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Characterization of Pre-Roll Events of Sport Utility Vehicles: Data and Analysis

Prepared for
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16. Abstract

A variety of roll stability enhancement technologies exist or are under active development. An enhanced understanding of the events and conditions that lead to rollovers of SUVs in traffic crashes can identify opportunities for these technologies to intervene and reduce the incidence of rollover.

Literature on SUV rollover is reviewed. Data from FARS and GES are analyzed to determine factors that affect rollover. SUVs are over three times more likely to roll over, given involvement in a traffic accident, than passenger cars. In single vehicle crashes, 29.9% of SUVs rolled over. Factors associated with higher rollover probability include driver age less than 25, driver drinking, three or more occupants in the vehicle, traversing a curve, road speed limits greater than 50 mph, roadway grades, ice on the roadway, and (for multiple vehicle accidents), travel between midnight and 6 a.m.

In addition, 262 SUV rollovers in the NASS CDS file were reviewed and major rollover event sequences were identified. Three primary scenarios were defined: Loss of control, collision with another motor vehicle, and all other roll sequences. In the latter group, three pre-cursor scenarios were defined: drift off road, evasive maneuver, and ran off road. It was concluded that there may be an opportunity for vehicle stability control devices to affect up to 48.5% of SUV rollovers.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kpa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
rnL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	**1.8C + 32**	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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Characterization of Pre-Roll Events of Sport Utility Vehicles: Data and Analysis

The purpose of the present work is to develop a deeper understanding of how rollover occurs for sport utility vehicles (SUVs) in real-world crashes. A variety of roll stability enhancement technologies exist or are under active development. An enhanced understanding of the events and conditions that lead to rollovers of SUVs in traffic crashes can identify opportunities for these technologies to intervene and reduce the incidence of rollover.

The work consists of three parts. The first part is a review of the existing literature on SUV rollover, with a particular focus on any studies that describe the sequences of events that lead to rollover. In the second phase of the work, the best available crash data sets are analyzed to identify operational and environmental factors associated with rollover. In identifying factors that contribute to an increase in the probability of rollover, given a crash, we focused on conditions that exist at the time of the crash, such as driver condition, roadway condition and geometry, weather, light condition, time of day, and other "environmental" conditions. Driver behavior during the rollover sequence, while likely of great interest, cannot be recovered from existing, publicly available crash data files. A subtask in the analysis of existing crash data is to develop a "crash event tree," which records the sequence of events prior to the rollover, as well as it can be determined from the crash files.

The third phase of the work is to identify and clinically examine a sample of SUV rollover crashes, using the National Automotive Sampling System Crashworthiness Data System (NASS CDS). The crashes of 262 SUVs that rolled over were selected for further examination from the NASS CDS files. Data was collected on the events in the crash sequence up to the point at which the SUV rolled over. Information was collected on roadway condition, vehicle evasive maneuvers, vehicle recovery maneuvers, vehicle stability after the maneuver, rollover initiating event, direction of roll, number of quarter turns of roll, roadway condition at the point of roll, and other factors. A short summary the researcher's conclusions and observations was recorded for each crash.

Literature

The factors leading to vehicle rollover have been the focus of many studies in recent years, due to the associated high rates of fatalities and serious injuries. Light trucks, particularly sport utility vehicles (SUVs), have been shown to rollover at a higher rate than passenger cars. The problem has taken on increased significance of late, due to the popularity of SUVs and their increased presence on the road. Available literature was reviewed as background for the primary task of this effort, which is to collect data on the sequence of events leading to rollover for SUVs. Accordingly, the focus of the literature search was studies specifically on crashes involving SUVs, the mechanisms that lead to SUV rollover, and the factors associated with increased risk of rollover in this vehicle type.

A summary of the results generates the following observations. First, that SUVs have a higher rollover rate than other passenger vehicles has been established for many years. Second, although much has been written on the SUV rollover problem, there have been few efforts to determine the sequence of events preceding the actual rollover. This is most likely due to limitations in available data. Most crash data files provide only limited data on the events leading to a crash, but instead focus on the fatalities and injuries resulting from the crash. A third observation is that there are relatively few studies that focus primarily on SUVs, or allow SUVs to be distinguished in the results. Most of the studies reviewed considered passenger cars or light trucks, which consist of pickups, vans, and SUVs. In the discussion below, we will consider primarily those studies on SUVs specifically or which allow SUVs to be identified.

Higher rollover rates in fatal crashes of light trucks (pickups, vans and SUVs) compared with other passenger vehicles, has been well-documented for over twenty years. In a recent paper providing descriptive statistics on fatal rollover crashes, Deutermann reported that the number of fatal SUV rollovers has more than doubled since 1991.[6][1] This is not due to a change in the rollover rate, but rather the number of SUVs on the roads. Deutermann showed that about 36% of all SUVS involved in a fatal crash experienced a rollover, compared with pickup trucks (24%), vans (19%), and passenger cars (15%). Table 1 shows the percentage of all seriously injured and fatally injured occupants that were injured in rollover crashes, for each of four vehicle types. Sixty-one percent of fatalities in SUVs occurred when the vehicle rolled over, and 46% of the serious injuries occurred in rollover.[2] The information presented in the table indicates that rollover is associated with most fatalities and serious injuries to SUV occupants. Accordingly, reducing rollover would have a significant safety benefit.

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[1] Numbers in square brackets specify references listed at the end of the paper.

Table 1 Percentage of Serious and Fatal Injuries in Rollover by Vehicle Type, NASS-CDS Estimates, 1997-2000 from Deutermann [6]

Vehicle type	Serious injuries	Fatalities
Passenger cars	16%	22%
Vans	13%	39%
Pickups	30%	44%
SUVs	46%	61%

Deutermann [6] has provided the most comprehensive look at the rollover crashes of passenger vehicles. He used the Fatality Analysis Reporting System (FARS) file, a census file of all fatal traffic accidents in the United States. Since the analysis is restricted to FARS, the findings are valid for fatal crashes only, but Deutermann has provided the most detailed examination of rollovers to date, and more importantly here, he broke out his findings by specific vehicle types, including passenger cars, SUVs, pickups, and vans. He found significant differences in the proportion of rollovers in single vehicle fatal crashes. Over 80% of the fatal single vehicle crashes of passenger cars included rollover, compared with 75% of SUV single vehicle fatal crash, 70% of pickups in fatal single vehicle crashes and 60% of fatal crashes involving vans.

Table 2 shows the percentage distribution of pre-crash maneuver in fatal single vehicle rollovers. Note that SUVs have a significantly lower proportion of “negotiating a curve” compared to passenger cars, 24% to 34% respectively. Two-thirds of the SUVs were coding as going straight prior to rollover.

Table 2 Distribution of Pre-crash Maneuver in Fatal Single Vehicle Rollovers by Vehicle Type from Deutermann [6]

Maneuver	Cars	SUVs	Pickup	Van	Total
Going straight	58	66	62	71	61
Passing	2	2	1	1	2
Changing lane	2	3	1	1	2
Negotiating curve	34	24	33	23	31
Other	4	5	3	4	4
Total	100	100	100	100	100

Drivers of vehicles that rolled over tended to be younger, but interestingly, 72% of passenger car drivers who rolled over in fatal crashes were under 40, while 65% of SUV drivers were under 40, and only 49% of van drivers were that young. Speeding was also associated with rollover—overall 40% of drivers involved in a fatal rollover were coded with speeding, compared with 15% for non-rollovers. Speeding was more likely to be reported for younger drivers than older.

Table 3 shows reported speeding reported by body type. It is interesting to note that speeding is significantly less likely in the fatal single vehicle rollovers of SUVs as compared to passenger cars. Speeding is also more likely in single- than multi-vehicle rollovers. On the other hand, a higher proportion of rollovers of SUVs and pickups occur on roads with a speed limit of 50 mph or greater: 76% of SUV rollovers compared to 68% of passenger car rollovers.

Table 3 Speeding by Vehicle Type in Single Vehicle Rollovers from Deutermann [6]

Passenger car	48%
SUV	33%
Pickup	36%
Van	24%
All	40%

Deutermann also reports differences in the rate of alcohol use associated with rollover by vehicle type. SUVs and vans have the lowest rate, with 27% and 24% respectively, compared with 39 and 43% for cars and pickups, respectively.

