

# Differential Rollover Risk in Vehicle-to-Traffic Barrier Collisions

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**ABSTRACT** – In the roadside safety community, there has been debate over the influence of vehicle and barrier type on rollover rates in traffic barrier crashes. This study investigated rollover rates between sport utility vehicles (SUVs), pickup trucks, and cars in vehicle-traffic barrier crashes and has examined the effect of barrier type on rollover risk for concrete barrier and metal barrier impacts. The analysis included 955 barrier impact cases that were selected from 11-years of in-depth crash data available through the National Automotive Sampling System (NASS) / Crashworthiness Data System (CDS). In real world tow-away level longitudinal barrier collisions, the most important predictors of vehicle rollover were found to be vehicle type and whether the vehicle was tracking prior to barrier impact. Based on binary logistic regression, SUVs were found to have 8 times the risk of rollover as cars in barrier impacts. Although pickups were found to have an increased risk of rollover compared to cars, the risk was not as pronounced as that found for SUVs. This finding has direct implications for the full scale crash testing of longitudinal barriers as the testing procedures have been predicated on the assumption that the pickup truck provides a critical or worst case impact scenario. In towaway crashes, our study does not support the notion that concrete barriers have a higher risk of vehicle rollover than metal beam barriers.

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## INTRODUCTION

In passenger vehicle-to-traffic barrier crashes, more than one-fourth of all fatalities involve a rollover (Gabler and Gabauer, 2007). A debated issue in the roadside safety community is the effect of barrier type on rollover. Anecdotal crash test evidence has suggested that vehicles impacting concrete barriers have an increased likelihood of rollover and researchers have used this to advocate a redesign of the current concrete barriers. In addition, previous research has shown that pickups and sport utility vehicles (SUVs) are more likely to roll than cars in vehicle-traffic barrier crashes. What is not known is how pickup and SUV rollover risk differs in this crash mode. Despite this unknown, however, current traffic barrier crash test procedures specify a large pickup truck as the critical test vehicle.

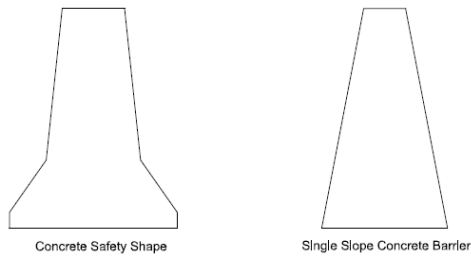
## OBJECTIVE

The purpose of this study is twofold: (1) to examine the effect of barrier type on rollover risk in vehicle-traffic barrier crashes and (2) to compare the rollover rates of SUVs, pickup trucks, and cars in collisions with traffic barriers.

## PREVIOUS RESEARCH

A limited number of previous studies have examined rollover in longitudinal traffic barrier crashes exclusively. These studies have primarily focused on

rollover caused by concrete barriers (shown in Figure 1), and more specifically, the concrete safety shape often termed the New Jersey Barrier. Using computer simulation, Perera and Ross (1989) found that overturns can be expected for small cars impacting concrete barriers when the impact angle is high or the vehicle is not tracking. Mak and Sicking (1990) used national and state crash data coupled with computer simulation to investigate the extent of the concrete safety shape rollover problem, identify causes of these rollovers, and investigate potential countermeasures. Based on 1,839 concrete barrier impacts occurring in Texas between 1982 through 1984, the rollover rate for concrete barrier was found to be 8.5 percent. Rollover rates were also found to be higher in dry conditions and when the vehicle was tracking as opposed to skidding prior to barrier impact. In a general study of rollover in roadside crashes in Illinois, Viner (1995) found much lower concrete barrier rollover rates (0.2 to 1.5 percent) but higher rates for metal beam barriers (3.7 to 5.7 percent).



