SUV ROLLOVER IN SINGLE VEHICLE CRASHES AND THE INFLUENCE OF ESC AND SSF

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ABSTRACT – The modern Sport Utility Vehicle (SUV) fleet continues to go through a transformation in response to the concern that they are at an increased risk of rollover. Our research objective was to look at changes in rollover rates for single vehicle crashes in the modern SUV fleet (corresponding to NCAP rollover testing model years) and the impact of electronic stability control (ESC) and lowered center of gravity. We looked at 2001-2006 NASS-GES data on a probability sample of 3,331 SUVs involved in single vehicle crashes, weighted to represent 324,149 crashes in the study population. Static Stability Factor (SSF) information from NCAP testing and ESC presence (from IIHS) were also incorporated. 20.2% of these SUVs were involved a rollover, which decreased by more than half from model year 2001 (25.3%) through 2006 (11.5%). Nearly 9% had ESC as a standard feature, including 47% in model year 2006. The majority of the late model year decline in rollover rates can be attributed to ESC presence and higher SSF. Rollover was two-thirds less likely (adjusted OR=0.33, 95% CI=0.20-0.55) in SUVs with ESC as a standard feature versus those known not to have ESC. Those SUVs with SSF ≥1.20 were significantly less likely to rollover (adjusted OR=0.31, 95% CI=0.20-0.48). Additional significant predictors of rollover included SUV size, driver age and alcohol use. Our study builds on the previous work of NHTSA, IIHS, and others with regard to rollover risk by looking at an even wider array of late model year SUVs.

INTRODUCTION

Previous research has shown rollover in passenger vehicles as problematic, consistantly resulting in a disproportionate number of serious injuries and fatalities when compared with other crash modes [NHTSA, 2003; NHTSA, 2007 (a)]. The problem is further magnified when looking specifically at light trucks, and in particular Sport Utility Vehicles (SUVs). Nearly twenty years ago, Robertson (1989) found SUVs to be significantly more likely to rollover when compared with passenger cars. As the passenger vehicle fleet evolved (both within and across vehicle types) throughout the 1990's and into the first years of the 21st century, the SUV went from a niche vehicle to more than one-quarter of passenger vehicle sales [EPA, 2007]. Yet given this evolving vehicle fleet, Robertson's finding that SUVs were more likely rollover than passenger cars continued to be demonstrated across a wide array of studies [NHTSA, 2000; Farmer and Lund, 2002; Kweon and Kockelman, 2003; Rivara, Cummings, and Mock, 2003; Daly, Kallan, Arbogast, et al., 2006; Kallan, Arbogast, and Durbin, 2006; NHTSA, 2007 (a)]. More than three-quarters of these SUV rollovers occurred during single vehicle crashes [NHTSA, 2003; Deutermann, 2002], with virtually all of these being tripped events [NHTSA, 2003].

The main reason behind the increased likelihood of SUVs to roll over comes down to geometry. The static stability factor (SSF) is the measurement most often used to illustrate rollover resistance, as it is a calculation of geometric factors demonstrating the 'top-heaviness' of a vehicle. During the first three model years of NCAP rollover ratings (2001-2003), the SSF was the sole factor used [NHTSA, 2003; Walz, 2005]; it is calculated as: SSF= T/2H (where T=vehicle track width and H=vehicle center of gravity height). Previous research has specifically shown lower SSF vehicles (i.e., more top-heavy) to have a greater likelihood to roll over than those vehicles with a higher SSF [Robertson, 1989; Farmer et al., 2002; NHTSA, 2003].

One way vehicle manufacturers have addressed the issue of rollover is through the introduction of the crossover SUV. Making its U.S. debut in model year 1997, the crossover SUV is manufactured with a unibody (i.e., car-based) construction [Walz, 2005] instead of with body-on frame construction. By model year 2003, crossovers made up 37% of the new SUV market, and both this percentage and the number of different crossover models available continue to rise [Walz, 2005]. The unibody SUVs tend to have a lower center of gravity height, which have had the effect of increasing the overall average SSF in the latest SUVs model years [Walz, 2005]. Accordingly, Wenzel and Ross (2005) have reported a corresponding mitigation of rollover in crossover SUVs when compared to their body-on frame counterparts.

