	0.5928		0.2290	0.0892	0.5148		0.2120	1.6733
Toyota	0.5095		0.2020	0.0745	0.2539		0.3910	1.2891
Crash Factors								
Blowout/flat tire	1.5031	***	0.0060	0.2843	0.4292		0.1310	1.5361
Drive off road	2.3518	***	0.0000	0.3830	2.0834	***	0.0000	8.0321
Control/traction loss	2.7930	***	0.0000	0.4008	2.3836	***	0.0000	10.8444
Avoid collision	2.4001	***	0.0000	0.4804	2.1299	***	0.0000	8.4142
End departure	-0.7025		0.5830	-0.0697	-0.4645		0.6500	0.6284
Other type of accident	1.9564	**	0.0220	0.3998	2.1533	***	0.0030	8.6128
Speed limit <40 km/h	-0.1978		0.8280	-0.0233	0.2544		0.5740	1.2897
Speed limit >80 km/h	1.0824	***	0.0000	0.1571	1.1992	***	0.0000	3.3175
Roadway Factors								
Curve	0.4278	*	0.0600	0.0553	0.2211		0.1920	1.2475
Uphill	0.3885		0.2800	0.0539	-0.0636		0.7800	0.9384
Downhill	0.5627	**	0.0270	0.0778	0.4210	***	0.0220	1.5235
Other roadway profile	-1.4698	*	0.0980	-0.1116	-0.7573		0.3920	0.4689
Asphalt road	1.4662	***	0.0000	0.1260	1.1041	***	0.0000	3.0165
Gravel road	4.6423	***	0.0000	0.8021	2.5894	***	0.0000	13.3216
Dirt road	2.7690	***	0.0010	0.5774	1.3315	***	0.0010	3.7868
Other type of road	0.6298		0.3670	0.0974	0.7708		0.2280	2.1615
Wet roadway condition	-0.2408		0.4440	-0.0289	-0.6899	***	0.0030	0.5016
Snow roadway condition	-0.8996	*	0.0590	-0.0856	-1.3488	***	0.0000	0.2596
Ice roadway condition	0.0564		0.8940	0.0072	-0.4381		0.1320	0.6452
Sand roadway condition	2.7184	***	0.0030	0.5766	1.2109	***	0.0010	3.3565
Other roadway condition	0.4021		0.7040	0.0580	0.9107		0.2790	2.486
Dark	-0.2274		0.4560	-0.0278	-0.2483		0.2390	0.7802
Darklight	-1.3098	***	0.0000	-0.1271	-1.1266	***	0.0000	0.3241
Dawn	0.4296		0.3550	0.0623	0.0269		0.9240	1.0272
Dusk	0.4760		0.4420	0.0701	0.5095		0.2220	1.6644
Driver Factors								
Alcohol presence	0.8254	***	0.0040	0.1256	0.8178	***	0.0000	2.2656
Alcohol presence missing	0.3767		0.3570	0.0530	0.5949	*	0.0680	1.8128
Youth (< 30yrs)	0.2387		0.3080	0.0298	0.2005		0.2210	1.222
Senior (> 60yrs)	0.5583		0.2650	0.0834	0.3381		0.3220	1.4023
Female	0.3474		0.1320	0.0454	0.2801	*	0.1030	1.3232
Alpha					2.7165	***	0.0000	
Number of observations	4,048				4,048			
Log-likelihood function	-1,579.4740				-2,125,160.2			
Restricted log-likelihood	-2,189.6580				-2,363,183.6			
McFadden-R^2	0.2610				0.101			
Wald x^2	169.190				345.480			

NOTE: Marginal effects are the changes in the dependent variable with a unit change in the independent variable. Robust standard errors were applied. *** = significant at a 99% confidence level; ** = significant at a 95% confidence level; * = significant at a 90% confidence level.

pickups are significantly more likely than passenger cars to roll over and they are also more likely to experience more intense rollovers than passenger cars, which is the "base" (excluded category) for the vehicle platform variable. The binary model shows that SUVs have a 0.29 greater probability (29% greater chance) of a rollover when all else is held equal. The binary model shows no major differences among manufacturers. Interestingly, tire blowout is associated with a greater rollover propensity but not necessarily intensity, increasing the chance of a rollover by 28%. Other factors that have particularly large effects are gravel roads and loss of control or traction.