**Figure 1 – Typical Concrete Barrier Cross Sections**

Several studies have investigated the effect of vehicle type on rollover risk in collisions with traffic barriers and/or other roadside hardware devices. Viner (1984) investigated the effects of vehicle size and weight on roadside crashes. Based on approximately 6,000 traffic barrier crashes occurring on California freeways in 1979, Viner found that smaller and lighter vehicles have a higher risk of rollover in run-off-road crashes. Also, concrete barriers were found to be associated with a much higher rate of rollover (9.9 percent) compared to cable median barriers (6.2 percent) and metal beam barriers (3.9 percent). Bryden and Fortuniewicz (1986) analyzed 3,302 barrier crashes in New York State that occurred between 1982 and 1983. Light trucks and vans were found to overturn in approximately 16 percent of crashes with post and rail barriers while passenger cars overturned in only 6 percent of those crashes. Using national and state data, Bligh and Mak (1999) investigated vehicle type performance in all roadside crashes. National data included Fatality Analysis Reporting System (FARS) data and National Automotive Sampling System (NASS) / General Estimates System (GES) data from 1991 through 1995. State data included Illinois Highway Safety Information System (HSIS) data from 1988 to 1992. In general, light trucks were found to be associated with higher overturn rates in barrier crashes.

Other studies investigating barrier crash performance also offered insight into one or both of these issues. Zweden and Bryden (1977) analyzed 324 crashes on the New York Thruway occurring between 1967 and 1969 and determined that heavy post barriers had a rollover rate roughly half that of light post barriers. More recently, Gabler and Gabauer (2007) found that light trucks were roughly three times more likely to overturn in police-reported guardrail crashes than passenger cars based on an analysis of FARS and GES (2000-2005).

Perhaps the most in-depth longitudinal barrier crash data was the Longitudinal Barrier Special Study

(LBSS). The LBSS was collected in tandem with the National Automotive Sampling System (NASS) / Crashworthiness Data System (CDS) for approximately 1,200 barrier crashes occurring between 1982 and 1986. NASS/CDS provides detailed information, including restraint performance and occupant injury, for a sample of U.S. police-reported crashes where at least one vehicle sustained damage that required it to be towed from the scene (NCSA, 2005). Researchers (Erinle et al., 1994; Hunter, Stewart and Council, 1993) used the LBSS database primarily to investigate injury differences between different barrier systems and investigate the performance of barrier end terminals with respect to impacts to the barrier face (also referred to as the length of need). The LBSS data suggested that concrete barrier length of need impacts have approximately double the risk of rollover than strong post metal beam barriers.

Several issues exist with the data in these previous studies. First, FARS and GES are based primarily on police-reported data which provides only a limited description of the barrier type, i.e. either concrete or guardrail. HSIS data are focused on linking crash and roadway data and thus does not suffer these shortcomings. However, it only provides data on the state level, which is likely not nationally representative. Similar to HSIS, the LBSS data also provides a strong link between crash and roadway characteristics. The crashes in the data set, though, are now over 20 years old and not representative of the current vehicle fleet or roadside barriers currently in use. Data set age is an issue with a majority of the previous studies with only two studies done with barrier crashes occurring post 1990. These factors coupled with the often conflicting results of these previous studies provide a strong argument for a new study on barrier rollover.

## METHODS

Data from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) was used to examine rollover in vehicle to traffic barrier crashes. NASS/CDS provides a detailed record of approximately 5,000 crashes investigated each year (NCSA, 2005). To be included in NASS/CDS, at least one of the vehicles in the crash had to have been towed from the scene. The NASS/CDS database includes only crashes involving cars, light trucks, vans and sport utility vehicles (SUVs). Heavy vehicles and motorcycles are not included as subject vehicles in the NASS/CDS database. Cases are selected for NASS/CDS investigation using a complex sampling strategy which oversamples certain types of crashes including fatal crashes,

crashes involving hospitalized occupants, and crashes involving late model year vehicles among other factors (NCSA, 2005).