Parenteau, et al., [15] analyzed data available from the National Automotive Sample System Crashworthiness Data System (NASS CDS) to identify common rollover types and associated factors. The vehicle type considered in the work was “light vehicles” (LTV) and included passenger cars, light trucks (rated weight under 4536 kg)[2], utility vehicles, and vans. Unfortunately, for the present purpose, the component vehicle types are not broken out specifically, but rather analyzed as a group, though some tables distinguish passenger cars from light trucks.

Parenteau found that most rollovers are initiated by tripping, when the lateral motion of the vehicle is suddenly slowed or stopped. As shown in Table 4, trip-overs account for 51% of light truck rollovers. (The appendix includes NASS-CDS definitions of rollover initiation types.) Fall-overs are the second most common light truck rollover type, accounting for 15%. Analysis of the NASS CDS data indicated that 93% of light truck trip-overs were caused by contact with the ground, and only 6% by hitting a curb. Most passenger vehicles involved in a rollover skidded prior to the roll, and more than 69% of trip-overs occurred outside of the roadway.

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[2] The text indicates that the vehicles *weighted* less than 4536 kg., but, since the body type variable in NASS CDS incorporates rated weight (GVWR) in the definition, this is likely a misstatement.

Table 4 Distribution of Light Truck Roll Initiation Type, after Parenteau, et al. [15]

Rollover initiation type	%
Trip-over	51.2
Fall-over	15.4
Turn-over	9.7
Bounce-over	7.6
Flip-over	7.3
Collision with other vehicle	7.3
Climb-over	0.9
Other	0.3
End-over-end	0.1
Total	100.0

In later work, Parenteau, et. al., [16] examined 1992-1996 NASS CDS data to assess the relevance of rollover tests to the actual rollover experience as recorded in crash data. The type of rollover initiation was used to judge the relevance of a suite rollover tests. The authors found that trip-overs were most common for both passenger cars and light truck vehicles (pickups, SUVs, and vans), with 56.8% and 51.2%. Turn-overs were more frequent for LTVs, accounting for 9.7% compared with 5.2% for passenger cars. The fall-over accounted for 12.9% of passenger cars and 15.4% of LTVs. See for Table 5 the distribution of all rollover types. The rollover tests judged consisted of tests for soil-trip, curb-trip, the ADAC corkscrew, ditch test, and the FMVSS 208 dolly test. See the paper for a description of each. The authors judged that the suite of tests were relevant to 83.0% of passenger car rollovers and 75.1% of LTV rollovers.

Table 5 Rollover Initiation Type for Passenger Cars and LTV after Parenteau, et. al., [16]

Rollover initiation type	Passenger car	LTV
Trip-over	56.8	51.2
Fall-over	12.9	15.4
Turn-over	5.2	9.7
Bounce-over	8.4	7.6
Flip-over	11.6	7.3
Collision with other vehicle	2.3	7.3
Climb-over	1.5	0.9
Other	0.7	0.3
End-over-end	0.6	0.1
Total	100.0	100.0

Determination of rollover initiation is difficult and has been subject to some correction. The turn-over type, in which friction at the tire/road interface provides sufficient resistance to lateral movement of the vehicle to over turn it, is of particular interest because it is difficult to identify and points most directly at vehicle instability. Hendricks, et al., [10] reviewed 267 rollovers coded turn-over from the NASS CDS 1992-1996. They reviewed hard copies of the cases, including scene diagrams, photos and other evidence, to determine rollover initiation type. The criteria to correct initiation type was rigorous, and required physical evidence of tripping, such as gouges in the road and corresponding damage to wheel rims. Moreover, a secondary criterion was that the evidence of the tripping mechanism must be sufficient to actually trip the vehicle. This is an admittedly subjective judgment, but the result is a rather conservative approach to changing the judgment of the original NASS researcher: Not only must there be physical evidence of a trip or other rollover type, but the evidence must also point to enough force to overturn the vehicle. Scratches in the road or abrasions to wheel rims are not sufficient. The review showed that of the 267 cases coded turn-over, only 107 should have been coded turn-over. Of the cases that were changed, 61.9% were trip-overs, 9.4% were assigned to the flip-over category, and 6.9% were coded fall-over. They also examined 100 tripped rollovers sampled from the 1701 in the period and found that three should have been coded turn-over.

Altman, et al. [4] compared the rollover characteristics of passenger cars, SUVs, and pickup trucks, using data from crash reconstructions and rollover tests. The source of the crash data is not well-described, so its representativeness cannot be evaluated. The results showed that the distance traversed during rollover and the number of rolls for SUVs were greater than for both other vehicle types (63% of SUVs rolled three or more times, compared with 32% for passenger cars). They also found that vehicles which began their rollover sequence on-road tended to be traveling at a higher speed than those vehicles which began to roll off-road. The authors concluded that the majority of the vehicles that began to roll on the road were sport utility vehicles that had not dissipated significant energy during their pre-trip/tip-up phase. The vehicles traveling at higher speeds at the time they began to roll off-road were also SUVs which had not dissipated significant energy prior to the initiation of rollover and prior to entering the shoulder. They attributed this to the low yaw angle at which SUVs began their rollover phase.

However, Eigen [7] used NASS CDS (1995-2001) data to analyze the number of quarter turns by vehicle type for single-vehicle rollovers and found little difference between SUVs and passenger cars. Forty percent of each rolled three or more times; approximately 39% of pickup trucks that rolled also experienced three or more quarter turns of roll. The differences could partly be due to the fact that the Altman study was based on only 38 vehicles, compared with an unweighted N of 2,944 in the Eigen study.

Another study by Krull, et al. (2000) [13] examined pre-rollover events as recorded in two crash data files from states. However the focus was on the relationship of roadside features to occupant injury severity, so the analysis was limited to rollovers occurring *after* the vehicle left the roadway. They looked at single-vehicle ran-off-road crashes for light vehicles, including passenger cars, pickup trucks and vans (apparently SUVs were not included). Three years of Illinois and Michigan data were evaluated. The results are shown in Table 6.

Table 6 Distribution of Rollovers by Sequence of Events from Krull et al. [13]

Sequence of events	IL data	MI data
Rolled over initially after leaving roadway	59%	78%
Left roadway, hit a point fixed object, then rolled over	15%	6%
Left roadway, hit a longitudinal object, then rolled over	7%	4%
Left roadway, hit a curb object (including traffic islands) then rolled over	1%	1%
Left the roadway, hit a ditch or embankment, then rolled over	18%	11%
Total	100%	100%
Total cases	4681	6384

Note: Point objects include roadside objects such as bridge ends, traffic signs, signal posts, light supports, utility poles, mailboxes, trees, fire hydrants, impact attenuators, and culverts. Longitudinal objects include bridge rails, guardrail faces, guardrail ends, and median barriers.

The limitations of using existing crash data to study the events leading to rollover were explicitly recognized in a study by Viano and Parenteau (2003) [19]. They reviewed case materials from 63 NASS-CDS single-event rollovers (passenger cars and light trucks) from 1995-1999 to determine the sequence of events leading to rollover. Of the original 63 cases, 12 could not be assigned a vehicle motion and were thus excluded from the study, resulting in 51 studied cases. Data were categorized by three types of pre-event scenarios.

Table 7 Vehicle Maneuvers Leading to Rollover from Viano and Parenteau (2003) [19]

	Precipitating vehicle motion			
Pre-event scenario	Drifting	Avoiding an obstacle	Negotiating a curve	Total
Departs road, comes back, departs road again, rolls over	9	5	9	23 (45.1%)
Departs road and rolls over	4	4	15	23 (45.1%)
Rolls on road	1	4	0	5 (9.8%)
Total	14 (27.5%)	13 (25.5%)	24 (47.1%)	51 (100.0%)

In 47% of the cases, the driver was negotiating a curve prior to rollover. In 63% of these cases, the vehicle departed the road and rolled over, and the remainder departed, returned, departed again and then rolled. In 28% of the studied cases, the vehicle was drifting at roadway exit. In the case of avoiding an obstacle (26% of cases), approximately an equal number rolled on the road, off the road (after departing once), and off the road (after departing twice).