One way to interpret the results is to examine the factor change in a parameter. Factor change is also referred to as incidence rate ratio. The last column of Table 3 reports the factor changes for the intensity rollover model. For SUVs, the factor is exp(0.9346) = 2.55, which means that SUVs increase the expected number of quarter turns by a factor of 2.55, or equivalently, they increase the expected number of turns by 155% [$100 \cdot (2.55 - 1)$] compared with the number for passenger cars.

Crash factors associated with increasing rollover intensity include driving off the road (present in 34% of the crashes), loss of control or traction (present in nearly 43% of the crashes), and avoiding collisions; see Figure 1 for a description of these variables. The base for this set of variables is forward impact (Collisions 11, 12, and 13 in Figure 1). These factors need further investigation, as they are clearly related to increased rollover propensity and intensity. Strategies that can effectively reduce the chances of loss of control and driving off the road can reduce the risk of rollover.

Many roadway factors increase rollover intensity; salient among these are posted speeds greater than 80 km/h relative to the base speed of 40 to 80 km/h; downhill slopes relative to level roads (present in 25% of crashes); and asphalt, gravel, and sand or dirt roads relative to concrete roads (the base). Although curves are associated with a greater rollover propensity than straight roads, they are not associated with greater rollover intensity. Sand roads are also associated with more rollovers. Wet and snowy roads relative to dry roads are associated with a lower rollover intensity. Although darkness is not statistically significant, lighted conditions during darkness (referred to as "Darklight" in Tables 2, 3, and 6) are associated with a lower rollover propensity and intensity. Among driver factors, alcohol presence (reported in almost 19% of the crashes) was statistically significant, increasing both the propensity and the intensity of rollovers, given a crash.

Several interactions between SUVs and other variables were evaluated, such as curves and seat belt use. However, they did not show statistical significance and were dropped from the final model.

Injury Severity Model

Tables 4 and 5 show the driver injury results. The key difference is that the model in Table 4 estimates the effect of rollover as a single indicator variable and the model in Table 5 estimates rollover intensity effects by using several indicator variables. A likelihood ratio test indicated that it is statistically justified (5% level) to keep all the rollover indicator variables together in the model. The models fit reasonably well, and the parameters have the expected signs. As expected, the model in Table 4 shows that rollovers increase injury severity, and the increase in the chance of injury is nearly 14%, as indicated by the marginal effects. The model in Table 5 shows that despite the insignificance of some rollover indicator variables, the trend is that more quarter turns increase injury severity. This effect happens to be nonlinear, with a significant increase in injury severity beyond one complete turn. The marginal effects in Table 5 show, for instance, that there is a nearly 15% greater chance of injury if the vehicle rolls over 0.75 to 1 turn than if there is no rollover, but the chance jumps to 44% if the vehicle rolls over between 1.25 and 1.5 turns.

Focusing on Table 5, the SUV variable is negative and statistically significant (at the 5% level), indicating that the injury propensity for drivers in these vehicles is lower than that for drivers in passenger cars. Perhaps these larger and sturdier vehicles are harder to penetrate and are more crashworthy. Therefore, SUVs might better dampen the direct energy transfer to the occupants (e.g., lower the chance of objects directly piercing the body) or the indirect energy transfer (e.g., reduce the possibility that different parts of the body travel at different speeds before coming to a stop), or both. Importantly, SUVs reduce the chance of injury by nearly 24%. This finding is discussed in the next section. The manufacturer effects are not statistically significant; also, the interactions of the manufacturer with SUVs were not statistically significant, so they were dropped from the final model specification.