The other main factor contributing to the reduction of rollover risk in the passenger vehicle fleet is electronic stability control (ESC). Also introduced in the United States during model year 1997, ESC availiability was originally restricted to a handful of luxury vehicles [Dang, 2007]. Despite the limited number of these vehicles available for analysis, ESC has been shown to be remarkably effective worldwide. Lie, Tingvall, Krafft, et al. (2006) found a 44% reduction in single vehicle serious/fatal crashes in Sweden, Page and Cuny (2006) found a similar 43% decrease for passenger cars on French roads, and Robertson (2007) determined fatalities would be reduced by 42% if all passenger vehicles were equipped with ESC. In the United States, results restricted to SUVs have yielded even stronger findings. Recent research by Farmer (2006) and Dang (2007) have shown ESC to significantly reduce fatal single-vehicle SUV crashes (by 59% and 63% respectively) and fatal single-vehicle rollovers (by 80% and 88% respectively).

In 2007, NHTSA issued a final rule mandating all new passenger vehicles, including SUVs, must have ESC by model year 2012 [NHTSA, 2007 (b)]. As of model year 2007, it was estimated that 87% of new SUVs had ESC as a standard feature [IIHS-HLDI, 2007 (a)]. Given its rapid increase as a standard feature in late model SUVs, our analysis is able to continue the investigation of ESC effectiveness in SUVs. The research objective is to look at changes in rollover rates for single vehicle crashes in the modern SUV fleet (model year 2001 and later, when NCAP rollover testing began) and how this has been impacted by the presence of ESC, changes in SSF, and other vehicle and driver characteristics.

METHODS

The main source of data used for this study is the National Highway Traffic Safety Administration National Automotive Sampling System General Estimates System (NASS-GES). Annual data for NASS-GES was obtained from a nationally representative three-stage probability sample of police-reported crashes in the United States [NHTSA, 2006]. Additional vehicle specific supporting information pertaining to both the ESC status [IIHS-HLDI, 2007 (b)] and the SSF measurement [Safercar.gov, 2007] was obtained separately.

Study Population

The study population was limited to police-reported single-vehicle crashes occurring during calendar years 2001 through 2006 that involved a late model SUV (model year 2001 and newer). Note that there were a small number (n=8) of model year 2007 vehicles that were grouped together with the model year 2006 SUVs.

Variable Definitions

Vehicle size: The analysis was initially limited to the approximately 85% of SUVs with a non-missing vehicle identification number (VIN) that could be decoded by the VINDICATOR program [IIHS-HLDI, 2008] into a specific make/series/model of SUV. Size classification (small, midsize, and large) information based primarily on vehicle curb weight was also provided by VINDICATOR [HLDI, 2003]. Though there was occasional overlap to keep individual vehicle series (and other market class competitors) within a single size classification, corresponding curb weight ranges were as follows: small ≤1,701 kg (3,750 lbs.), midsize 1,702-2,154 kg (3,751-4,750 lbs.), and large 2,155-2,608 kg (4,751-5,750 lbs.). The approximately 1% of SUVs classified as very large, with corresponding curb weights ≥2,609 kg (5,751 lbs.) were excluded from the analysis.

Rollover: The definition in the analysis included rollover of any type (tripped, untripped, or unknown) captured by NASS-GES [NHTSA, 2006].

Electronic stability control (ESC): This information was obtained for each of the specific SUV make/series/model combinations (by model year) from the IIHS website (2007 (a)) and merged with the NASS-GES crash data. Vehicles were classified as having the ESC feature as standard, optional, or not available.

Static stability factor (SSF): Specific SSF values were obtained from the Safercar.gov website (2007) for each make/series/model (by model year) of SUV and merged with the NASS-GES data. These values were regularly available starting with model year 2001, the first year of NCAP rollover testing. For just under one-quarter (22%) of SUVs, the SSF needed to be obtained from similar SUVs, which differed only by (two vs. four) wheel drive, model year (lacking a redesign), or name (i.e., "clones" or "corporate cousins") [Scalia, 2005; Walz, 2005]. The remaining 1% with irreconcilable SSF values was excluded from the analysis. A dichotomous SSF variable was created, categorizing SSF as either below or at least 1.20 as previously done by Robertson (1989 and 2007). Additionally, a 2005 report by Walz noted that for the model years in question, the average SSF for crossover SUVs was above this threshold while the comparable average SSF of body-on-frame SUVs fell well below.