Although the articles reviewed above relate to the issue of defining the pre-rollover events sequence, there is clearly a dearth of definitive literature on the subject, and particularly for the SUV vehicle type. The work reported below is an attempt to address the issue. In the next section, SUV rollover is explored in the available crash data files. Following that, we report on an examination of pre-roll events of 262 SUVs in traffic crashes.

Crash data analysis

In this section, the results of the crash data analysis are presented. The full and complete set of tables can be found in the Appendix.

Data

The data used in the analysis are the 1999-2001 Fatality Analysis Reporting System (FARS) and the 1999-2001 General Estimates System (GES) files. The FARS and GES crash files are compiled by the National Center for Statistics and Analysis (NCSA) within the National Highway Traffic Safety Administration (NHTSA). FARS is a census file of all fatal traffic accidents occurring in the United States. It is compiled from data collected by analysts in each state and provides the most comprehensive and detailed data on fatal traffic accidents. The GES file is a nationally-representative sample of police-report traffic accidents. The file is coded from a set of police reports selected through a stratified sampling system that, when the sample weights are correctly applied, provides national estimates of traffic accidents of all severities.

FARS and GES data are combined for the analysis. FARS provides a census of fatal crash involvements; as such, FARS data are the best source of counts of fatal crash involvements, including SUV rollovers that include a fatality. The GES data cover all crash severities reportable in the sampled jurisdictions—from property-damage-only crashes to fatal crashes—but only a sample of crashes are selected for the file. Because the cases in the GES file are sampled, there is an associated sampling error. In small subsets of the file, the sampling error can be large relative to the point estimate. Moreover, it is known that the GES file underestimates fatal crashes.

Accordingly, to improve the accuracy of the crash estimates presented here, two strategies are employed. First, three years of data are combined. By increasing the amount of data, the relative sampling error is reduced and the precision of the estimates is increased. Second, FARS data are substituted for GES data for fatal crashes. In constructing the data files used in the analysis, data on crashes that do not involve a fatality are taken from GES, while data on fatal crashes are taken from FARS.

The internal structure of the FARS and GES files facilitate the combination. The two data systems have many variables in common, and, since both are compiled by the same organization, the variables used in the analysis have the same code levels, definitions, and rules for coding. Thus it was not necessary to harmonize any variables to permit combining FARS with GES. Since GES is the product of a sample survey, each record has a sample weight that reflects the probability of selection. Since FARS is a census file, the probability of selection is essentially one, and in the FARS file a weight variable was created and assigned the value of one.

The combination of FARS and GES data provides the most accurate account of traffic crashes in the United States.

Vehicles

The primary focus in this analysis is on sport utility vehicles, or SUVs in the conventional acronym. The “body type” variable in FARS and GES was used to identify SUVs. Codes 14 and 15 of the body type variable identify compact utility and large utility vehicles respectively. Vehicles identified using these codes comprehend the most common SUVs on the road. Table 8 shows the top seven make/models of SUVs in the FARS/GES crash data, which together account for almost two-thirds of all SUVs in the combined crash file.

Table 8 Most Common SUV Make/Models 1999-2001 FARS and GES

Make/model	Percent
Ford Explorer	20.14
Jeep Liberty	16.62
Chevrolet S-10 Blazer	11.80
Toyota 4-Runner	4.75
Chevrolet Blazer-fullsize/Tahoe	4.59
GMC Jimmy/Typhoon/Envoy	4.36
Ford Expedition	3.66
All others	34.08

A comparison group was defined as passenger cars. Cases selected for the comparison group had body type codes from 1 through 9. These codes identify convertibles, two-, three-, and four-door sedans, hatchbacks, and station wagons. Comparison with this group will allow the special characteristics of SUVs to be more easily highlighted. Passenger cars serve as a baseline case against which to judge SUVs.

Overview

In this section we will discuss factors that significantly affect the probability of rollover. The focus is on pre-crash conditions, rather than crash configuration or actions of the driver. Factors considered here include time of day, ambient light, weather, road type, road condition, posted speed limit, driver age, sex, drinking, and number of occupants in the vehicle. A complete set of tables is included in the Appendix. The discussion here focuses on the primary factors that contribute to increasing rollover risk, as determined from available crash data.

Many factors contribute to rollover in traffic crashes. In general it is useful to group the factors into three primary domains: operating environment, vehicle design, and driver behavior. Operating environment captures features that include roadway curvature, grade, speed limit, road surface condition, weather, and time of day. The primary vehicle factor considered here is the contrast between passenger cars and SUVs. Relevant design differences are well-known. SUVs are characterized by a lower static roll stability and higher ground clearance than passenger cars. Factors in the driver domain are age, sex, and alcohol use.

By comparing probability of rollover in SUVs and passenger cars across the different dimensions of the domains, we can gain insight into the contribution of vehicle design to the probability of rollover. It is acknowledged that the overall differences in rollover probability is not due solely to differences in vehicle design—specifically, the lower static roll stability. Differences in how the vehicles are operated also contribute. But by comparing rollover probabilities of SUVs and passenger cars across a variety of the factors that affect the probability of rollover, we can show the contribution of vehicle design to the higher rollover rate of SUVs. The exploration presented here is admittedly preliminary. A full consideration would involve development of statistical models specifying all the factors that affect the risk of rollover, which is outside of the scope of the current effort.

Table 9 provides estimates of the crash involvements of passenger cars and sport utility vehicles (SUVs) by crash severity and rollover. This table captures the scope of the safety problem related to SUV rollover. The estimates are generated from the FARS and GES data files for 1999 through 2001. Over that period, over 20 million passenger vehicles were involved in a crash, and 361,071 of those vehicles rolled over. In the same period, 2.7 million SUVs were involved in a traffic crash, and 166,065 rolled over as a consequence.

Table 9 Rollover and Crash Severity for Passenger Cars and Sport Utility Vehicles 1999-2001 FARS and GES

	Passenger cars			SUVs		
Crash severity	No roll	Roll	Total	No roll	Roll	Total
Fatal	69,818	12,883	82,701	9,620	5,671	15,291
Incapacitating	774,398	56,437	830,835	88,818	30,036	118,854
Non-incapacitating	1,720,122	105,278	1,825,400	203,137	45,064	248,201
Possible injury	4,114,703	68,382	4,183,084	471,492	28,713	500,205
Injured, unknown severity	24,574	1,262	25,835	1,878	699	2,577
No injury	12,110,000	105,457	12,220,000	1,706,310	52,978	1,759,288
Unknown	892,703	11,372	904,075	77,589	2,905	80,494
Total	19,706,318	361,071	20,071,930	2,558,845	166,065	2,724,909
	Crash severity probability by vehicle type and rollover					
Fatal	0.4	3.6	0.4	0.4	3.4	0.6
Incapacitating	3.9	15.6	4.1	3.5	18.1	4.4
Non-incapacitating	8.7	29.2	9.1	7.9	27.1	9.1
Possible injury	20.9	18.9	20.8	18.4	17.3	18.4
Injured, unknown severity	0.1	0.3	0.1	0.1	0.4	0.1
No injury	61.5	29.2	60.9	66.7	31.9	64.6
Unknown	4.5	3.1	4.5	3.0	1.7	3.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

In Table 9, the column percentages show the distribution of crash severity for rollover, no rollover and all involvements for both passenger cars and SUVs. Rollover increases the risk of a fatal injury substantially. While about 0.4% of non-rollover crash involvements resulted in a fatality for SUVs, 3.4% of rollover involvements resulted in a fatality. Note that the increase in the probability of injury given a rollover is about the same for both SUVs and passenger cars.

While crash severity given rollover is similar for passenger cars and SUVs, SUVs have a significantly higher probability of rollover, given involvement in a traffic accident, than passenger cars. Table 10 shows the probability of rollover for the two vehicle types. “Probability of rollover” is just the proportion of crash involvements that resulted in a rollover. Note that SUVs rollover at more than three times the rate of passenger vehicles. This comparison does not take into account any differences in operating environment and driver behavior that may contribute to the higher SUV rollover rate. It does however indicate that rollover is a significant safety problem for SUVs. Technical interventions to reduce the rollover rate can have a substantial impact.