Among crash factors, driving off the road and losing control of the vehicle were associated with greater injury severity, as expected. Speeding is also associated with higher injury levels. Other variables that significantly increase single-vehicle injury severity include young drivers, female drivers (who are involved in 35% of the crashes), and ejection from the vehicle. The factors that reduce injury severity include the wearing of seat belts (which were worn in 55% of the crashes) and the presence of air bags, although the last variable was not statistically significant. The variable for "seat belt missing" was negative and significant, which implies lower injury levels in crashes when the seat belt variable was not recorded. The interaction between seat belt use and SUVs was not statistically significant and was dropped from the final model specification.

Path Analysis

It is clear that SUVs are more likely to roll over, and because rollovers increase injury severity, SUVs will indirectly increase driver injury severity. However, SUVs directly reduce driver injury severity, compensating for their indirect effect. The questions are, which effect is larger and what is the net effect of SUVs? Path analysis allows the probabilities of binary and ordered logit models to be compared by using the structure outlined in Figure 2. The impact of each variable on rollovers is calculated by using the marginal effects of the binary logit model, while the impact of each variable on injury levels is calculated by using the marginal effects for the ordered logit model.

Path analysis allows quantification of the net effect or total effect of SUVs on driver injury severity (Table 6). The total effect is the sum of the direct and indirect effects manifested through rollovers. SUVs increase the probability of rollovers by 0.290, calculated by using the marginal effects from the logit model. The injury severity model (Table 4) shows that rollovers in turn increase the probability of minor to maximum injury by 0.138, so the indirect effect of SUVs on increasing injury probability is 0.040 ($0.290 \cdot 0.138$). SUVs directly reduce the probability of driver injury by 0.238. Therefore, the net effect of SUVs compared with the net effect of passenger cars is to reduce driver injury probability by 0.198 (or to reduce the chance by 19.8%).

The injury severity model in Table 5 shows that even for the most intense rollovers (three or more turns), the increase in the probability of a minor to a maximum injury is 0.441, so the indirect effect of SUVs on injury probability is 0.128 ($0.290 \cdot 0.441$). SUVs directly reduce the probability of injury by 0.228 in this model. The net safety effect of SUVs is still beneficial to the driver, which reduces the chances of injury by 10%. The key point is that by decomposing the two effects, it is found that the direct protective crashworthiness effect of SUVs is greater than their harmful indirect rollover effect.

The results also show that posted speed limits in excess of 80 km/h increase both the rollover intensity and the injury severity. As expected, it has a greater total effect on injury severity, equaling 0.1483. Note that the effects presented here are based on the marginal effects of unstandardized coefficients. Analysis results based on standardized coefficients are available from the authors.

TABLE 4 Ordered Logit Model of AIS Injury (Binary Rollover)