To permit nationally representative estimates to be computed, NASS/CDS provides weighting factors which account for this sampling scheme. These weights were applied in the analysis which follows. All statistical analyses were performed using the SAS V9.1.3 software package.

### Case Selection

Cases were selected from an 11-year NASS/CDS data set spanning 1997 to 2007, inclusive. Cases selected from NASS/CDS were single vehicle crashes that fell into one of two categories:

1. The first and only event was a vehicle impacting a longitudinal barrier.
2. A vehicle struck a longitudinal barrier and subsequently overturned.

Only passenger vehicles, light trucks, vans and SUVs were included; all heavy vehicles were excluded from the analysis. No restriction was placed on the vehicle model year. For the purpose of this study, a longitudinal barrier included concrete barriers, metal beam guardrails, and cable barriers. Longitudinal barriers in NASS/CDS are grouped into one of two categories: (1) concrete barriers, and (2) other barriers. The latter category includes all types of steel guardrail systems such as w-beam guardrails, box beam barriers, and cable barriers. For the purpose of this study, the “other” category will be referred to as metal barriers. Using crash scene photographs available online for the NASS/CDS years 1997 through 2007, each case was checked for the following:

1. Proper barrier coding. Any concrete barriers miscoded as “other barrier” were reclassified accordingly and any metal barrier systems miscoded as concrete barrier were reclassified accordingly. Also, any cases which were coded incorrectly as barrier impacts were omitted from the data set.
2. Impact location. Based on the available scene diagram and photos, a determination was made as to whether the vehicle impacted the end of the barrier or the length of need (portion between the end terminals).

Bridge rails and transition sections were also excluded from the study. Although these are types of longitudinal barriers, there were too few cases to present a meaningful analysis. Another purpose for checking the barrier coding was to ensure that only barriers specifically designed to redirect an impacting vehicle were included. Miscoded objects included, but were not limited to, poles, curbs, planters or bridge support structure impacts. The determination of impact location was prompted by previous research (Erinle et al., 1994 and Hunter, Stewart and Council, 1993) indicating that impacts with barrier end terminals are more likely to result in rollovers than impacts with the length of need portion of the barrier. No effort was made to establish the type of end terminal since a majority of the barriers in the available scene photographs had already been repaired. Unless the end terminal was an obsolete model replaced in-kind, there is no way of ensuring that the replaced end terminal was the same type as the impacted end terminal.

The different types of metal barriers present in the data set are illustrated in Figure 2 through Figure 6. The strong post and weak post w-beam barriers use the same cross section beam element but differ in post cross section, presence of a blockout, and post spacing. A more detailed description of the differences between barrier types can be found in Ray and McGinnis (1997). A typical w-beam barrier end terminal is shown in Figure 7.



**Figure 2 – Strong Post W-Beam Barrier  
(NASS/CDS Case 2003-009-167)**



**Figure 3 – Weak Post W-Beam Barrier (NASS/CDS Case 2002-002-041)**



**Figure 4 – Strong Post Thrie-Beam Barrier (NASS/CDS Case 2007-011-152)**



**Figure 5 – Box-Beam Barrier (NASS/CDS Case 2007-002-071)**



**Figure 6 – Cable Barrier (NASS/CDS Case 2007-043-166)**



**Figure 7 – Guardrail End Terminal (NASS/CDS Case 2006-076-065)**

Vehicle type was determined using the “Bodytype” variable in NASS/CDS. The NASS/CDS rollover variable was used to determine if the vehicle overturned in the crash. The event table was used to ensure that any rollover occurred directly following the impact with a barrier.

#### **Statistical Analysis and Model Development**

Contingency table analysis was used to provide a preliminary investigation of how barrier type and vehicle type influenced rollover in traffic barrier crashes. For each vehicle type, the proportion of barrier rollovers was computed along with the confidence limits of those estimates that account for the variation introduced by the complex sampling design of NASS/CDS. Similarly, rollover proportions were computed for all vehicles impacting each barrier type (concrete barrier and metal barrier). In each case, a contingency table analysis was used to determine if differences exist in barrier crash rollover by vehicle type and barrier type.

