A COMPARISON OF ROLLOVERS WITH NON-ROLLOVERS AND ANALYSIS OF INJURY SEVERITY IN LARGE TRUCK CRASHES

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ABSTRACT--Society pays a cost for truck crashes in terms of operational disruptions, injuries and loss of life. Among the 700 large-truck occupant fatalities that occur every year, about 400 occur in single-vehicle truck crashes and many involve rollovers. This study attempts to understand how truck driver behaviors, vehicle factors and crash events influence large-truck rollovers and occupant injuries in single-vehicle crashes. A relatively clean crash and inventory database, named HSIS (Highway Safety Information System) is used for crash analysis. The data come from police-reported crashes in North Carolina for 1996-1998. Over this three-year period, truck rollovers occurred in almost 30% of the 5,163 single-vehicle truck crashes. Rollover propensity is investigated using binary probit models, and injury severity is examined using ordered probit models. Injury severity is measured on the KABCO scale from fatal, severe, moderate, minor to no injury. New insights that emerge about the direct and indirect effects of high-risk factors imply that through a combination of countermeasure strategies, we must attempt to:

1) Reduce dangerous truck-driver behaviors, particularly speeding, reckless driving, alcohol and drug use, non-use of restraints, and traffic control violations.

2) Reduce truck exposure to roadways that have dangerous geometry, particularly more curves.

3) Explicitly deal with the transportation of hazardous materials and with reducing post-crash fires.

INTRODUCTION

Truck rollovers and the resulting safety problems have serious consequences for the traveling public, trucking companies, and truck drivers. For the traveling public, single-vehicle truck crashes can cause traffic congestion and disruptions in supply of certain goods; hazardous truck cargo can be dangerous to humans and the environment if spilled. For the trucking organizations and truck owner-operators, crashes entail delivery disruption, uncertainty and higher overall transportation costs. For truck drivers, crashes represent an occupational hazard. A significant number of truck drivers die from injuries in roadway crashes. Specifically, there were 702 large-truck occupant deaths in roadway crashes in the US during 1998, of which about 90% were truck-drivers. A majority of the truck-occupants who died in crashes were riding tractor-trailers (498 in 1998) and about two-thirds occurred in single-vehicle crashes (Insurance Institute for Highway Safety, 1998). Therefore, this study focuses on analyzing single-vehicle truck crashes.

Owing to their performance, size, maneuverability, design and higher center of gravity trucks have a high rollover propensity with many truck rollovers resulting from the vehicle leaving the roadway and tripping. In response to the need to understand the behavioral and vehicle factors associated with such large truck rollovers in real-life situations, this study applies rigorous statistical methods to analyze North Carolina HSIS (Highway Safety Information System) data from 1996 to 1998. HSIS is a relatively high-quality crash and road inventory database. North Carolina data are used specifically because there are many truck routes in the state and there are a variety of roadway designs, terrain and weather, exposing trucks to a diverse set of conditions. The key research questions are:

- What behavioral, vehicle and roadway factors increase the propensity of single-vehicle truck rollovers?
- How do rollovers and other driver, vehicle and roadway factors impact the severity of injuries to truck occupants?

HYPOTHESES

Given the lack of knowledge regarding single-vehicle large truck crashes, we hypothesized the effects of several driver, vehicle and roadway factors on truck rollovers and injury severity. The issue of truck crash injury severity is complicated for several reasons (see Proceedings of Conferences on Large Truck Safety, 1997, 1999 and 2002 (1)). Large trucks are particularly prone to rollovers, and rollovers in turn are typically associated with higher injury severity. Among large trucks, the occupational hazards faced by those driving single-unit trucks versus combination vehicles can vary. On the one hand, combination trucks might be less maneuverable in crash situations, and therefore more likely to roll over and cause more severe occupant injuries. On the other hand, larger combination vehicles may provide greater occupant protection in crash situations (due to their larger mass) and drivers of combination trucks may compensate for their lack of maneuverability by driving more carefully.

A relatively common problem with trucks is their performance. Poor truck performance can be caused by defective equipment, in particular defective truck brakes, which can lead to more severe injuries during collisions. In fact, Jones and Stein (2) found that brake defects were quite common and were found in 56% of the tractor-trailers involved in crashes. Among other truck factors, vehicle age and manufacturer might have different effects on rollovers and injuries.