Other variables: SUVs were further classified by either two-wheel drive or four-wheel drive per VINDICATOR. Both driver age (<25 vs. 25+ years) and gender were explored; in the <1% of these cases where driver age or gender were unknown, the hot deck imputed values (i.e., based on information from correlated variables) for each were used [NHTSA, 2006]. We also looked at whether or not there was any reported alcohol use by the driver; in the approximately 5% of crashes with missing information, the univariate imputed values (i.e., random assignment made in equal proportion to the known values for the individual variable) were used [NHTSA, 2006].

Statistical Analyses

To account for the unequal probability of selection in the NASS-GES data and to then calculate estimates of national crash characteristics, probability case weights equal to the inverse of the selection probability were used [NHTSA, 2006]. Due to the disproportional probability of selection by crash along with clustering of subjects by primary sampling unit (PSU), Taylor Series linearization estimates of the logistic regression parameter variance were calculated using SAS-callable SUDAAN®: Software for the Statistical Analysis of Correlated Data, Version 9.0.1 (Research Triangle Institute, Research Triangle Park, NC, 2007). Results of logistic regression modeling were expressed as adjusted odds ratios with corresponding 95% confidence intervals. Adjustments in the modeling of rollover risk included the variables described earlier (ESC, SSF, SUV classification, two-wheel vs. four-wheel drive, driver age, driver gender, and driver alcohol use).

RESULTS

Complete data was obtained on 3,331 single-vehicle SUV crashes weighted to represent 324,149 crashes in the study population. Rollover was reported in just over one-fifth of these crashes (20.2%). Table 1 presents the overall distribution of vehicle, driver, and crash characteristics in the study population.

Changes by model year for both ESC and SSF are shown in Table 2. While just under nine percent of vehicles had ESC as a standard feature, this increased to nearly one-quarter (23.3%) of our model year 2005 SUVs and just under half (47.5%) for model year 2006. There was also a trend of increasing SSF by model year, demonstrated in both the average as well as the proportion of vehicles with an SSF ≥ 1.20.

Table 1: Vehicle, Driver, and Crash Characteristics

Characteristics	Weighted % (Unweighted n)
Total	100.0 (3,331)
Rollover	20.2 (1,006)
Model Year	
M/Y 2001	27.2 (924)
M/Y 2002	27.0 (923)
M/Y 2003	19.3 (618)
M/Y 2004	15.9 (514)
M/Y 2005	7.6 (255)
M/Y 2006	3.0 (97)
SUV Size	
Small	20.6 (702)
Midsize	59.3 (1,988)
Large	20.1 (641)
ESC Availability	
Standard (Std.)	8.7 (278)
Optional (Opt.)	15.1 (492)
Not available	76.2 (2,561)
Four-Wheel Drive	62.0 (1,936)
Driver Age < 25 years	20.7 (768)
Driver Gender (Male)	47.1 (1,645)
Driver Alcohol Use	6.6 (337)
SSF ≥ 1.20	12.8 (417)
Average (and Median) SSF	*1.15*

Table 2: ESC and SSF by Model Year

Model Year	ESC		SSF	
	Std. only (%)	Std. or Opt. (%)	Avg.	≥ 1.20 (%)
2001	5.6	6.2	1.12	12.7
2002	3.9	19.3	1.14	9.4
2003	5.2	33.1	1.15	11.2
2004	12.0	35.2	1.16	11.0
2005	23.3	40.7	1.18	25.4
2006	47.5	61.8	1.18	31.7

Table 3 provides the rollover rates and adjusted odds ratios of rollover; the multivariate logistic regression model had an area under the curve (AUC) measure of 0.653. The crude rollover rate declined 55% from model year 2001 through 2006; however there was not a significant difference after adjusting for the other vehicle and driver factors. The majority of this late model year decline in rollover rates appears to be attributable to the presence of ESC and higher SSF.