To provide further comparison of the effect of barrier and vehicle type on rollover risk, odds ratios were compared from developed binary logistic regression models. Each of the models predicted vehicle rollover risk based on vehicle type, barrier type, and other confounding factors, while considering the complex sampling design of NASS/CDS.

Confounding factors were vehicle and barrier related variables including impact location relative to the barrier and vehicle tracking. Barrier impact location was a dichotomous variable indicating whether the vehicle impacted the length of need or the end terminal of the barrier. The pre-impact stability variable (PREISTAB) in NASS/CDS was used to assess whether the vehicle was tracking prior to impact with the barrier. Three categories were used to describe the traction of the vehicle: tracking (PREISTAB = 1), non-tracking (PREISTAB = 2, 3, or 4), and unknown (PREISTAB missing/unknown).

A PREISTAB value of 2, 3, and 4 correspond to a vehicle skidding longitudinally, laterally clockwise, or laterally counterclockwise, respectively. In general, a vehicle is defined as tracking if the following are met: (1) no skid marks present at the scene, (2) the police report or interviewee does not indicate skidding, and (3) the vehicle did not rotate 30 degrees or more in either horizontal direction (NCSA, 2007).

The first level stratification and clustering within NASS/CDS was accounted for using the “surveylogistic” procedure available in SAS. Case stratification in NASS/CDS is based on vehicle tow status, occupant injury level, and hospitalization (NCSA, 2005). The first level clusters are represented by the primary sampling units (PSUs) located across the United States. Each represents either a central city, a county surrounding a central city, an individual county or a continuous group of counties (NCSA, 2005). A more detailed description of the NASS/CDS sampling design methodology can be found in the NASS/CDS Analytical User’s Manual (NCSA, 2005).

## RESULTS

### Data Characterization

Using the initial selection criteria, 1094 NASS/CDS cases were available for review. The available scene photographs in NASS/CDS were used to confirm the barrier type classification as well as impact location. Approximately 9 percent of the available cases were not suitable for analysis. These included 39 bridge rail impacts and 57 instances where the struck barrier was not specifically designed to redirect a vehicle or, in some cases, was not a longitudinal barrier. Objects that fell in this category included concrete median planters, crash cushions, poles, curbs and highway noise barriers. In addition, there were 28 cases where the barrier type was coded improperly by the NASS investigator. A total of 24 concrete barriers had been coded as “other barrier” while 4 metal beam barriers had been coded as “concrete barrier.” After exclusion of the unsuitable barrier types and correction of the miscoded barrier types, there were a total of 998 cases suitable for analysis. A closer examination of the vehicle type composition of this data set revealed that there were only a small number of vans (43 unweighted; 16,200 weighted). As a result, vans were excluded from further analysis.

The final data set, summarized in Table 1, consisted of 955 cases representing more than 450,000 impacts into traffic barriers.