Another set of risk factors relate to the truck driver. Dangerous driver behaviors such as speeding, reckless driving and driving under the influence of alcohol, as well as fatigue and sleep deprivation, can significantly increase the risk of a severe crash. For example, fatigued and sleepy drivers are less likely to take last-second evasive actions to avoid a collision and, given a collision, mitigate its severity. Braver et al. (3) found that fatigue and long driving hours have been implicated as risk factors in truck crashes. They reported that almost three-fourths of truck drivers surveyed violated hours-of-service rules. A primary impetus for violating rules appeared to be economic factors (e.g., tight delivery schedules and low payment rates), as well as driver, job, and vehicle characteristics. Furthermore, speeding (and higher striking speed) is expected to result in more forceful impacts and therefore more severe injuries to the occupants. Though truck occupants are increasingly using restraints, they are often inconvenient and uncomfortable on long trips. Clearly, the lack of restraint use is likely to increase the risk of injuries in a collision. Stoohs et al. (4) found that obesity correlates highly with certain sleep disorders that cause daytime sleepiness and that truck drivers who are obese and have these sleep disorders are twice as likely to be involved in a crash as truck drivers who do not have a sleep disorder.

Transportation of hazardous materials including gasoline, diesel and fuel oil shipments can complicate the work environment for truck drivers and possibly increase their injury risk during collisions, e.g., due to post-crash fires—Figure 1 shows post-crash fire and rollover crash situations. The risk of severe truck crashes can also increase due to longer stopping distances, particularly in wet and slippery road conditions when the ability to control large trucks deteriorates significantly. However, truck drivers might over-compensate by driving slowly and carefully or they might under-compensate for wet road surfaces. Another risk factor is likely to be darkness. Rollovers and more severe injuries may occur in darkness because it inhibits a driver's visibility, allowing less time for last-second maneuvering and braking before tripping/impact. Indeed, Cate and Richards (5) found that rollover crashes in Tennessee were most common in the overnight hours (suggesting that these crashes may be related to driver fatigue and diminished sight distances). Improving roadway lighting may help mitigate the effects of darkness on these crashes.

Within roadway factors, heavy trucks might be harder to control on grades and curves, largely due to their speed and inertia. Therefore, rollovers and injuries may be more likely to occur on curves and grades. Cate and Richards (5) found that the greatest rollover risk was posed by curves producing readings of five degrees or more. Furthermore, the recent increases in speed limits, if associated with higher actual speeds, can limit a driver's ability to slow down to reduce the force of impact. Therefore, more rollovers and severe injuries are expected on roadways that allow higher speeds, all else being equal.

Finally, certain combinations of factors (interactions) might be associated with higher injury severity. For instance, crashes that occur on curves and result in rollovers may be more severe; or truck rollovers where post-crash fires occurred may be more severe.

METHOD

The 1996-1998 North Carolina HSIS database contains information on over 400,000 crashes and over 700,000 vehicles involved in these crashes (Figure 2). During this three-year period, rollovers occurred in 1,503 (almost 30%) of the 5,163 single-vehicle truck crashes. A majority of the HSIS data required recoding in order to isolate relevant factors for this analysis. For example, the vehicle make HSIS variable was recoded into different indicator variables for each large truck manufacturer, such as Chevrolet, International, Mack, and Toyota. Vehicle year was also recoded into pre-1992 (1) and post-1992 (0) partly because about half of the vehicles in the data set were manufactured pre-1992. HSIS classifies injury severity into five different categories according to Killed (4), Severely Injured (3), Moderately Injured (2), Minor injury (1), and No injury (0).

We first analyzed descriptive statistics (frequency analysis, means, and variances) and explored relationships in the data using cross-tabulations. Then multivariate statistical techniques were used to examine the effects of several factors individually and jointly and account for inter-dependencies among explanatory variables. Binary probit models were estimated to analyze rollover propensity, given a crash, and the ordered probit model to analyze injury severity, given a crash. The advantage of ordered probability models is that they can capture the qualitative differences between different injury categories, e.g., the effect of a particular variable such as truck type or year of manufacture on the likelihood of a fatality, differently from its influence on the likelihood of a minor or incapacitating injury (also see O'Donnell and Connor (6) and Duncan, Khattak and Council (7)). This model uses the following form:

$$y^* = \boldsymbol{\beta}'\mathbf{x} + \varepsilon$$

Where y^* is the dependent variable (injury severity) coded as 0, 1, 2, 3, 4; $\boldsymbol{\beta}'$ is the vector of estimated parameters and $\mathbf{x}$ is the vector of explanatory variables; ε is the error term, which is assumed to be normally distributed (zero mean and unit variance). A measure of goodness of fit can be obtained by calculating:

$$\rho^2 = 1 - [\ln L_b / \ln L_o]$$

Where $\ln L_b$ is the log-likelihood at convergence and $\ln L_o$ is the log-likelihood computed at zero. This measure is bounded by 0 and 1. As the model fit improves, ρ^2 increases (Greene (8)). Finally, computation of marginal effects is particularly meaningful for the ordered probit model because the effect of variables $\mathbf{x}$ on the intermediate categories is ambiguous if only the parameter estimates are available.