Rollover was two-thirds less likely (adjusted OR=0.33, 95% CI=0.20-0.55) in SUVs with ESC as a standard feature compared to those vehicles known to be without ESC. Separate sub-analyses that assigned all optional ESC to either the standard (adjusted OR=0.54, 95% CI=0.39-0.74) or no availability (adjusted OR=0.36, 95% CI=0.22-0.59) categories respectively did not change the overall protective nature of the result. Similarly, SUVs with higher SSF (≥1.20) were significantly less likely to rollover compared to those with lower SSF (adjusted OR=0.31, 95% CI=0.20-0.48). Additional factors that were related to and increased likelihood of rollover included the following: SUV size (small vs. large: adjusted OR=1.33, 95% CI=1.03-1.71; midsize vs. large: adjusted OR=1.37, 95% CI=1.06-1.79), drivers < 25 years of age (adjusted OR=1.67, 95% CI=1.31-2.11), and driver alcohol use (adjusted OR=2.70, 95% CI=1.77-4.12).

Table 3: Rollover Rates and Adjusted Odds Ratios

Characteristics	Rate	Adjusted OR (95% CI)
Model Year		
M/Y 2001	25.3	Reference
M/Y 2002	18.8	0.72 (0.52-1.00)
M/Y 2003	19.2	0.84 (0.60-1.19)
M/Y 2004	19.3	0.90 (0.69-1.17)
M/Y 2005	14.9	0.78 (0.49-1.25)
M/Y 2006	11.5	0.87 (0.39-1.91)
SUV Size		
Small	20.7	1.33 (1.03-1.71)
Midsize	21.4	1.37 (1.06-1.79)
Large	16.4	Reference
ESC Availability		
Standard (Std.)	8.1	0.33 (0.20-0.55)
Optional (Opt.)	15.1	0.67 (0.46-0.96)
Not available	22.6	Reference
Wheel Drive		
2WD	22.6	Reference
4WD	18.8	0.88 (0.68-1.15)
Driver Age		
< 25 years	29.6	1.67 (1.31-2.11)
25+ years	17.8	Reference
Driver Gender		
Male	21.5	1.04 (0.84-1.30)
Female	19.1	Reference
Driver Alcohol Use		
Yes	39.1	2.70 (1.77-4.12)
No	18.9	Reference
SSF		
< 1.20	22.0	Reference
1.20+	8.4	0.31 (0.20-0.48)

DISCUSSION

Results of this study have illustrated the declining rollover rate in single-vehicle SUV crashes, dropping by more than half from model year 2001 to 2006. This relationship appears to coincide with both the increased availability of ESC as a standard feature and the ever lower average center of gravity in the newest SUVs (i.e., an increased average SSF). Even after controlling for a variety of driver and vehicle factors, it was observed that those SUVs with ESC were two-thirds less likely to roll over than their counterparts known not to have the technology. Likewise, those SUVs with SSF ≥1.20 were found to be 69% less likely to rollover in these same single-vehicle crashes. Additionally, we observed an increased likelihood to rollover in small and midsize SUVs (compared to large), for younger drivers (< 25 years of age), and in those crashes in which the driver had been using alcohol. Going forward, we expect to see a continued decrease in the rollover rates of SUVs as ESC and lower centers of gravity become an ever larger proportion of the SUV fleet.

There has been a great deal of prior investigation into the issue of vehicle rollover. The focus of much of this recent research has been the benefit of ESC in new vehicles [Dang, 2007; Farmer, 2006; Lie et al., 2006; Page et al., 2006; Robertson, 2007]. Yet ESC technology and changes in vehicle design have been evolving at a rapid pace. In particular, the focus on SUVs in single-vehicle crashes looks at the combination in which there has historically been the greatest rollover risk [NHTSA, 2000; Deutermann, 2002; NHTSA, 2003]. Our current research extends this previous work by looking at the widest array yet of new model year SUVs; in particular those with ESC as a standard feature and lower average centers of gravity.