**Table 1 – Vehicle-Barrier Crash Data Set  
[NASS/CDS 1997-2007, inclusive]**

<b>Variable</b>	<b>Raw Cases</b>	<b>Weighted</b>
<b>All</b>	955	452,111
<b>Rollover</b>		
Yes	331	97,579
No	624	354,532
<b>Barrier Type</b>		
Concrete	454	144,308
Metal	501	307,803
Strong Post W-beam	399	225,089
Thrie Beam	43	38,074
Weak Post W-beam	30	21,387
Box Beam	18	17,023
Cable	11	6,230
<b>Component Struck</b>		
<i>Concrete</i>		
Length of Need	439	139,618
End Terminal	15	4,690
<i>Metal</i>		
Length of Need	337	230,560
End Terminal	164	77,242
<b>Vehicle Type</b>		
Car	630	302,566
Pickup Truck	140	79,473
SUV	185	70,072
<b>Vehicle Model Year</b>		
< 1980	15	6,503
≥ 1980, < 1990	160	56,599
≥ 1990, < 2000	536	307,535
≥ 2000, ≤ 2007	244	81,474
<b>Vehicle Tracking</b>		
Tracking	353	193,433
Non-Tracking	395	183,986
Unknown	207	74,692
<b>Equivalent Barrier Speed</b>		
Known	445	216,561
Mean [km/hr]	[24.7]	[20.4]
Unknown	510	235,550
<b>Delta-V</b>		
Known	289	97,060
Mean [km/hr]	[24.0]	[18.9]
Unknown	666	355,051

The metal post and beam barriers were predominantly strong post w-beam barriers (73 percent, weighted) with a much smaller contingent of strong post thrie beam barriers (12 percent), weak

post w-beam barriers (7 percent), box beam barriers (6 percent), and cable barrier (2 percent).

Approximately 18 percent of the total available cases (18.7 percent unweighted, 18.1 weighted) were impacts with barrier end terminals. A vast majority of these end terminal hits were to metal post and beam barriers. Vehicle rollover occurred in 35 percent of the unweighted cases (331 cases) and 22 percent of the weighted cases.

**Barrier Impact Rollover by Vehicle Type**

Table 2 provides a summary of the contingency table analysis of barrier crash rollover by vehicle type. The table shows the weighted rollover proportion by vehicle type along with the 95 percent confidence intervals of these estimates.

**Table 2 – Barrier Crash Rollover Rates and 95% Confidence Intervals by Vehicle Type, [NASS/CDS 1997-2007, inclusive]**

Vehicle Type	Rollover	Weighted Percent	95% CI on Percent
Car	No	86.9	78.9 – 94.9
	Yes	13.1	5.1 – 21.0
Pickup Truck	No	70.8	52.4 – 89.2
	Yes	29.2	10.7 – 47.6
SUV	No	50.2	29.1 – 71.4
	Yes	49.8	28.6 – 70.9

Cars had the lowest barrier rollover percentage (13.1 percent) followed by pickups (29.2 percent) and SUVs (49.8 percent). Likewise, the variation in these estimates varied according to vehicle type, with cars having the smallest and SUVs having largest. Based on the Rao-Scott modified likelihood ratio chi-squared test, a statistically significant difference was found between the barrier crash rollover rates of cars, pickups and SUVs ( $p = 0.0132$ ).

**Rollover by Barrier Type**

Table 3 provides a summary of the contingency table analysis of barrier crash rollover by barrier type. The table shows the weighted rollover proportion by barrier type along with the 95 percent confidence intervals of these estimates.

Based on the available data, concrete barriers have a lower rollover percentage compared to metal post/beam barriers. Based on the Rao-Scott modified likelihood ratio chi-squared test, no statistically significant difference was found between the barrier crash rollover rates between concrete and metal barriers ( $p = 0.2052$ ). Note, however, that this does

not account for end terminal versus length of need impacts.

**Table 3 – Barrier Crash Rollover Rates and 95% Confidence Intervals by Barrier Type, [NASS/CDS 1997-2007, inclusive]**

Vehicle Type	Rollover	Weighted Percent	95% CI on Percent
Concrete	No	83.4	75.1 – 91.6
	Yes	16.6	8.4 – 24.9
Metal	No	76.1	65.8 – 86.4
	Yes	23.9	13.6 – 34.2

**Binary Logistic Regression Model**

Binary logistic regression was used to predict barrier crash rollover by vehicle and barrier type while accounting for vehicle tracking and impact location on the barrier. A summary of the binary logistic regression model parameters is shown in Table 4. For each parameter, the Wald Chi-Square statistic and associated  $p$ -value has been included as well as the C-statistic for the model. The C-statistic represents the area under the Receiver Operator Characteristic (ROC) curve and provides a single numerical value of how well the model distinguishes between the response variable, in this case, vehicle rollover versus no rollover.