RESULTS

Over the three-year period, truck rollovers occurred in nearly 30% of the 5,163 single-vehicle truck crashes. Though most crashes resulted in no injuries to the truck occupants (64.7%), 0.7% crashes turned out to be fatal, 3.9% involved severe injuries, 13.2% moderate injuries, and 17.2% minor injuries. Rollovers were more likely to result in injury, as expected. In fact, 58% of all fatal and 62% of all severe crashes involved a rollover. Single-unit trucks were involved in 47% of the crashes and the rest were combination vehicles. About 22.5% of the involved trucks were longer than 45 feet and 52% were pre-1992 models. Only 13% of all Dodge trucks and 16% of all Toyota trucks rolled over, but 36% of all Peterbilt trucks involved in multi-vehicle collisions rolled over. Though rare, alcohol and drugs were present in about 2% of the crashes. Thirty-five percent of the 118 single-vehicle crashes involving alcohol were rollovers, compared to 29% of single-vehicle crashes not involving alcohol. Speeding was a factor in 1,555 (30%) of the single-vehicle crashes—7% of these crashes resulted in fatal or severe injuries compared to 4% of the non-speeding crashes that resulted in fatal or severe injuries.

Large Truck Rollovers in Single-Vehicle Crashes

In the following sections, we focus on discussing the model results for statistically significant factors at the customary 95% confidence level, although the 90% confidence level is considered to be marginally significant. A positive sign in the models implies higher propensity of rollovers or injuries. Table 1 shows the binary probit model, which is statistically significant and has a reasonably good overall fit ($\rho^2 = 0.2233$). Among vehicle factors, trucks with longer trailers (greater than 45 feet) were more likely to roll over, given a crash. Surprisingly, post-1992 manufactured trucks were significantly more likely to roll over than those manufactured pre-1992. This raises concern about relatively newer model year trucks, requiring further investigation. Though many vehicle makes were included in the model, only trucks produced by Dodge and Toyota were slightly less likely (at the 90% confidence level) to roll over, while those made by Peterbilt were slightly more likely to be involved in rollovers (90% level). No statistical association was found between 1) defective truck brakes and rollovers and 2) single-unit trucks versus combination vehicles and rollover propensity.

Importantly, dangerous driving behaviors that were associated with higher rollover propensity included truck drivers cited with reckless driving, speeding (i.e., violating the speed limit or exceeding the safe speed), passing violation (i.e., passing a school bus or vehicles on a hill or curve), and alcohol/drugs. As indicated by the magnitude of the marginal effects, reckless driving has the largest influence on increasing rollover propensity.

If a truck was making a right, left or a U-turn, then the possibility of a rollover increased significantly. Driving maneuvers that are perhaps not accommodated easily by standard roadway designs can increase the rollover propensity in crash situations. It will be valuable if this risk factor can be communicated to truck drivers.

Crashes that occurred on curves were significantly more likely to involve rollovers. Approximately 43% (503 of 1176) of curve-related crashes were rollovers, while 25% (999 of 3973) of straight roadway crashes were rollovers. Clearly curves represent a rollover hazard for large trucks, although grades were not problematic in single-vehicle truck crashes. Posting signs at sharp curves to warn truck drivers of increasing rollover propensity is one way to communicate the higher risk that curves pose to trucks. Crossing a median is associated with higher rollover propensity. On the other hand, slippery road surfaces are associated with lower truck rollover propensity, perhaps due to slower and more cautious driving on slippery surfaces. Similarly, striking a tree, pole, guardrail or barrier was not as dangerous in terms of rolling over as striking other objects.

The marginal effects presented in Table 1 indicate that relatively large reductions in rollover propensity can be achieved by reducing dangerous driving behaviors; in particular reckless driving, speeding and passing violations, and alcohol/drug use. In this regard, truck driver education and enforcement are two obvious strategies that need to be investigated. Furthermore, counter-measures that can facilitate turning maneuvers for large trucks or at least warn drivers about higher rollover risks need further investigation. Preventing median crossovers and communicating with truck drivers about dangerous curves can perhaps reduce rollover propensity and require further study.

Injury Severity in All Single-Truck Crashes

Table 2 presents the ordered probit model that is statistically significant and reflects a reasonably good overall fit ($\rho^2 = 0.1350$). Injury severity among all occupants in single-vehicle truck crashes was significantly higher when a rollover occurred, as expected. The marginal effects of the ordered probit model, presented in Table 3 are interesting to note. In rollover crashes the chances of injuries are higher by 26%, i.e., the chances of minor injuries are 11% higher, moderate injuries are 12% higher, severe injuries are about 3% higher and there is a relatively small increase of 0.35% in the chances of fatalities. Thus, reducing rollover propensity will clearly reduce truck driver injury severity. As expected, with more truck occupants, injuries are more severe, perhaps due to the higher number of people exposed to crash conditions, although this relationship may also reflect the distractions that the truck drivers may experience due to the presence of others.

While Nissan trucks were associated with slightly higher injury severity, the vehicle make variables were mostly non-significant. Defective truck brakes were marginally significant (90% confidence level) and associated with higher truck-occupant injury severity. However, vehicle type (single-unit or combination) was not statistically significant in terms of injury severity.