	Ordered Logit								
Independent Variable	Beta	P-value	Marginal Effects – Injury Level						
			None	Minor	Moderate	Serious	Severe	Critical	Max
Rollover Factors									
Rollover	0.5542 ***	0.0130	-0.1377	0.0854	0.0360	0.0113	0.0027	0.0019	0.0004
Vehicle Factors									
SUV	-1.0322 ***	0.0000	0.2383	-0.1727	-0.0463	-0.0135	-0.0031	-0.0022	-0.0005
Van	-0.8591 **	0.0400	0.1970	-0.1451	-0.0368	-0.0106	-0.0025	-0.0017	-0.0004
Pickup	-0.0894	0.7880	0.0222	-0.0149	-0.0051	-0.0015	-0.0004	-0.0002	-0.0001
Chrysler	0.3425	0.3580	-0.0854	0.0534	0.0221	0.0069	0.0016	0.0011	0.0003
Ford	0.2453	0.4700	-0.0612	0.0395	0.0150	0.0046	0.0011	0.0008	0.0002
General Motors	-0.0692	0.8300	0.0172	-0.0115	-0.0040	-0.0012	-0.0003	-0.0002	0.0000
Honda	-0.1625	0.6920	0.0401	-0.0273	-0.0090	-0.0027	-0.0006	-0.0004	-0.0001
Toyota	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crash Factors									
Drive off road	1.0240 ***	0.0000	-0.2505	0.1508	0.0683	0.0219	0.0052	0.0036	0.0008
Control/traction loss	0.5947 **	0.0330	-0.1471	0.0959	0.0356	0.0109	0.0026	0.0018	0.0004
Avoid collision	0.9635 **	0.0300	-0.2331	0.1233	0.0739	0.0249	0.0060	0.0042	0.0009
End departure	0.7594	0.3330	-0.1855	0.1008	0.0573	0.0190	0.0045	0.0032	0.0007
Other type of accident	0.8469	0.1120	-0.2050	0.1067	0.0661	0.0223	0.0054	0.0037	0.0008
Speed limit <40 km/h	0.4824	0.3210	-0.1198	0.0710	0.0334	0.0107	0.0025	0.0018	0.0004
Speed limit >80 km/h	0.5100 **	0.0160	-0.1267	0.0805	0.0320	0.0099	0.0023	0.0016	0.0004
Driver Factors									
Alcohol presence	0.0873	0.7570	-0.0217	0.0143	0.0052	0.0016	0.0004	0.0003	0.0001
Alcohol presence_mis	0.3438	0.3080	-0.0857	0.0534	0.0223	0.0070	0.0016	0.0011	0.0003
Youth (< 30yrs)	-0.5136 **	0.0260	0.1273	-0.0832	-0.0306	-0.0094	-0.0022	-0.0015	-0.0003
Senior (> 60yrs)	0.3893	0.3220	-0.0970	0.0595	0.0258	0.0081	0.0019	0.0013	0.0003
Female	0.7893 ***	0.0000	-0.1947	0.1221	0.0501	0.0157	0.0037	0.0026	0.0006
Driver Restraint Factors									
Airbag	-0.0552	0.8140	0.0137	-0.0091	-0.0032	-0.0010	-0.0002	-0.0002	0.0000
Airbag missing	-0.3669	0.5290	0.0892	-0.0626	-0.0187	-0.0055	-0.0013	-0.0009	-0.0002
Seat Belt	-1.1425 ***	0.0000	0.2781	-0.1698	-0.0742	-0.0237	-0.0056	-0.0039	-0.0009
Seat Belt missing	-1.1393 ***	0.0000	0.2592	-0.1891	-0.0495	-0.0144	-0.0033	-0.0023	-0.0005
Ejection	2.0670 ***	0.0000	-0.4142	0.0687	0.2025	0.0949	0.0254	0.0184	0.0042
μ_1	0.2275								
μ_2	2.3739								
μ_3	3.7088								
μ_4	4.9442								
μ_5	5.7312								
μ_6	7.4291								
Number of observations	3,883								
Log-likelihood function	-3,751.7450								
Restricted log-likelihood	-4,187.248								
McFadden-R^2	0.1040								
Wald x^2	175.46								

NOTE: Marginal effects are the changes in the dependent variable with a unit change in the independent variable. Robust standard errors were applied. *** = significant at a 99% confidence level; ** = significant at a 95% confidence level; Alcohol presence_mis = alcohol presence missing.

LIMITATIONS

The AIS available in NASS-CDS is based on information from several sources that include police reports, newspapers, medical records, and interview information. This limits the potential biases relating to injury severity measurement, although it does not eliminate them. Additionally, the relative distribution of injury severity was reasonable; that is, there are few maximum and critical injuries and many more minimum or no-injury cases, although NASS-CDS crashes are more severe than the severity for the population of crashes, given that they are all tow-away crashes. Thus, in this analysis severe crashes have a relatively greater influence than nonsevere crashes.

Furthermore, the assumption made in the analysis, that is, that there is no difference in underreporting of rollover and nonrollover crashes with vehicle platform, is recognized. Given that light trucks are more likely to be driven on longer trips on rural roads and given that they have a greater rollover tendency, perhaps their rollovers are underreported. If this were the case, then their rollover probability will be greater than that captured in the present analysis, and thus their indirect effect on (increasing) injury severity could be larger.