Our results were of a similar nature to what has been shown in previous research on rollover. We found a 67% reduction in the likelihood of single-vehicle rollover in those SUVs with ESC versus those vehicles known not to have the feature. This compared to the 88% and 80% reductions in rollover rate found by Dang (2007) and Farmer (2006) respectively. While our findings showed a slight attenuation of ESC effectiveness, this may be due to two main factors. One, our crash population was less severe than that of the other research (police report versus fatal single-vehicle crashes). Secondly, being newer on average, we were better able to capture ongoing SUV fleet changes such as the increase in crossover vehicle market share and the related jump in average SSF [Walz, 2005]. Per our adjusted multivariate model, the 69% reduction in rollover likelihood that we found for those vehicles with higher than average SSF lends support to the preliminary finding by Wenzel et al. (2005) that crossover SUVs were at lower risk of rollover than their body-on-frame counterparts.

Our findings have shown that declining rollover rates in newer SUVs appear to have been directly related to both increased ESC availability and average SSF. Crude rollover rates were 14.9% and 11.5% for model years 2005 and 2006 respectively; yet still the majority of these SUVs lacked ESC. With an estimated 87% of model year 2007 SUVs having ESC as a standard feature and this climbing to 95% for model year 2008 [IIHS-HLDI, 2007 (a)], virtually all new SUVs will be in compliance with the NHTSA final rule well in advance of the 2012 deadline. In addition, the continued growth of the crossover SUV market share should guarantee further gains in average SSF [Walz, 2005]. This suggests that (after extrapolating from our findings) the rollover rate for SUVs in single-vehicle crashes may approach 5% (or even less) within the next couple of model years. To put this in perspective, 1995-1999 accident year NASS-GES data showed a 32% rollover rate for SUVs (also 13% and 14% in passenger cars and minivans respectively) in comparable police-reported single vehicle crashes [NHTSA, 2000]. Given the disproprtionate number of rollovers occurring in single vehicle crashes [NHTSA, 2000; Deutermann, 2002; NHTSA, 2003], an estimated 5% rollover rate among the newest model year SUVs should bring their overall rollover likelihood more in line with both the current passenger car and minivan fleets [NHTSA, 2007 (a)]. Further protection can then be achieved through addiitonal improvements in rollover crashworthiness, such as a 2005 government proposal to increase the decades old roof strength requirements in FMVSS 216 [IIHS, 2008].

Our analyses were not without limitations. About fifteen percent of potential SUV crashes were initially excluded due to a missing VIN. While this subset of crashes was predominantly concentrated in a handful of PSUs, their model year and vehicle make distribution was found to be similar to those vehicles with a valid VIN. For approximately 15% of our crash population, ESC availability for the vehicle was classified as optional. These SUVs were an unknown blend of having and not having ESC as a feature. However, our previously described sensitivity analyses demonstrated that treating the optional ESC vehicles as either all having or all not having the feature yielded similar protective results in both scenarios. Finally, a small percentage (~ 5%) of our crashes used imputed data for missing driver alcohol use. A sensitivity analysis showed that even in the most extreme situation of replacing all imputed values with those of ‘yes’ (despite its prevalence of <7% in the study population), driver alcohol use was still a significant predictor of rollover in an adjusted multivariate model.

CONCLUSION

The results of our analysis used a newer vehicle fleet to confirm findings of prior research that both the presence of ESC and an increased SSF are extremely important in helping to reduce to likelihood of rollovers in SUVs. With ESC now a standard feature in virtually all current model year SUVs and the continued popularity of crossover vehicles, we should continue to see drops in rollover rates across the entire SUV fleet as it becomes dominated by these newer vehicles. Occupant protection in SUVs will continue to improve as manufacturers emphasize unibody construction, continue to refine ESC technology, and increase the focus on improved roof strength.

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REFERENCES

Daly L, Kallan MJ, Arbogast KB, et al. Risk of injury to child passengers in sport utility vehicles. Pediatrics, 117(1): 9-14; 2006.

Dang JN. Statistical analysis of the effectiveness of electronic stability control (ESC) systems – final report. NHTSA Technical Report, DOT HS 810 794; 2007.