Dangerous driving behaviors are significantly associated with higher injury severity. Consistent with other safety research, speeding, alcohol/drug use and non-use of restraints significantly increases truck occupant injury severity. Further, injury severity in a crash was significantly higher when the truck driver violated a traffic control sign or signal. The marginal effects indicate that when alcohol or drugs were involved the chance of severe injuries or fatality was about 3% higher and the chance of no injury was 20% lower. Similarly, not wearing seatbelts increased the chance of injury by about 17%. Note that some of the dangerous driving behaviors have a direct effect on injury severity as quantified in this model, and they also increase rollover propensity, indirectly increasing injury severity.

The occupants of trucks that were carrying hazardous materials were likely to receive more severe injuries, on average. This could be due to the dangerous nature of the cargo and/or circumstances. Separately, post-crash fires also increased injury severity. The marginal effects show that the presence of hazardous materials is associated with increased chances of injuries by about 16%; when there is a post-crash fire, the chances of injuries are higher by 20%. The only significant interaction (90% level) was that between post-crash fire and a rollover, indicating that rollovers and fires are a particularly dangerous combination, as one would expect.

Integrating Rollover and Injury Severity Results

When the rollover results are analyzed in conjunction with injury severity results, new insights emerge. Among roadway factors, curves are related to higher injury severity. They increase the chances of truck occupant injury by about 4%. In addition, they have significant indirect effects on injuries through rollovers, as do some other variables including reckless driving, speeding violations and alcohol presence. Specifically, curves increase the rollover propensity by about 9%, as shown by the marginal effect of curves in Table 1. Additionally, rollovers increase the chance of truck occupant injury by about 26% as shown by the marginal effect of rollover in Table 3. So the indirect effect of curves via rollovers is to increase the chances of injury by 2.4% (= 0.0920 * 0.2608 * 100). Likewise, reckless driving increases rollover propensity by about 19%, so the indirect effect of reckless driving via rollovers is to increase injury by 5%. Clearly reducing dangerous driving behaviors, e.g., through truck driver education and enforcement, can have dual benefits: Reducing rollovers and indirectly reducing injury severity as well as directly reducing truck-occupant injury severity.

Injury Severity in Single-Truck Rollover Crashes

A separate model for trucks that rolled over was estimated to understand the factors that might be particularly strong in rollover crashes (Table 2). Interestingly, compared to combination vehicles, single-unit truck occupants experienced less severe injuries after rolling over. There may be safety benefits to the single-unit vehicle design, given a rollover crash. The effect of post-crash fires in rollover crashes is almost double that of the pooled model, indicating that such fires are particularly dangerous (in terms of causing higher injuries, and perhaps burns) when rollovers are involved. This corroborates the above finding that rollovers and fires are a particularly dangerous combination.

CONCLUSIONS

This paper contributes by investigating the effects of valuable information about the effect high-risk behavioral, vehicle and roadway factors on single-vehicle truck rollovers and occupant injury severity. A key contribution of the research is to quantify the direct and indirect effects of key risk factors on occupational injuries sustained by truck occupants, mostly truck drivers.

While the Federal Motor Carrier Safety Administration (FMCSA) has instituted safety programs dealing with truck brakes, alcohol/drugs, hazardous materials, and speed management, this study points to additional programs that might be needed (not only at the federal level, but also at the state and private sector levels). First, rollover reduction programs are needed to promote countermeasure strategies that reduce rollovers by reducing reckless driving, problematic truck turning, and risky behavior on roadway curves. Second, an injury reduction program is needed to promote strategies for reducing the risk of injury to truck occupants, focusing on dangerous driving behaviors, particularly traffic control violations; speeding; alcohol and drug use; non-use of restraints; post-crash fires; and roadway features, especially curves.

Private-sector trucking firms can institute similar rollover and injury reduction programs. For example, they may contribute to rollover and injury reduction through disincentives and incentives (reflected in pay) to reduce dangerous driving behaviors and by providing drivers with greater knowledge about how to negotiate difficult turning maneuvers and informing them about the higher rollover propensity of longer trucks. Through various compensation schemes, they can target driver alcohol use and other dangerous driving violations (especially speeding, reckless driving and dangerous passing maneuvers) to reduce rollover risk. Firms should encourage restraint use and reduce truck exposure to curvy roads. Ultimately, the public and private sector stakeholders must collaborate on finding comprehensive and integrated countermeasure strategies that cover both truck rollover reduction and injury mitigation. Typical countermeasure strategies for crashes include technology, engineering, education, enforcement, encouragement and exposure reduction to dangerous roads. This study hints at where we might see greater reductions in risks, although the extent to which specific strategies can reduce truck rollover and injury risk needs further investigation.