Table 10 Passenger Car and SUV Probability of Rollover 1999-2001 FARS and GES

Vehicle type	Involvements	Probability of rollover
Passenger car	20,071,930	1.8
SUV	2,724,909	6.1

Rollover in single and multiple vehicle crashes is considered separately. Table 11 illustrates that the probability of rollover is significantly different between the two crash types, and between the two vehicle types. For SUVs, almost 30% of single vehicle crash involvements resulted in a rollover. This percentage includes all single vehicle crashes, including minor ones. In contrast, the rollover probability in multiple vehicle crashes is much lower, only 1.6%. SUVs are almost three times more likely than passenger cars to roll over in single vehicle crashes, and almost seven times more likely to roll in multiple vehicle crashes.

Table 11 Rollover Probability by Vehicle Type and Number of Vehicles in Crash
1999-2001 FARS and GES

	Passenger car		SUV		
Crash type	Involvements	Probability of rollover	Involvements	Probability of rollover	Ratio SUV/ Passenger car
Single vehicle	3,091,401	10.4	432,548	29.9	2.9
Multiple vehicle	16,976,335	0.2	2,292,360	1.6	6.7

The effect of driver condition and characteristics on rollover is discussed first. In terms of the human contribution to rollover, the conditions are the age, sex, and alcohol use of the driver, as well as the number of occupants of the vehicle.

The tables that follow have been structured to provide the relevant information compactly. The N column shows weighted estimates of the number of involvements for a cell. The roll probability is just the proportion of those involvements that resulted in a rollover. The relative risk column shows the rollover risk for that cell normalized to the overall rollover risk for the relevant combination of vehicle type and single- or multiple vehicle crashes. For example, the table shows that there were 28,065 single vehicle crash involvements of an SUV with a driver over age 55. Of those involvements, 20.3% rolled over. Compared to the rollover probability of all SUVs in single vehicle crashes (29.9%), the rollover risk of drivers over 55 involved in a single vehicle crash is only 0.678 of the overall risk (20.3/29.9=0.678).

Note that there is some minor variation in the involvement marginal totals shown in the different tables. This variation is due to variations in the precision of cell frequencies printed by the statistical software used in performing the analysis. For very large numbers (from the GES file), scientific notation is used in printing cell frequencies, which limits the precision of the numbers printed. For example, 1.462E7 might be printed, rather than 14,623,486, the actual cell frequency. When these frequencies are summed, the totals can be different from totals summed from cells with numbers small enough for full precision to be preserved.

Rollover risk, given involvement in a single vehicle crash, varies significantly by driver age. (Table 12) Younger drivers are more likely to roll as a consequence of crash involvement for both SUVs and passenger cars. Thirty-seven percent of SUV drivers younger than 25 in single vehicle crashes rolled over, compared with 29.9% of all single vehicle crashes, for an increase in the rollover risk associated with age of 1.238. Young drivers of passenger cars are also more likely to roll over in single vehicle crashes, and in fact the size of the effect is greater than that for SUVs. In single vehicle crashes, the relative rollover risk of a driver under 25 is 1.424, compared with 1.238 for drivers of SUVs in the same age group. The effect of age is much lower, and in fact the apparent age effect on rollover probability in multiple vehicle crashes for SUVs may not be statistically significant. For passenger vehicles, the relative rollover risk of younger drivers is 1.205.

Table 12 Roll Probability by Driver Age, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

Driver age	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
	Single vehicle crashes					
<25	1,158,984	14.8	1.424	142,234	37.0	1.238
25-55	1,345,676	9.0	0.864	245,710	27.8	0.928
>55	339,001	5.3	0.510	28,065	20.3	0.678
Unknown	247,738	4.4	0.425	16,540	17.2	0.574
Total	3,091,399	10.4	1.000	432,549	29.9	1.000
	Multiple vehicle crashes					
<25	5,040,659	0.3	1.205	554,337	1.7	1.062
25-55	8,617,227	0.2	0.948	1,499,637	1.6	0.985
>55	2,658,277	0.2	0.937	186,467	1.7	1.068
Unknown	661,410	0.1	0.366	51,920	0.8	0.512
Total	16,977,573	0.2	1.000	2,292,360	1.6	1.000

It had been expected that driver sex would significantly affect rollover probability, on the theory that males tend to driver more aggressively, but, at least as far as the conditional probability of rollover in single vehicle crashes, there is no significant difference in these data. (Table 13) Note that this measures only rollover probability given a crash, not the probability of crash involvement in the first place. The relative risk of rollover in multiple vehicle crashes is somewhat higher for males, for both SUVs and passenger cars, but the effect is small, and likely not statistically significant for SUVs.

Table 13 Roll Probability by Driver Sex, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Driver sex	Single vehicle crashes					
Male	1,665,381	10.8	1.045	259,300	30.4	1.016
Female	1,249,587	10.5	1.013	161,285	30.2	1.008
Unknown	176,432	5.0	0.482	11,964	16.6	0.554
Total	3,091,400	10.4	1.000	432,549	29.9	1.000
	Multiple vehicle crashes					
Male	8,175,136	0.3	1.181	1,207,541	1.7	1.082
Female	8,491,010	0.2	0.853	1,064,617	1.5	0.920
Unknown	311,427	0.1	0.263	20,203	0.4	0.268
Total	16,977,573	0.2	1.000	2,292,361	1.6	1.000

Driver alcohol use, however, contributes significantly to rollover probability for both SUVs and passenger vehicles, and in both single and multiple vehicle crashes. (Table 14) Almost 39% of drinking SUV drivers in single vehicle crashes rolled over, compared with 29.9% rollover probability for all single vehicle SUV crashes. In multiple vehicle SUV crashes the increase in roll risk is even greater, with drinking SUV drivers 3.957 times more likely to rollover than all multiple vehicle SUV crashes.

Table 14 Roll Probability by Driver Drinking, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Driver drinking	Single vehicle crashes					
Drinking	330,510	17.4	1.682	51,900	38.6	1.289
Not drinking	2,361,806	10.0	0.962	341,361	29.6	0.989
Unknown	399,085	6.8	0.659	39,289	21.3	0.713
Total	3,091,401	10.4	1.000	432,550	29.9	1.000
	Multiple vehicle crashes					
Drinking	253,709	1.3	5.510	33,627	6.3	3.957
Not drinking	15,495,071	0.2	0.947	2,134,455	1.6	0.980
Unknown	1,227,042	0.2	0.732	124,278	0.9	0.545
Total	16,975,822	0.2	1.000	2,292,361	1.6	1.000

Note again the curious result that the effect of drinking on rollover probability is greater for passenger car drivers than for SUVs. Rollover rates are consistently and significantly lower for passenger cars, regardless of alcohol use, but the increase of rollover risk associated with drinking is greater for passenger cars than for SUVs. In single vehicle crashes, drinking increases the rollover risk by 1.289 times for SUVs, but 1.682 times for passenger cars. In multiple vehicle crashes, drinking increases rollover risk by a factor of 3.957 for SUVs, compared with 5.510 for passenger cars.

Table 15 shows the rollover risk by the number of occupants in the vehicle, split into one or two occupants, and three or more. The number of occupants in a vehicle can potentially affect rollover risk in two ways. First, additional occupants can raise the center of gravity, and thus decrease vehicle stability. Second, driver distraction may increase because of additional passengers. The distraction effect would primarily affect crash probability, but it may also affect roll probability given a crash, if the distraction induces speeding or other erratic driving behaviors. In any case, three or more occupants is associated with an increase in the relative risk of rollover for SUVs in both single vehicle and multiple vehicle crashes. In single vehicle crashes, 36.0% of involvements with the greater number of occupants included a rollover, compared with 29.9% of all single vehicle SUV crashes. The increase in the relative risk of rollover was actually greater in multiple vehicle crashes, where three or more occupants was associated with a 1.614 time increase in roll probability. For passenger cars, the increased risk in multiple vehicle crashes was only 1.270 (actually lower than the increase for SUVs) and 1.361 times in single vehicle crashes (higher than the 1.205 increase noted for SUVs).