Certain measurement errors are possible. Specifically, the restraint and air bag variables can be problematic, even though the data in NASS-CDS are the most thorough and comprehensive. The more problematic variable is the police-reported seat belt use. The problem can manifest itself in two ways. First, people who were not wearing seat belts during crashes are likely to report that they were (if they survive the crash), so this will make the injury model parameter estimates more conservative; that is, the effects of seat belts are possibly overestimated. Second, as expected, there are quite a few missing values for the seat belt variable. To address this problem, a dummy

TABLE 5 Ordered Logit Model of AIS Injury (Rollover Frequency)

	Ordered Logit								
Independent Variable	**Beta**	**P-value**	**Marginal Effects – Injury Level**						
			None	**Minor**	**Moderate**	**Serious**	**Severe**	**Critical**	**Max**
Rollover Factors									
Rolled 0.25 to 0.5 turn	0.1307	0.6060	-0.0326	0.0217	0.0078	0.0022	0.0005	0.0003	0.0001
Rolled 0.75 to 1 turn	0.6352 *	0.0640	-0.1567	0.0924	0.0451	0.0136	0.0031	0.0021	0.0005
Rolled 1.25 to 1.5 turns	2.2785 ***	0.0000	-0.4353	0.0455	0.2294	0.1079	0.0279	0.0200	0.0046
Rolled 1.75 to 2 turns	1.5139 ***	0.0060	-0.3334	0.1179	0.1415	0.0514	0.0122	0.0085	0.0019
Rolled 2.25 to 2.5 turns	2.5960 ***	0.0000	-0.4572	-0.0168	0.2566	0.1427	0.0393	0.0288	0.0067
Rolled 2.75 to 3 turns	0.5385	0.5450	-0.1332	0.0793	0.0379	0.0113	0.0025	0.0017	0.0004
Rolled more than 3 turns	2.4211 *	0.0570	-0.4413	0.0084	0.2440	0.1255	0.0335	0.0243	0.0056
Vehicle Factors									
SUV	-0.9774 ***	0.0000	0.2275	-0.1670	-0.0438	-0.0119	-0.0026	-0.0018	-0.0004
Van	-0.8234 **	0.0440	0.1903	-0.1419	-0.0351	-0.0095	-0.0021	-0.0014	-0.0003
Pickup	-0.1390	0.6820	0.0345	-0.0237	-0.0077	-0.0022	-0.0005	-0.0003	-0.0001
Chrysler	0.3669	0.3380	-0.0915	0.0581	0.0237	0.0069	0.0015	0.0011	0.0002
Ford	0.2558	0.4640	-0.0638	0.0420	0.0155	0.0044	0.0010	0.0007	0.0002