Acknowledgment

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Authors' note

We conducted similar analysis for multi-vehicle large-truck-involved crashes (N=37,497 NC crashes). However, because the incidence of rollovers in such crashes was rather low at 1%, we decided not to model the rollovers. We estimated ordered probability models for the most injured occupant (N = 453) and driver injury (N = 446), given a crash and a rollover. These models can be requested from the PI, Dr. Khattak.

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LIST OF FIGURES AND TABLES

FIGURE 1 Post-crash fire and rollover crash.

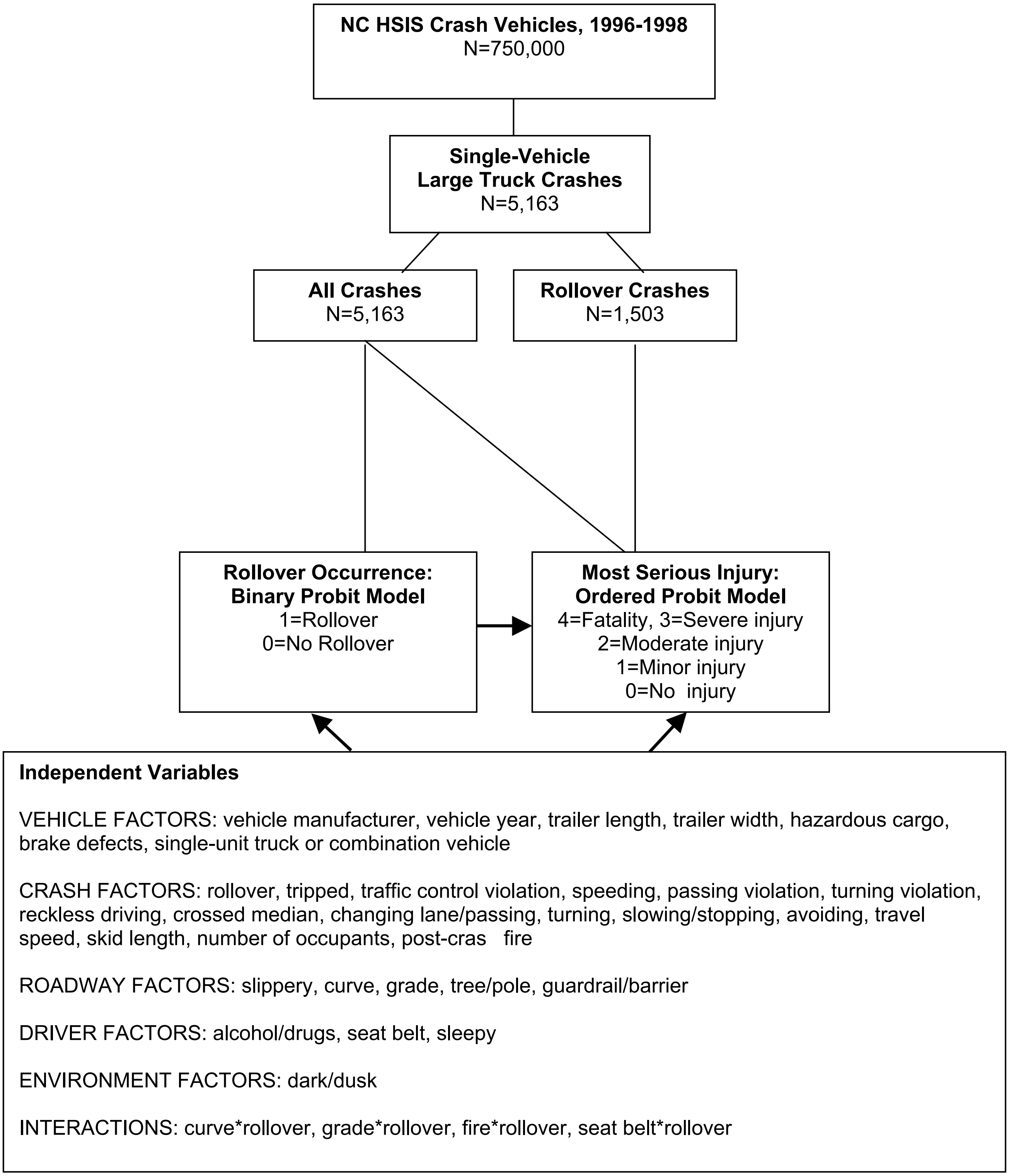

FIGURE 2 Large truck rollover analysis structure

TABLE 1 Factors Associated with Large Truck Rollovers (Binary Probit Model)