Table 15 Roll Probability by Number of Occupants, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

Number of occupants	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
	Single vehicle crashes					
1 or 2	2,824,979	10.1	0.971	385,378	29.2	0.977
3 or more	255,785	14.1	1.361	46,289	36.0	1.205
None or unknown	10,636	0.1	0.007	883	12.0	0.402
Total	3,091,400	10.4	1.000	432,550	29.9	1.000
	Multiple vehicle crashes					
1 or 2	15,395,862	0.2	0.975	2,046,211	1.5	0.928
3 or more	1,546,896	0.3	1.270	243,498	2.6	1.614
None or unknown	36,696	0.0	0.046	2,652	0.1	0.047
Total	16,979,454	0.2	1.000	2,292,361	1.6	1.000

Next the effect of the environment, broadly defined, on conditional rollover probability is considered. Table 16 shows roll probability by roadway alignment, that is, whether the roadway at the point of the crash was curved or straight. Naturally it is expected that rollover is more likely on curved sections of road, since the physical mechanism of rollover requires some lateral acceleration. The table shows evidence that rollover is much more likely on curved than straight roadway sections. This is true for both single vehicle and multiple vehicle crashes and for both passenger cars and SUVs. Almost half (48.2%) of single vehicle SUV crash involvements on curves resulted in a rollover, compared with 29.9% rollovers in all single vehicle crashes. Curves are associated with an increase in roll probability of 1.612. An increase in roll probability is also observed for SUVs in multiple vehicle crashes, though the increase is significantly less at 1.290

times. The affect of roadway curvature is greater for passenger vehicles. In single vehicle crashes, passenger vehicles are 1.752 times more likely to roll. In multiple vehicle crashes, the proportion of rollovers on curves in 1.912 times greater than the overall proportion of rollovers for passenger cars. Given crash involvement, roadway curvature is associated with an increase in roll risk. And the effect is somewhat larger for passenger cars than for SUVs, though as usual the absolute roll risk is much higher for SUVs than passenger cars. Note, for example, that the rollover risk for an SUV on a straight section of road is significantly higher than the rollover risk of a passenger vehicle on a curved section.

Table 16 Roll Probability by Roadway Alignment, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

Roadway alignment	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
	Single vehicle crashes					
Straight	2,107,922	8.2	0.789	290,998	25.2	0.844
Curve	705,510	18.2	1.752	94,067	48.2	1.612
Unknown	277,968	7.1	0.687	47,483	22.3	0.745
Total	3,091,400	10.4	1.000	432,548	29.9	1.000
	Multiple vehicle crashes					
Straight	14,171,899	0.2	0.942	1,887,060	1.6	0.993
Curve	931,513	0.5	1.912	147,783	2.1	1.290
Unknown	1,872,681	0.2	0.984	257,518	1.4	0.886
Total	16,976,093	0.2	1.000	2,292,361	1.6	1.000

Speed limit can serve as a surrogate for travel speed, which is not reliably available in the crash files. One would expect a higher conditional probability of rollover (conditioned on accident involvement), on high speed roads compared with low speed roads. Table 17 provides evidence that higher speed roads are associated with significant variation in rollover probability. Almost 40% (38.5%) of SUVs involved in single vehicle crashes on roads with speed limits greater than 50 mph overturned, compared with 29.9% overall and 16.5% rollovers for passenger cars on the same roadways. In contrast, only 15.2% of single vehicle SUV crashes resulted in rollover, for a relative risk of 0.507. The same effect is observed in multiple vehicle crashes, where again high speed roads are associated with a significant increase in rollover, given a crash.

Table 17 Roll Probability by Speed Limit, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Speed limit	Single vehicle crashes					
<=25 mph	474,186	4.0	0.385	62,324	15.2	0.507
30-50 mph	793,179	11.1	1.067	124,861	30.0	1.002
>50 mph	1,018,164	16.5	1.590	179,565	38.5	1.287
Unknown	805,870	5.7	0.551	65,800	20.4	0.680
Total	3,091,399	10.4	1.000	432,550	29.9	1.000
	Multiple vehicle crashes					
<=25 mph	1,797,737	0.1	0.338	228,494	0.9	0.565
30-50 mph	8,497,635	0.1	0.611	1,307,846	1.4	0.871
>50 mph	2,230,150	0.9	3.780	367,933	3.5	2.194
Unknown	4,452,050	0.1	0.617	388,088	0.9	0.559
Total	16,977,573	0.2	1.000	2,292,362	1.6	1.000

The effect is greater for passenger vehicles than for SUVs, though the absolute probability of rollover is much lower. Passenger cars involved in single vehicle crashes on high speed roads are 1.590 times more likely to rollover as a result, compared with all single vehicle crashes. In multiple vehicle crashes, the increase in roll probability is 3.780 for passenger cars, compared with only a 2.194 increase for SUVs. This is an increase in risk compared with the baseline roll risk for each vehicle type. In terms of absolute risk, the rollover risk of an SUV in a multiple vehicle crash on roads with speed limits 25 mph and below is the same as that of passenger cars on the high speed roads. About 0.9% of each group roll over given crash involvement, which is a telling comparison of relative stability. But the *relative* increase in roll probability is greater for passenger cars than SUVs.

Table 18 tabulates the association between roadway grade at the accident site and the probability of rollover. As might be expected, rollover is less likely to accompany crash involvements that occur at sites where the roadway is level than on hills. (In the table, the "other" category is primarily at "sag" locations—the low point between slopes—and is too small to be reliable.) For SUVs in both single vehicle and multiple vehicle crashes, rollover is more likely to occur on grades than on level roads, by 1.267 and 1.341 times respectively. Grades are also associated with an increase in rollover probability for passenger cars, and by a greater amount than for SUVs. The relative increase in rollover risk for passenger cars in single vehicle crashes in 1.436 on grades and 1.925 in multiple vehicle crashes.

Table 18 Roll Probability by Roadway Profile, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

Roadway profile	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
	Single vehicle crashes					
Level	1,582,579	9.3	0.901	193,181	28.8	0.962
Grade	632,899	14.9	1.436	101,074	37.9	1.267
Other	55,803	14.8	1.430	6,468	45.3	1.513
Unknown	820,119	8.6	0.825	131,825	24.7	0.827
Total	3,091,399	10.4	1.000	432,550	29.9	1.000
	Multiple vehicle crashes					
Level	9,437,318	0.2	0.986	1,195,893	1.6	0.989
Grade	2,076,899	0.4	1.599	313,512	2.1	1.341
Other	255,578	0.5	1.925	28,796	0.8	0.505
Unknown	5,207,777	0.2	0.742	754,159	1.4	0.895
Total	16,977,573	0.2	1.000	2,292,362	1.6	1.000

The effect of weather on conditional rollover probability may be counter-intuitive. It is expected that adverse weather conditions would increase the probability of crash involvement, but Table 19 shows that weather has less impact on the probability of rollover given crash involvement than other factors. For SUVs involved in single vehicle crashes, rain only slightly increases the probability of rollover, with 1.111 times greater risk, while the risk is somewhat lower in dry conditions. (Note that most rollovers occur in dry conditions: 321,189 of the 432,548 total SUV rollovers.) Precipitation in the form of rain, snow, or sleet is associated with significantly lower risk of rollover in multiple vehicle crashes for both SUVs and passenger cars. Dry conditions are associated with a slightly higher rollover risk, which is nearly the same increase for both passenger cars and SUVs.

Table 19 Roll Probability by Weather, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Weather	Single vehicle crashes					
No adverse	2,449,081	10.7	1.028	321,189	29.4	0.984
Rain	379,509	8.9	0.859	57,072	33.2	1.111
Snow/sleet	157,921	9.9	0.958	35,868	28.7	0.961
Fog	29,516	11.1	1.074	3,595	30.3	1.012
Other	18,458	18.1	1.742	4,131	52.7	1.761
Unknown	56,916	6.0	0.576	10,694	22.1	0.738
Total	3,091,400	10.4	1.000	432,548	29.9	1.000
	Multiple vehicle crashes					
No adverse	14,406,895	0.3	1.072	1,947,830	1.8	1.108
Rain	1,843,023	0.2	0.670	236,859	0.5	0.336
Snow/sleet	446,735	0.1	0.412	66,311	0.8	0.514
Fog	53,578	0.1	0.258	6,961	2.8	1.733
Other	84,678	0.1	0.437	9,211	1.0	0.654
Unknown	138,495	0.1	0.463	25,189	0.1	0.057
Total	16,973,405	0.2	1.000	2,292,361	1.6	1.000

Table 20 tabulates rollover risk for passenger cars and SUVs for road surface condition, which is a more direct measure of road surface friction than precipitation. The results, however, are quite similar to those presented in Table 19: Road surface condition has a relatively small association with the probability of rollover, given a collision. Some conditions, such as ice, have a significant magnitude to the associated effect, but, given the small sample size, the reliability of that effect is uncertain. On the other hand, it appears that wet roads in multiple vehicle crashes are associated with lower risk of rollover, compared to other road conditions (dry, primarily) in multiple vehicle crashes. It could be, that given a crash, a lower friction coefficient surface reduces rollover because the tires, if a lateral movement is induced by collision, slide rather that grip.