General Motors	-0.0395	0.9030	0.0098	-0.0067	-0.0023	-0.0006	-0.0001	-0.0001	0.0000
Honda	-0.3219	0.3950	0.0788	-0.0558	-0.0166	-0.0046	-0.0010	-0.0007	-0.0002
Toyota	-0.0861	0.8260	0.0214	-0.0147	-0.0048	-0.0014	-0.0003	-0.0002	0.0000
Crash Factors									
Drive off road	0.9741 ***	0.0010	-0.2388	0.1480	0.0640	0.0190	0.0043	0.0029	0.0007
Control/traction loss	0.6593 ***	0.0170	-0.1630	0.1080	0.0392	0.0112	0.0025	0.0017	0.0004
Avoid collision	0.9535 **	0.0330	-0.2306	0.1258	0.0727	0.0226	0.0051	0.0035	0.0008
End departure	0.7701	0.3320	-0.1877	0.1044	0.0580	0.0179	0.0040	0.0028	0.0006
Other type of accident	0.8427	0.1290	-0.2038	0.1093	0.0655	0.0205	0.0047	0.0032	0.0007
Speed limit <40 km/h	0.4584	0.3170	-0.1139	0.0696	0.0312	0.0092	0.0021	0.0014	0.0003
Speed limit >80 km/h	0.3751 *	0.0840	-0.0934	0.0614	0.0228	0.0065	0.0015	0.0010	0.0002
Driver Factors									
Alcohol presence	0.0745	0.7920	-0.0186	0.0125	0.0044	0.0012	0.0003	0.0002	0.0000
Alcohol presence_mis	0.3401	0.3060	-0.0848	0.0541	0.0218	0.0063	0.0014	0.0010	0.0002
Youth (< 30yrs)	-0.5309 **	0.0220	0.1316	-0.0876	-0.0314	-0.0089	-0.0020	-0.0014	-0.0003
Senior (> 60yrs)	0.4363	0.2600	-0.1085	0.0673	0.0292	0.0086	0.0019	0.0013	0.0003
Female	0.7588 ***	0.0000	-0.1874	0.1204	0.0476	0.0138	0.0031	0.0021	0.0005
Driver Restraint Factors									
Airbag	-0.0892	0.7020	0.0222	-0.0150	-0.0051	-0.0014	-0.0003	-0.0002	0.0000
Airbag missing	-0.3563	0.5400	0.0869	-0.0619	-0.0180	-0.0050	-0.0011	-0.0007	-0.0002
Seat Belt	-1.1736 ***	0.0000	0.2853	-0.1775	-0.0759	-0.0226	-0.0051	-0.0035	-0.0008
Seat Belt missing	-1.1363 ***	0.0000	0.2593	-0.1920	-0.0487	-0.0132	-0.0029	-0.0020	-0.0004
Ejection	1.7080 ***	0.0000	-0.3654	0.1109	0.1640	0.0625	0.0151	0.0106	0.0024
μ_1	0.1208								
μ_2	2.3241								
μ_3	3.7192								
μ_4	4.9937								
μ_5	5.7875								
μ_6	7.4928								
Number of observations	3,883								
Log-likelihood function	-3,697.4900								
Restricted log-likelihood	-4,187.2480								
McFadden-R^2	0.1170								
Wald x^2	204.9400								