	Single-Vehicle Crash Model (N=5,098)		
Independent Variable	**Beta**	**Mean**	**Marginals**
Constant	-0.1518	1.000	-0.0474
VEHICLE FACTORS			
Chevrolet	-0.0423	0.0853	-0.0132
Dodge	-0.6005*	0.0108	-0.1874
Ford	-0.0766	0.1738	-0.0239
Freightliner	0.0331	0.1436	0.0103
GMC	0.0054	0.0557	0.0017
International	0.0107	0.1758	0.0033
Isuzu	-0.0128	0.0143	-0.0040
Kenworth	0.0286	0.0614	0.0089
Mack	0.1721	0.0565	0.0537
Nissan	-0.2088	0.0071	-0.0652
Peterbilt	0.2235*	0.0551	0.0698
Toyota	-0.4525*	0.0088	-0.1412
Volvo	-0.0129	0.0269	-0.0040
Whit	-0.0562	0.0386	-0.0175
Pre-1992 Model Year	-0.1391**	0.5190	-0.0434
Trailer length over 45’	0.1319**	0.2224	0.0412
Trailer width over 100”	0.1175*	0.3539	0.0367
Defective brakes	-0.0097	0.0316	-0.0030
Single-unit truck	0.2172	0.4706	0.0678
CRASH FACTORS			
Traffic control violation	-0.0878	0.0161	-0.0274
Speeding	0.5365**	0.3025	0.1675
Passing	0.6778*	0.0027	0.2116
Turning violation	-0.3093	0.0198	-0.0966
Reckless driving	0.6372**	0.0194	0.1989
Crossed median	0.3588**	0.0180	0.1120
Changing lanes/passing	0.1917	0.0155	0.0598
Turning	0.5063**	0.1022	0.1580
Slowing/stopping	-0.2250	0.0249	-0.0702
Avoiding object in road	-0.4897	0.0051	-0.1529
Travel speed	-0.0044**	43.8868	-0.0014
Skid length over 100’	-0.3384**	0.1858	-0.1056
Number of occupants	0.0450	1.1746	0.0140
ROADWAY FACTORS			
Slippery surface	-0.2454**	0.3076	-0.0766
Curve	0.2948**	0.2279	0.0920
Grade	0.0250	0.2373	0.0078
Struck tree/pole	-0.7584**	0.1624	-0.2367
Struck guardrail/barrier	-0.2297**	0.1149	-0.0717
DRIVER FACTORS			
Alcohol/drug presence	0.3425**	0.0228	0.1069
Sleepy	-0.0595	0.0247	-0.0186
ENVIRONMENTAL FACTORS			
Darkness/Dusk/Dawn	-0.0738	0.2332	-0.0230
SUMMARY STATISTICS			
Log likelihood	-2400		
Restricted log likelihood	-3090		
Chi-squared	1370		
Significance level (alpha)	0.000		

TABLE 2 Factors Associated with Large Truck Crash Injury Severity (Ordered Probit Model)

	Single-Vehicle Crash Model (N=5,031)		Single-Vehicle Rollover Model (N=1,487)	
Independent Variable	**Beta coefficient**	**Mean**	**Beta coefficient**	**Mean**
Constant	-1.0563**		-0.5892**	
VEHICLE FACTORS				
Chevrolet	-0.0462	0.0821	-0.1074	0.0814
Dodge	-0.1699	0.0105	-0.6117	0.0040
Ford	-0.1052	0.1739	-0.1796	0.1762
Freightliner	-0.1375	0.1453	0.1198	0.1385
GMC	-0.0617	0.0555	-0.1352	0.0558
International	-0.0140	0.1771	-0.0141	0.1782
Isuzu	-0.0404	0.0145	-0.2729	0.0114
Kenworth	-0.1426	0.0618	-0.1152	0.0612
Mack	0.0466	0.0570	0.2343	0.0740
Nissan	0.4375*	0.0072	0.9223*	0.0047
Peterbilt	-0.1547	0.0557	-0.1083	0.0686
Toyota	-0.0939	0.0089	-0.6171	0.0047
Volvo	0.0097	0.0272	0.2335	0.0229
Whit	-0.0791	0.0390	0.0731	0.0370
Pre-1992 Model Year	0.0035	0.5232	0.0782	0.4593
Trailer length over 45'	-0.0609	0.2250	-0.1163	0.2643
Trailer width over 100"	0.0004	0.3548	-0.0376	0.3847
Hazardous material	0.4377**	0.0312	0.5558**	0.0504
Defective brakes	0.2001*	0.0306	0.1450	0.0356
Single-unit truck	-0.1940	0.4675	-0.7365**	0.4835
CRASH FACTORS				
Rollover	0.7295**	0.2956		
Untripped rollover	0.0288	0.3691	0.0336	0.7888
Traffic control violation	0.3351**	0.0159	0.2948	0.0155
Speeding	0.1246**	0.3035	-0.0772	0.4970
Passing	-0.5467	0.0028	-0.4968	0.0054
Turning violation	-1.4012**	0.0189		
Reckless driving	0.2058	0.0195	0.0244	0.0309
Crossed median	0.2330*	0.0181	-0.1310	0.0262
Changing lanes/passing	0.0619	0.0157	0.1382	0.0182
Turning	-0.1223	0.1016	-0.0755	0.1163
Slowing/stopping	-0.2303**	0.0252	-0.6268**	0.0195
Avoiding object in road	0.0706	0.0052	0.0300	0.0027
Travel speed	0.0071**	44.1115	0.0155**	47.2482
Skid length over 100'	-0.2663**	0.1853	-0.2212**	0.2354
Number of occupants	0.1657**	1.1870	0.2085**	1.2065
Post-crash fire	0.5684**	0.0244	1.0867**	0.0128
ROADWAY FACTORS				
Slippery surface	-0.0206	0.3091	-0.1145	0.2468
Curve	0.1105*	0.2278	0.1399**	0.3342
Grade	-0.0468	0.2361	-0.0538	0.2690
Struck tree/pole	0.3560**	0.1600	0.2566**	0.0733
Struck guardrail/barrier	0.2317**	0.1159	0.1403	0.0975
DRIVER FACTORS				
Alcohol/drug presence	0.5647**	0.0231	0.1135	0.0276
Sleepy	0.1153	0.0250	-0.0823	0.0256
No seat belt	0.4839**	0.0962	0.5200**	0.1580