**Table 4 – Summary of Binary Logistic Regression Parameters**

Parameter	Wald $\chi^2$	P	C
Barrier Type	0.193	0.6607	0.63
Vehicle Type	15.38	0.0005	
Impact Location	0.033	0.8569	
Vehicle Tracking	7.240	0.0268	

Based on the parameter estimates, the effects of vehicle type and vehicle tracking were found to be statistically significant ( $p = 0.0005$ , and  $p = 0.0268$ , respectively). Neither barrier type nor impact location was found to have a statistically significant effect in our data set.

Table 5 shows the odds ratios for barrier type, vehicle type, impact location, and vehicle tracking for the binary logistic regression model. For the dichotomous barrier type and impact location variables, the odds ratio shown was with respect to the other possible value (i.e. concrete barrier and length of need impact location). The vehicle tracking comparison group was vehicles that were not tracking while the vehicle type comparison group was

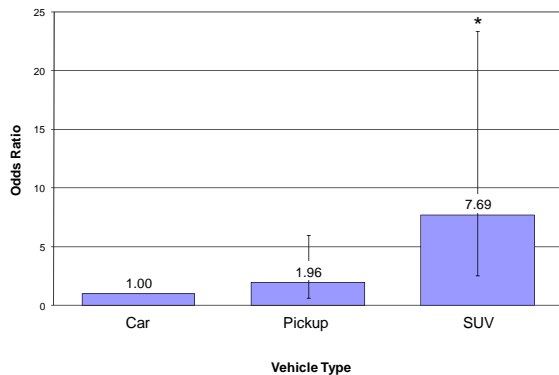
passenger cars. The 95 percent confidence bounds on each odds ratio are also shown.

**Table 5 – Summary of Odds Ratios and 95% Confidence Intervals for Barrier Crash Rollover**

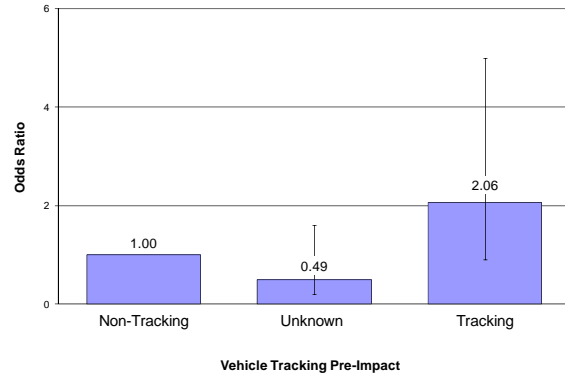
Parameter	Value	Odds Ratio	95% CI
Barrier Type	Metal	1.22	0.5 - 3.0
Vehicle Type	SUV	7.69	2.5 - 23
	Pickup Truck	1.96	0.6 - 6
Impact Location	End Terminal	1.12	0.3 – 3.9
	Length of Need	1.00	
Vehicle Tracking	Yes	2.06	0.9 – 5.0
	Unknown	0.49	0.2 – 1.6

With the exception of vehicles with unknown tracking, the model predicts an increased risk of vehicle rollover. These increases were only statistically significant for SUVs, which were found to have an eight-fold increase in rollover risk in barrier collisions compared to cars. Although not statistically significant, concrete barrier impacts, end terminal hits, and tracking impacts were associated with higher vehicle rollover risk in barrier crashes.