Deutermann W. Characteristics of fatal rollover crashes. NHTSA Technical Report, DOT HS 809 438; 2002.

Farmer CM and Lund AK. Rollover risk of cars and light trucks after accounting for driver and environmental factors. Accident Analysis and Prevention, 34(2): 163-173; 2002.

Farmer CM. Effects of electronic stability control: an update. Traffic Injury Prevention, 7(4): 319-324; 2006.

Highway Loss Data Institute (HLDI). Technical Appendix, Arlington, VA; 2006.

Insurance Institute for Highway Safety, Highway Loss Data Institute (IIHS-HLDI). Vehicles equipped with electronic stability control (ESC); 2007 (a). Available online at http://www.iihs.org/ratings/esc/esc.aspx (First accessed December 28, 2007).

Insurance Institute for Highway Safety, Highway Loss Data Institute (IIHS-HLDI). Q&As: Rollover and roof crush; 2007 (b). Available online at http://www.iihs.org/research/qanda/rollover.html (Accessed March 14, 2008).

Insurance Institute for Highway Safety, Highway Loss Data Institute (IIHS-HLDI). VINDICATOR Version 2008 6.04, Arlington, VA; 2008.

Insurance Institute for Highway Safety (IIHS). Strength of the roofs on SUVs. IIHS Status Report, 43(2): 1-5; 2008.

Kallan MJ, Arbogast KB, and Durbin DR. Effect of model year and vehicle type on rollover crashes and associated injuries to children. Annual Proceedings Association for the Advancement of Automotive Medicine, 50: 163-176; 2006.

Kweon YJ and Kockelman KM. Overall injury risk to different drivers: combining exposure, frequency, and severity models. Accident Analysis and Prevention, 35(4): 441-450; 2003.

Lie A, Tingvall C, Krafft M, et al. The effectiveness of electronic stability control (ESC) in reducing real life crashes and injuries. Traffic Injury Prevention, 7(1): 38-43; 2006.

National Highway Safety Transportation Administration (NHTSA). Rollover resistance - response to comments, notice of final decision. Docket number NHTSA-2000-8298; 2000.

National Highway Safety Transportation Administration (NHTSA). Initiatives to address the mitigation of vehicle rollover. Docket number NHTSA-2003-14622; 2003.

National Highway Safety Transportation Administration (NHTSA). National Automotive Sampling System General Estimating System (NASS-GES). Analytical User's Manual 1988-2006; 2006.

National Highway Safety Transportation Administration (NHTSA). Table 37 – Vehicles involved in crashes by vehicle type, rollover occurrence, and crash severity. Traffic Safety Facts 2006; 2007 (a).

National Highway Safety Transportation Administration (NHTSA). FMVSS No. 126: electronic stability control systems. Final Rule – NHTSA-2007-27662; 2007 (b).

Page Y and Cuny S. Is electronic stability program effective on French roads? Accident Analysis and Prevention, 38(2): 357-364; 2006.

Rivara FP, Cummings P, and Mock C. Injuries and death of children in rollover motor vehicle crashes in the United States. Injury Prevention, 9(1): 76-80; 2003.

Robertson LS. Risk of fatal rollover in utility vehicles relative to static stability. American Journal of Public Health, 79(3): 300-303; 1989.

Robertson LS. Prevention of motor vehicle deaths by changing vehicle factors. Injury Prevention, 13(5): 307-310; 2007.

Safercar.gov. Crash test and rollover ratings; 2007. Available online at http://www.safercar.gov/ (First accessed December 28, 2007).

Scalia Safety Engineering (Scalia). Year/model interchange list – trucks, vans, sport utilities, etc., Madison, WI; 2005.

United States Environmental Protection Agency (EPA). Appendix D – Data stratified by vehicle type. Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007; 2007.

Walz MC. Trends in the static stability factor of passenger cars, light trucks, and vans. NHTSA Technical Report, DOT HS 809 868; 2005.

Wenzel T and Ross M. The effects of vehicle model and driver behavior on risk. Accident Analysis and Prevention, 37(3): 479-494; 2005.