Table 20 Roll Probability by Road Condition, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Road surface	Single vehicle crashes					
Dry	2,200,501	10.5	1.015	278,967	27.7	0.927
Wet	565,379	9.3	0.894	77,489	31.1	1.038
Snow/slush	129,119	8.9	0.859	24,144	30.0	1.003
Ice	126,517	13.9	1.344	41,479	42.4	1.416
Other	18,056	25.1	2.417	2,779	73.0	2.441
Unknown	51,829	5.5	0.534	7,692	14.6	0.488
Total	3,091,401	10.4	1.000	432,549	29.9	1.000
	Multiple vehicle crashes					
Dry	13,415,252	0.3	1.100	1,813,396	1.8	1.146
Wet	2,745,670	0.2	0.677	353,056	0.7	0.442
Snow/slush	340,047	0.1	0.247	47,786	0.6	0.372
Ice	268,611	0.1	0.531	44,842	0.8	0.489
Other	19,076	1.0	4.074	2,664	5.0	3.126
Unknown	190,124	0.1	0.334	30,616	0.5	0.304
Total	16,978,781	0.2	1.000	2,292,359	1.6	1.000

Light condition can capture a number of different effects. One effect of darkness is simply to reduce the sight distance of the driver. When sight distance is reduced, drivers have less time to react to problems. Darkness is also associated with fatigue and increased alcohol use. The dark/lighted category captures crashes that occur at night, but in lighted areas. These areas, since they often urban, tend to have lower travel speeds and therefore a lower risk of rollover. Table 21 shows rollover risks associated with different light conditions. In single vehicle crashes, daylight is associated with only a very small increase in rollover risk. For SUVs, the increase in rollover risk in single vehicle crashes for darkness is also slight, but considerably greater for passenger cars. In contrast, single vehicle rollover is associated with a significantly lower risk in dark/lighted conditions. This could be due to lower travel speeds, compared to the unlighted dark condition, which would tend to be more in rural areas. In multiple vehicle crashes, both dark and dark/lighted are associated with higher rollover risk for both passenger cars and SUVs. Speed, fatigue, and alcohol may all be implicated here.

Table 21 Roll Probability by Light Condition, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Light	Single vehicle crashes					
Daylight	1,441,541	10.5	1.017	206,042	32.4	1.082
Dark	857,218	13.8	1.328	130,000	31.9	1.065
Dark/lighted	579,266	5.6	0.545	67,256	20.7	0.692
Dawn	77,652	11.3	1.088	9,339	27.7	0.926
Dusk	78,509	8.9	0.855	12,150	33.2	1.109
Unknown	57,216	3.5	0.339	7,760	9.5	0.318
Total	3,091,402	10.4	1.000	432,548	29.9	1.000
	Multiple vehicle crashes					
Daylight	13,026,705	0.2	0.858	1,788,182	1.4	0.888
Dark	753,659	0.7	2.927	99,864	3.3	2.045
Dark/lighted	2,467,096	0.3	1.110	304,253	2.1	1.297
Dawn	160,392	0.5	1.929	25,792	2.8	1.747
Dusk	449,421	0.2	0.745	58,992	1.5	0.944
Unknown	118,853	0.4	1.763	15,277	0.6	0.344
Total	16,976,125	0.2	1.000	2,292,360	1.6	1.000

Time of day captures a number of different factors that may influence the probability of rollover. Day time hours are associated with higher traffic densities, while night time is associated with lower traffic density, darkness and therefore shorter sight distances, higher rates of alcohol use, and higher rates of driver fatigue.

Table 22 shows rollover probability and relative rollover risk in three-hour increments for passenger cars and SUVs. Rollover probability in single vehicle crashes is not greatly affected by time of day. Particularly for SUVs, the range of variability in the relative risk of rollover is fairly narrow. The highest risk is from 3 p.m. to 5:59 p.m., but there the increase in risk is only 1.190. For passenger cars, the hours between midnight and 2:59 a.m., have the highest relative risk, with an risk elevated by about 1.217. In multiple vehicle crashes, however, the risks are considerably higher at certain hours. Between midnight and 5:59 a.m., the relative rollover risk is much higher in multiple vehicle crashes for both passenger cars and SUVs. Sample sizes are somewhat small for SUVs in these two time periods, but the effect is large and in the same direction as for passenger cars, so the direction, at least, of the effect is likely to be reliable. These hours are associated with both fatigue and alcohol use. In these circumstances, erratic driver behavior is likely and contributory to rollover, given a collision.

Table 22 Roll Probability by Time of Day, Vehicle Type, and Number of Vehicles in the Crash 1999-2001 FARS and GES

	Passenger car			SUV		
	N	Roll probability	Relative risk	N	Roll probability	Relative risk
Hour	Single vehicle crashes					
12am-2:59am	356,176	12.6	1.217	48,354	30.8	1.030
3am-5:59am	235,753	12.1	1.170	35,513	31.4	1.050
6am-8:59am	358,248	11.4	1.103	54,227	26.9	0.898
9am-11:59am	296,676	10.6	1.022	40,040	34.2	1.144
12pm-2:59pm	355,555	10.0	0.964	51,856	32.3	1.081
3pm-5:59pm	478,716	9.5	0.918	68,503	35.6	1.190
6pm-8:59pm	515,183	8.9	0.854	69,390	25.0	0.835
9pm-11:59pm	467,395	9.9	0.953	62,495	25.9	0.865
Unknown	27,696	5.9	0.571	2,168	19.3	0.646
Total	3,091,398	10.4	1.000	432,546	29.9	1.000
	Multiple vehicle crashes					
12am-2:59am	400,169	0.8	3.151	46,736	4.2	2.609
3am-5:59am	198,726	0.6	2.386	20,740	5.9	3.673
6am-8:59am	2,105,803	0.2	0.979	324,265	1.5	0.920
9am-11:59am	2,306,947	0.2	0.919	296,526	2.1	1.294
12pm-2:59pm	3,560,728	0.2	0.755	480,849	1.3	0.790
3pm-5:59pm	4,927,966	0.2	0.823	688,080	1.1	0.681
6pm-8:59pm	2,360,434	0.2	0.999	303,289	1.8	1.121
9pm-11:59pm	1,068,657	0.4	1.798	125,263	2.8	1.747
Unknown	48,144	0.2	0.816	6,610	1.2	0.724
Total	16,977,573	0.2	1.000	2,292,359	1.6	1.000

Review of SUV Rollovers

The major task in the work performed for this project was to examine clinically a set of SUV rollovers in order to establish a detailed understanding of maneuver events and other factors leading to rollover in traffic crashes. This information can provide baseline knowledge used in evaluating various stability enhancing technologies and their impact on reducing rollover propensity.

Rollover is known to be overrepresented in certain passenger vehicle types. The analysis of the GES and FARS files has shown that SUVs are about three times more likely to rollover in a traffic accident than passenger cars. Moreover, rollover is associated with high rates of occupant fatal and serious injuries. An occupant is about eight times more likely to be fatally injured in a crash if his vehicle rolls over. Improvements to the roll stability of the target passenger vehicles therefore would significantly enhance the crashworthiness of the vehicles and reduce injuries and fatalities in traffic accidents. Potentially, such improvements could reduce crash rates in addition to reducing crash severities.