ENVIRONMENTAL FACTORS				
Darkness/dusk/dawn	-0.0333	0.2304	-0.1441*	0.1896
INTERACTIONS				
Curve and rollover	0.0083	0.0988		
Grade and rollover	-0.0220	0.0795		
Fire and rollover	0.5148*	0.0038		
No seat belt and rollover	-0.0519	0.0467		
THRESHOLDS				
μ_1	0.6666	0.0000	0.7578	0.0000
μ_2	1.5849	0.0000	1.7985	0.0000
μ_3	2.4986	0.0000	2.8422	0.0000
SUMMARY STATISTICS				
Log likelihood	-4420		-1850	
Restricted log likelihood	-5110		-1990	
Chi-squared	1390		288	
Significance level (alpha)	0.000		0.000	

**=Significant association with injury severity (95% confidence level)
*=Significant association with injury severity (90% confidence level)

TABLE 3 Marginal Effects for the Two Ordered Probit Models

	Single-Vehicle Crash Model (N=5,031)					Single-Vehicle Rollover Model (N=1,487)				
	Dependent Variable									
Independent Variable	**No injury**	**Minor**	**Moderate**	**Severe**	**Fatality**	**No injury**	**Minor**	**Moderate**	**Severe**	**Fatality**
Constant	0.3775	-0.1564	-0.17	-.0460	-0.0051	0.2235	-0.0101	-0.1348	-0.0688	-0.0098
VEHICLE FACTORS										
Chevrolet	0.0165	-0.0068	-0.0074	-.0020	-0.0003	0.0407	-0.0018	-0.0246	-0.0125	-0.0018
Dodge	0.0607	-0.0251	-0.0273	-.0074	-0.0009	0.232	-0.0105	-0.14	-0.0715	-0.01
Ford	0.0376	-0.0156	-0.0169	-.0046	-0.0005	0.0681	-0.0031	-0.0411	-0.021	-0.0029
Freightliner	0.0491	-0.0204	-0.0221	-.0060	-0.0006	-0.0454	0.0021	0.0274	0.014	0.0019
GMC	0.022	-0.0091	-0.0099	-.0027	-0.0003	0.0513	-0.0023	-0.0309	-0.0158	-0.0023
International	0.005	-0.0021	-0.0023	-.0006	0.0000	0.0053	-0.0002	-0.0032	-0.0016	-0.0003
Isuzu	0.0145	-0.006	-0.0065	-.0018	-0.0002	0.1035	-0.0047	-0.0625	-0.0319	-0.0044
Kenworth	0.0509	-0.0211	-0.0229	-.0062	-0.0007	0.0437	-0.002	-0.0264	-0.0135	-0.0018
Mack	-0.0167	0.0069	0.0075	.0020	0.0003	-0.0889	0.004	0.0536	0.0274	0.0039
Nissan	-0.1563	0.0648	0.0704	.0190	0.0021	-0.3498	0.0158	0.2111	0.1077	0.0152
Peterbilt	0.0553	-0.0229	-0.0249	-.0067	-0.0008	0.0411	-0.0019	-0.0248	-0.0127	-0.0017
Toyota	0.0336	-0.0139	-0.0151	-.0041	-0.0005	0.2341	-0.0106	-0.1412	-0.0721	-0.0102
Volvo	-0.0035	0.0014	0.0016	.0004	0.0001	-0.0886	0.004	0.0534	0.0273	0.0039
Whit	0.0283	-0.0117	-0.0127	-.0034	-0.0005	-0.0277	0.0013	0.0167	0.0085	0.0012
Pre-1992 Model Year	-0.0013	0.0005	0.0006	.0002	0.0000	-0.0297	0.0013	0.0179	0.0091	0.0014
Trailer length over 45’	0.0218	-0.009	-0.0098	-.0027	-0.0003	0.0441	-0.002	-0.0266	-0.0136	-0.0019
Trailer width over 100”	-0.0001	0.0001	0.0001	.0000	-0.0001	0.0143	-0.0006	-0.0086	-0.0044	-0.0007
Hazardous material	-0.1564	0.0648	0.0704	.0190	0.0022	-0.2108	0.0095	0.1272	0.0649	0.0092
Defective brakes	-0.0715	0.0296	0.0322	.0087	0.001	-0.055	0.0025	0.0332	0.0169	0.0024
Single-unit truck	0.0693	-0.0287	-0.0312	-.0084	-0.001	0.2793	-0.0126	-0.1685	-0.086	-0.0122
CRASH FACTORS										
Rollover	-0.2608	0.108	0.1175	.0318	0.0035					
Untripped rollover	-0.0103	0.0043	0.0046	.0013	0.0001	-0.0128	0.0006	0.0077	0.0039	0.0006
Traffic control violation	-0.1198	0.0496	0.0539	.0146	0.0017	-0.1118	0.0051	0.0675	0.0344	0.0048
Speeding	-0.0445	0.0184	0.02	.0054	0.0007	0.0293	-0.0013	-0.0177	-0.009	-0.0013
Passing	0.1954	-0.0809	-0.088	-.0238	-0.0027	0.1884	-0.0085	-0.1137	-0.058	-0.0082
Turning violation	0.5008	-0.2074	-0.2255	-.0610	-0.0069					
Reckless driving	-0.0735	0.0305	0.0331	.0090	0.0009	-0.0093	0.0004	0.0056	0.0029	0.0004
Crossed median	-0.0833	0.0345	0.0375	.0101	0.0012	0.0497	-0.0022	-0.03	-0.0153	-0.0022
Changing lanes/passing	-0.0221	0.0092	0.01	.0027	0.0002	-0.0524	0.0024	0.0316	0.0161	0.0023
Turning	0.0437	-0.0181	-0.0197	-.0053	-0.0006	0.0286	-0.0013	-0.0173	-0.0088	-0.0012
Slowing/stopping	0.0823	-0.0341	-0.0371	-.0100	-0.0011	0.2377	-0.0108	-0.1434	-0.0732	-0.0103
Avoiding object in road	-0.0252	0.0104	0.0114	.0031	0.0003	-0.0114	0.0005	0.0069	0.0035	0.0005