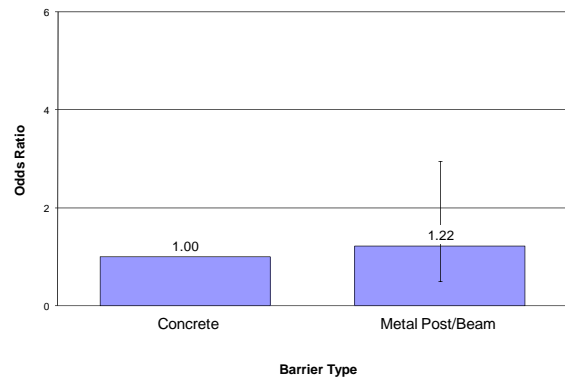
Figure 8 shows the odds ratio results graphically for the three vehicle types based on the binary logistic regression model. All odds ratios are with respect to cars and the error bars represent the 95 percent confidence bounds on the point estimates. Statistically significant differences from the passenger car comparison group are noted by an asterisk (\*). Figure 9, Figure 10, and Figure 11 show analogous odds ratio data for vehicle tracking, barrier type, and barrier impact location, respectively.



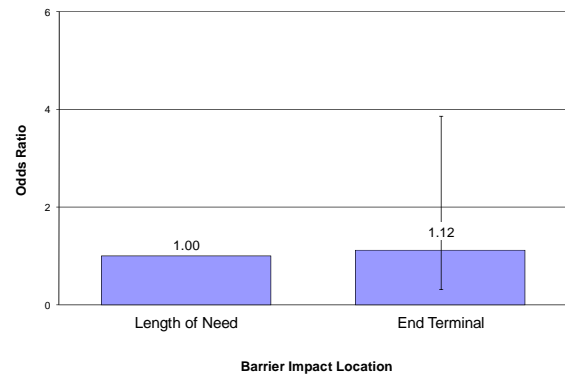
**Figure 8 – Odds Ratio and 95% Confidence Interval Plot for Barrier Crash Rollover by Vehicle Type (n = 955)**



**Figure 9 – Odds Ratio and 95% Confidence Interval Plot for Barrier Crash Rollover by Vehicle Tracking**



**Figure 10 – Odds Ratio and 95% Confidence Interval Plot for Barrier Crash Rollover by Barrier Type**



**Figure 11 – Odds Ratio and 95% Confidence Interval Plot for Barrier Crash Rollover by Barrier Impact Location**

## DISCUSSION

The results of the contingency table analysis suggested that the SUVs and pickups have higher rates of rollover than cars in barrier crashes. The rollover rates for pickups (29 percent) were roughly

double that of cars and the rate for SUVs (50 percent) was in excess of 3 times that of cars (13 percent). Compared to the previous literature, the rollover rates found in this study were at the upper limit of those previously reported. Similar rollover rates were found by Bligh and Mak (1999) using only fatal crash data. Although light trucks were found to have a higher rollover rate than cars in that study, no attempt was made to separate pickups from SUVs. The bias of NASS/CDS toward higher severity crashes may contribute to these high values to some degree. The most appropriate study to provide a comparison, however, is the NASS-based LBSS study conducted by Hunter, Stewart and Council (1993). In our study, the concrete barrier rollover rate was almost identical to the Hunter study (16.8 percent compared to 16.3 percent in Hunter et al.) despite crashes in our data set occurring at a minimum of 10 years later. What is alarming, though, is the comparison between metal beam barrier rollover rates. We find a rollover rate of 24 percent (20 percent for length of need, 27 percent for end terminals); approximately double that of the Hunter et al. study (8 percent rollover rate for length of need and 13 – 17 percent for end terminals).

The results of the binary logistic regression suggest that the most important aspects of a barrier crash are the striking vehicle type and whether the vehicle is tracking, when accounting for other confounding factors. SUVs were found to have a rollover risk approximately 8 times higher than cars in crashes with longitudinal barriers. This result was statistically significant. Tracking vehicles were also found to have an increased rollover risk, roughly double that of non-tracking vehicles. This result approached statistical significance with the lower confidence bound of the odds ratio at 0.9. This somewhat counterintuitive finding may be a result of the tendency of barriers to redirect vehicles back across the roadway (perhaps in a non-tracking manner), where the vehicle then rolls over. Previous research has been mixed with respect to the effect of vehicle stability on rollover risk; Mak and Sicking (1990) found higher rollover rates for tracking vehicles while Perera and Ross (1989) found higher rollover rates for non-tracking vehicles.