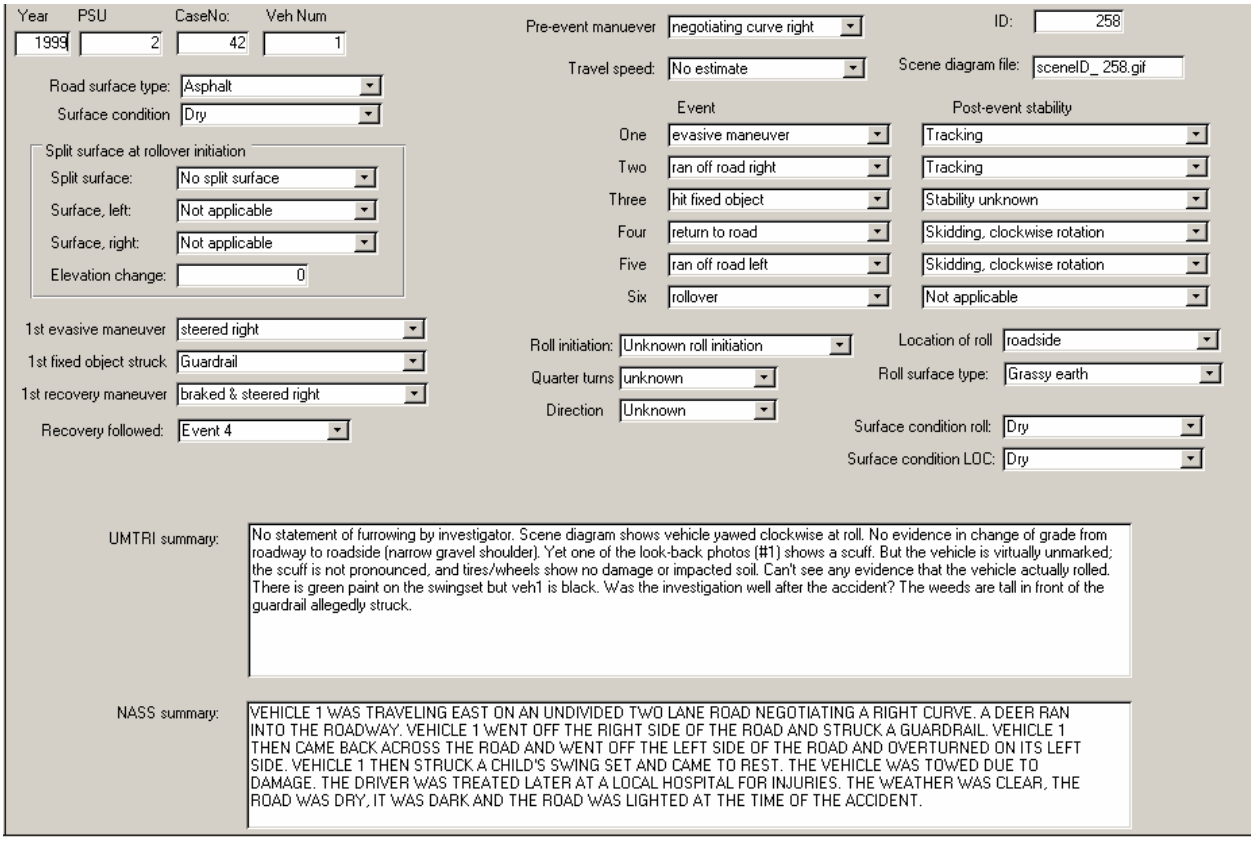
NHTSA's National Accident Sample Survey Crashworthiness Data System (NASS CDS) file was selected to provide cases for the in-depth review of SUV rollovers. NASS CDS cases are available for review through a web browser interface. CDS cases are subject to in-depth investigation to support crashworthiness analyses. Though the focus of NASS CDS is on post-crash injury and damage, the data includes the usual pre-crash variables available in most files. In addition, much of the supporting case material is available over the Web, including the scene diagram, photos of the scene and the crashed vehicles, a text summary of the events recorded by the NASS researchers, and reconstruction of travel and crash speeds. The scene diagram, scene and vehicle photos, text summary of the events, and other information were used to record the sequence of events up to the point of rollover for selected SUVs.

Table 23 shows the make, model, and model year of the 262 SUVs selected from the 1999-2001 NASS CDS file. All rollovers of the selected make/models and model years were included in the sample.

Table 23 Make/Model and Model Year, UMTRI SUV Rollover Data

Model year	Jeep Cherokee	Ford Explorer	Chevrolet Blazer	GMC Jimmy	Toyota 4-Runner	Total
1989	2	0	4	3	0	9
1990	2	0	2	0	1	5
1991	2	7	5	0	2	16
1992	1	7	2	0	2	12
1993	6	7	2	1	1	17
1994	9	4	5	1	6	25
1995	3	7	4	3	2	19
1996	10	5	6	1	3	25
1997	6	10	6	2	7	31
1998	7	20	6	2	7	42
1999	3	13	4	3	2	25
2000	7	9	5	1	3	25
2001	1	7	3	0	0	11
Total	59	96	54	17	36	262

A data collection instrument was developed to record selected information for each case on events and conditions prior to the rollover. Figure 1 shows a screen-shot of the data collection instrument used in coding the rollovers. A description of the data collection protocol is provided in the Appendix. Researchers coded up to six pre-rollover events, along with the stability of the vehicle (tracking or skidding) after each event. In addition, crash avoidance and recovery maneuvers were recorded, along with the rollover initiation type, location of rollover initiation, direction of roll, number of quarter turns of roll, location of roll, and surface condition at rollover initiation.



Year: 1999
PSU: 2
CaseNo: 42
Veh Num: 1
Road surface type: Asphalt
Surface condition: Dry

Split surface at rollover initiation
Split surface: No split surface
Surface, left: Not applicable
Surface, right: Not applicable
Elevation change: 0

1st evasive maneuver: steered right
1st fixed object struck: Guardrail
1st recovery maneuver: braked & steered right
Recovery followed: Event 4

Pre-event manuever: negotiating curve right
ID: 258
Travel speed: No estimate
Scene diagram file: sceneID_ 258.gif

	Event	Post-event stability
One	evasive maneuver	Tracking
Two	ran off road right	Tracking
Three	hit fixed object	Stability unknown
Four	return to road	Skidding, clockwise rotation
Five	ran off road left	Skidding, clockwise rotation
Six	rollover	Not applicable

Roll initiation: Unknown roll initiation
Quarter turns: unknown
Direction: Unknown
Location of roll: roadside
Roll surface type: Grassy earth
Surface condition roll: Dry
Surface condition LOC: Dry

UMTRI summary: No statement of furrowing by investigator. Scene diagram shows vehicle yawed clockwise at roll. No evidence in change of grade from roadway to roadside (narrow gravel shoulder). Yet one of the look-back photos (#1) shows a scuff. But the vehicle is virtually unmarked; the scuff is not pronounced, and tires/wheels show no damage or impacted soil. Can't see any evidence that the vehicle actually rolled. There is green paint on the swingset but veh1 is black. Was the investigation well after the accident? The weeds are tall in front of the guardrail allegedly struck.

NASS summary: VEHICLE 1 WAS TRAVELING EAST ON AN UNDIVIDED TWO LANE ROAD NEGOTIATING A RIGHT CURVE. A DEER RAN INTO THE ROADWAY. VEHICLE 1 WENT OFF THE RIGHT SIDE OF THE ROAD AND STRUCK A GUARDRAIL. VEHICLE 1 THEN CAME BACK ACROSS THE ROAD AND WENT OFF THE LEFT SIDE OF THE ROAD AND OVERTURNED ON ITS LEFT SIDE. VEHICLE 1 THEN STRUCK A CHILD'S SWING SET AND CAME TO REST. THE VEHICLE WAS TOWED DUE TO DAMAGE. THE DRIVER WAS TREATED LATER AT A LOCAL HOSPITAL FOR INJURIES. THE WEATHER WAS CLEAR, THE ROAD WAS DRY, IT WAS DARK AND THE ROAD WAS LIGHTED AT THE TIME OF THE ACCIDENT.

Figure 1 Data Collection Interface, UMTRI SUV Rollover Data

The purpose of this section is to provide a discussion of the primary rollover scenarios discovered from the clinical review of the selected NASS CDS SUV rollover cases. It identifies the major event pathways that culminated in rollover. As mentioned above, researchers could record up to six events prior to rollover, along with vehicle stability after the event. Table 24 shows the list of possible events that could be coded.