Travel speed	-0.0025	0.0011	0.0011	.0003	0.0000	-0.0059	0.0003	0.0035	0.0018	0.0003
Skid length over 100'	0.0952	-0.0394	-0.0429	-.0116	-0.0013	0.0839	-0.0038	-0.0506	-0.0258	-0.0037
Number of occupants	-0.0592	0.0245	0.0267	.0072	0.0008	-0.0791	0.0036	0.0477	0.0244	0.0034
Post-crash fire	-0.2031	0.0841	0.0915	.0247	0.0028	-0.4122	0.0186	0.2487	0.1269	0.018
ROADWAY FACTORS										
Slippery surface	0.0074	-0.0031	-0.0033	-.0009	-0.0001	0.0434	-0.002	-0.0262	-0.0134	-0.0018
Curve	-0.0395	0.0164	0.0178	.0048	0.0005	-0.0531	0.0024	0.032	0.0163	0.0024
Grade	0.0167	-0.0069	-0.0075	-.0020	-0.0003	0.0204	-0.0009	-0.0123	-0.0063	-0.0009
Struck tree/pole	-0.1272	0.0527	0.0573	.0155	0.0017	-0.0973	0.0044	0.0587	0.03	0.0042
Struck guardrail/barrier	-0.0828	0.0343	0.0373	.0101	0.0011	-0.0532	0.0024	0.0321	0.0164	0.0023
DRIVER FACTORS										
Alcohol/drug presence	-0.2018	0.0836	0.0909	.0246	0.0027	-0.0431	0.0019	0.026	0.0133	0.0019
Sleepy	-0.0412	0.0171	0.0186	.0050	0.0005	0.0312	-0.0014	-0.0188	-0.0096	-0.0014
No seat belt	-0.1729	0.0716	0.0779	.0211	0.0023	-0.1972	0.0089	0.119	0.0607	0.0086
ENVIRONMENTAL FACTORS										
Darkness/dusk/dawn	0.0119	-0.0049	-0.0054	-.0014	-0.0002	0.0547	-0.0025	-0.033	-0.0168	-0.0024
INTERACTIONS										
Curve and rollover	-0.003	0.0012	0.0013	.0004	0.0001					
Grade and rollover	0.0079	-0.0033	-0.0035	-.0010	-0.0001					
Fire and rollover	-0.184	0.0762	0.0829	.0224	0.0025					
No seat belt and rollover	0.0185	-0.0077	-0.0083	-.0023	-0.0002					