Pickup trucks were also associated with twice the rollover risk of passenger cars in barrier crashes, but this was not statistically significant. This suggests that while the pickup does have an increased risk of rollover in barrier crashes it likely does not represent a worst case in terms of vehicle rollover propensity.

Although not statistically significant, metal beam barriers were found to increase risk of rollover by a

factor of 1.2 compared to concrete barriers. Our study does not support the notion suggested by previous researchers that concrete barriers pose a greater rollover risk than metal barriers. A much more discerning factor in determining rollover in traffic barrier crashes appears to be vehicle type. This finding has direct implications on the full-scale crash testing of these barriers, which has traditionally been based on the assumption that the pickup truck is the critical vehicle. Our study suggests that SUVs have roughly 4 times the risk of rollover compared to pickup trucks impacting traffic barriers.

## LIMITATIONS

The primary limitation of the study was the inability to account for crash severity, which likely affects rollover risk in barrier crashes. Delta-V, the preferred measure of crash severity, is difficult to estimate for longitudinal barrier crashes (Smith and Noga, 1982). In addition, delta-V was not available for approximately 80 percent of the suitable cases (see Table 1). Due to the uncertainty in the delta-V estimates for this crash mode, the authors opted not to pursue a multiple imputation approach involving vehicle delta-V. Coon and Reid (2005; 2006) have developed a longitudinal barrier-specific methodology for determining vehicle delta-V in these collisions. These procedures are currently not incorporated into the NASS/CDS delta-V estimates. Another explored option was the use of equivalent barrier speed (EBS). EBS can be determined based on the crush of the subject vehicle. EBS avoids many of the difficulties associated with delta-V computations for vehicles impacting objects of unknown stiffness such as guardrails. Similar to delta-V, however, more than half of the EBS values were unknown for the suitable cases.

Another limitation of this study was the relatively small number of suitable raw barrier crashes available in NASS/CDS database. Despite the use of procedures to account for the complex sampling design of NASS/CDS, extrapolating the raw cases to a nationally representative sample adds some inherent uncertainty to the conclusions.

Also, our study was limited to police-reported tow-away crashes. Many crashes into longitudinal barrier are not police-reported (Michie and Bronstad, 1994) and would not be included in our analysis. It is unknown if crashes into concrete barrier or guardrail are more likely to result in tow-away level damage. If concrete barriers are more likely to lead to tow-away damage than guardrail, this would affect the odds ratio computation of guardrail versus concrete barrier risk.

Finally, the determination of the pre-impact stability of the vehicle is assessed by the NASS investigator based on the available scene information, interviewee information, and police accident report data. As the data available for each case can vary, the determination of the stability has an associated uncertainty. Also, it is possible that the determination of stability varies between investigators. The uncertainty of this determination would affect the barrier crash rollover odds ratio computation for tracking versus non-tracking vehicles.

## CONCLUSION

This study has investigated vehicle overturn in tow-away level traffic barrier crashes. In real world longitudinal barrier collisions, the most important predictors of vehicle rollover were found to be the vehicle type and whether the vehicle was tracking prior to impact with the barrier. When adjusting for other confounding factors, SUVs were found to have 8 times the risk of rollover as cars in barrier impacts. Although pickups were found to have an increased risk of rollover compared to cars, the risk was not as pronounced as that found for SUVs. This finding has direct implications for the full scale crash testing of longitudinal barriers as the testing procedures have been predicated on the assumption that the pickup provides a critical or worst case impact scenario. Metal beam barriers were also found to be associated with a slightly higher rate of vehicle rollover.

## ACKNOWLEDGMENTS

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