NOTE: Marginal effects are the changes in the dependent variable with a unit change in the independent variable. Robust standard errors were applied. *** = significant at a 99% confidence level; ** = significant at a 95% confidence level; * = significant at a 90% confidence level; Alcohol presense_mis = alcohol presence missing.

variable was created for the missing data and was included in the model to control for the missing values.

CONCLUSIONS

This paper contributes valuable information about the effects of SUVs on rollover propensity and intensity and driver injury. While rollovers are important safety performance measures, they should be analyzed together with the resulting injuries. This study takes the first steps toward viewing rollovers and injuries as separate yet related phenomena. Although the study is limited by (*a*) the quality of the NASS-CDS data, which are perhaps biased toward more severe crashes, and (*b*) the inherent assumptions of regression models, the analysis presented is both rigorous and insightful. Stratification of the random sample is accounted for by weighting of the data. After controlling for driver, vehicle, and roadway factors, it was found that SUVs are still more likely than passenger cars to roll over. SUVs also experience

TABLE 6 Direct, Indirect, and Total Effects of Key Variables on Injury Severity

Total effects using unstandardized coefficients					
Variables	**Direct effect on injury**	**Direct effect on rollover**	**Direct effect of rollover on injury**	**Indirect effect on injury**	**Total effects**
SUV	-0.2383	0.29	0.1377	0.0399	-0.1984
Van	-0.197	0.0271	0.1377	0.0037	-0.1933
Pickup	-0.0222	0.0723	0.1377	0.0100	-0.0122
Chrysler	0.0854	0.0622	0.1377	0.0086	0.0940
Ford	0.0612	-0.0374	0.1377	-0.0051	0.0561
General Motors	-0.0172	0.0744	0.1377	0.0102	-0.0070
Honda	-0.0401	0.0892	0.1377	0.0123	-0.0278
Toyota	0	0.0745	0.1377	0.0103	0.0103
Blowout/flat tire		0.2843			0.2843
Drive off road	0.2505	0.383	0.1377	0.0527	0.3032
Control/traction loss	0.1471	0.4008	0.1377	0.0552	0.2023
Avoid collision	0.2331	0.4804	0.1377	0.0662	0.2993
End departure	0.1855	-0.0697	0.1377	-0.0096	0.1759
Other type of accident	0.205	0.3998	0.1377	0.0551	0.2601
Speed limit <40 km/h	0.1198	-0.0233	0.1377	-0.0032	0.1166
Speed limit >80 km/h	0.1267	0.1571	0.1377	0.0216	0.1483
Curve		0.0553			0.0553
Uphill		0.0539			0.0539
Downhill		0.0778			0.0778
Other roadway profile		-0.1116			-0.1116
Asphalt road		0.126			0.126
Gravel road		0.8021			0.8021
Dirt road		0.5774			0.5774
Other type of road		0.0974			0.0974
Wet roadway condition		-0.0289			-0.0289
Snow roadway condition		-0.0856			-0.0856
Ice roadway condition		0.0072			0.0072
Sand roadway condition		0.5766			0.5766
Other roadway condition		0.058			0.058
Dark		-0.0278			-0.0278
Darklight		-0.1271			-0.1271
Dawn		0.0623			0.0623
Dusk		0.0701			0.0701
Alcohol presence	0.0217	0.1256	0.1377	0.0173	0.0390
Alcohol presence_mis	0.0857	0.053	0.1377	0.0073	0.0930
Youth (< 30yrs)	-0.1273	0.0298	0.1377	0.0041	-0.1232
Senior (> 60yrs)	0.097	0.0834	0.1377	0.0115	0.1085
Female	0.1947	0.0454	0.1377	0.0063	0.2010
Airbag	-0.0137				-0.0137
Airbag missing	-0.0892				-0.0892
Seat Belt	-0.2781				-0.2781
Seat Belt missing	-0.2592				-0.2592
Ejection	0.4142				0.4142

NOTE: Alcohol presence_mis = alcohol presence missing.

more intense rollovers. By linking rollover propensity and intensity to injury severity, it was found that rollovers strongly increase driver injury severity, as expected. The interesting part is that SUVs also protect their occupant drivers during crashes because of their greater mass and crashworthiness. This direct protective effect of SUVs (on injury severity) exceeds their harmful indirect effect through rollovers. Therefore, the net effect of SUVs on injury severity is to reduce injury severity, given a crash. These new insights indicate that when injury severity is included as a performance measure of safety, in addition to rollovers, SUVs perform better than passenger cars.

The authors believe that consumers should be informed not only about the higher rollover propensities and intensities of SUVs but also about their greater crashworthiness effect (at least in single-vehicle collisions). Clearly, a more comprehensive study is desirable, given that this study relates to only a sample of single-vehicle crashes and does not consider the role of SUVs in multivehicle collisions. Importantly, the research did not investigate consumers' purchasing decisions, and it should not be interpreted as encouraging people to buy SUVs (because of their greater crashworthiness). Interestingly, Kockelman asserts that, on average, new SUVs have an implicit subsidy of $4,400, with about $1,600 attributed to deaths among non-SUV occupants (*18*). Additionally, in two-vehicle crashes, SUV and pickup drivers experienced less severe injuries, although the occupants of their collision partners experienced more severe injuries (*19*). Clearly, there is a need to investigate this issue further.

The results also point to certain factors that, when investigated and addressed, can perhaps lower the numbers of rollovers and injury severity. These factors include more attention to tire failures, certain types of rollovers (driving off the road, loss of control and traction, and avoiding collisions), dangerous curves and down slopes, posting of speed limits, removal of sand and dirt, alcohol and restraint use, and gender differences. Future research should also investigate why people lose control of their vehicles and the effects of new electronic stability systems.

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