Table 24 Event List for SUV Rollover Data

Code	Event	Code	Event
1	lane excursion, same dir.	13	Collision with motor vehicle
2	lane excursion, opp. dir.	14	hit fixed object
3	LOC, reduced road friction	15	hit nonfixed object
4	tire failure	16	rollover
5	other vehicle failure	18	adverse ground contour
6	evasive maneuver	21	negotiate turn left
7	ran off road right	22	negotiate turn right
8	ran off road left	23	negotiate curve left
9	drift off road left	24	negotiate curve right
10	drift off road right	97	other
11	return to road	98	no other event
12	Maintain heading off road	99	unknown

For each of the 262 SUV rollovers, UMTRI researchers examined the scene diagram, reviewed the NASS researcher's written summary, and examined numerous photographs of the scene and vehicle to determine the sequence events prior to the rollover. For the 262 rollovers, 124 distinct different sequences of events were recorded. In addition, UMTRI researchers estimated the vehicle's stability after each event. If differences in stability are taken into account, of the 262 rollovers, there were 189 distinct patterns of events and stability that resulted in rollover. The approach here will be to organize the events and search for patterns to identify opportunities for stability enhancement to intervene in the rollover sequence. When this perspective is applied, the primary rollover sequences fall into a manageable number of scenarios.

At the fine-grained detail of the data collected for this project, a very large majority of the sequences of events leading to rollover is unique. Aggregation of certain codes is necessary for analytical purposes. The goal is to combine codes where appropriate into more general categories, identifying common patterns and crash sequences. Accordingly, for the bulk of the analysis presented here, some groupings are made to aggregate rollovers into major categories. The purpose of these groupings is to identify rollover patterns that could be affected by Vehicle Stability Control (VSC) devices.

In sorting through the pre-roll events, we have tried to consider whether and how devices that could enhance vehicle stability and control could be effective in preventing rollover. For this purpose, certain assumptions were made. One is that the devices are primarily effective on the roadway. Once the vehicle is off the roadway, the devices may have some effect, but determining that effect is highly uncertain. Another assumption is that the effect of the devices after a collision is also highly uncertain. Accordingly, we defined broad rollover categories that identified whether the vehicle collided with another vehicle and whether it exited the roadway. Rollovers that occur after a collision with a motor vehicle are unlikely to be affected by VSC, unless VSC could prevent the collision in the first place. Similarly, rollovers that occur when a vehicle exits the roadway are unlikely to be reduced, unless VSC could have helped keep the vehicle on the road.

In the first part of the analysis, distributions of important variables will be presented and briefly discussed. Next the primary rollover patterns as identified in the UMTRI SUV rollover data coding will be introduced and each will be discussed in some detail.

In many of the tables both “weighted” and “unweighted” frequencies are presented. A brief explanation of the difference is in order. The cases for clinical review were selected from the NASS CDS file. The NASS CDS file is a nationally-representative sample of police-reported crashes meeting the selection criteria. Since NASS CDS is a statistically valid sample file, each case has a selection probability. For example, if there were 10,000 SUV rollovers nationally, and 100 were sampled for the NASS CDS file, the selection probability of each case would be 100/10000, or 0.01. The inverse of the selection probability is the case weight. In the example, each case weight would be 100. In effect, each sampled rollover "stands for" 100 rollovers that actually occurred. The NASS CDS sampling strategy is more complex, with multiple levels of sampling, but the principal is the same. Applying the case weights to the raw frequencies produces valid national estimates.

Since the rollovers selected for clinical analysis by UMTRI were extracted from three years of NASS CDS data (1999-2001), the weighted estimates in the tables are the totals for three years, not annual estimates. Unweighted counts are also given for perspective. Weights in the NASS CDS file vary from zero to 8030.03, with a mean case weight of 348.10 and a median weight of 86.05. Given the wide range of weights, relatively large weighted totals can be based on only a few cases. While confidence intervals for the weighted totals are not included here, the reader is well-advised to interpret results based on small numbers of unweighted cases with caution.

Table 25 shows the distribution of pre-crash maneuver for the SUV rollovers. Pre-crash maneuver captures the state of the vehicle prior to entering the sequence of events that led to a rollover. In effect, this is what the vehicle was doing before anything happened. Almost half (49.8%) of the SUVs were going straight prior to the crash. Almost an equal proportion, 48.3%, was engaged in some sort of turning maneuver, either turning from one roadway to another or negotiating a curve in the road. Most of the vehicles engaged in a steering maneuver prior to the crash sequence were traveling through a curved portion of the roadway, rather than turning from one roadway to another. A total of 3.5% of the rollovers occurred after turning from one roadway to another, compared to the almost 45% of rollovers that occurred while negotiating a curved stretch of roadway. While turning from one roadway to another is a much sharper maneuver, it is also typically performed at lower speeds than negotiating a curve.

Table 25 Pre-crash Maneuver, UMTRI SUV Rollover Data

Pre-crash maneuver	Unweighted	Weighted	%
Going straight	152	45,422.30	49.8
Accelerating in lane	1	519.85	0.6
Turning left	13	2,524.92	2.8
Turning right	6	669.64	0.7
Passing or overtaking	2	362.99	0.4
Negotiating curve left	51	26,237.59	28.8
Negotiating curve right	32	14,617.35	16.0
Change lanes left	1	19.68	0.0
Change lanes right	2	624.65	0.7
Other	2	203.53	0.2
Total	262	91,202.49	100.0

Table 26 shows the distribution of the initiating event for the SUV rollovers. This is the immediate, physical cause of the rollover. Complete definitions of each type will be included as an appendix to the final report. In coding this variable, the UMTRI researcher tried to rely on the physical evidence, as available in photographs of the vehicle and scene, as much as possible. For example, in coding tripped rolls, we looked for evidence both in the scene photographs and on the vehicle. In the case of tripped, gouging pavement, the standard of evidence was to find sufficient gouge marks in the road and corresponding damage to the wheel rim of the SUV. In the case of tripping off road, we looked for furrowing in the ground and impacted soil in the SUV’s wheel rims. The turn-over category is the one roll initiation type that relies purely on tire friction on the roadway. In these cases we looked for on road rollovers, with no evidence of gouging or pavement irregularities, and no evidence of significant damage to the wheel rims.

Note that only 6.4% of the rollovers were coded turn-over, where the roll forces are generated solely by the friction of the tires on the roadway. Almost one-third (32.8%) of the rollovers were tripped, either by soft soil, curbs, gouging pavement or some other trip mechanism. Another third of the rollovers were due some sort of interaction with fixed objects or ground contours off the road such as a collision with a fixed object (bounce-over), running off the road onto a slope (fall-over), or running up onto a guardrail and either falling over the other side (climb-over) or being flipped back over (flip-over). The largest single rollover initiation type, however, is collision with another motor vehicle, accounting for 23.8% of the rollovers. Initiation type could not be determined for 3.8% of the cases.

Table 26 Rollover Initiation Type, UMTRI SUV Rollover Data

Rollover initiation type	N	Total	%
Tripped, curb	14	5,326.06	5.8
Tripped, soft soil	58	12,437.11	13.6
Tripped, pavement irregularity	2	1,091.41	1.2
Tripped, gouging pavement	22	5,358.62	5.9
Tripped, other	13	5,697.69	6.2
Tripped, unknown mechanism	1	9.83	0.0
Flip-over	10	2,017.88	2.2
Turn-over	20	5,830.22	6.4
Climb-over	6	808.20	0.9
Fall-over	16	12,484.43	13.7
Bounce-over	24	14,452.81	15.8
Collision with another vehicle	70	21,750.78	23.8
Other rollover initiation	1	430.32	0.5
End-over-end	1	9.83	0.0
Unknown roll initiation	4	3,497.31	3.8
Total	262	91,202.49	100.0

Table 27 presents a fundamental perspective on the rollovers examined. It shows the first event and subsequent stability of the vehicle. As such, it presents the first level of categorization of the rollover scenarios that were developed. For the purpose of the table, some event categories were aggregated to simplify the analysis. For example, in the original data, we coded ran off road left and ran off road right, but in Table 27 and subsequently, they were combined into ran off road. If the direction of roadway exit becomes important in later analysis, that can be recovered.

Table 27 First Event and Stability, UMTRI SUV Rollover Data

First event	Stability	Unweighted	Weighted	%
Loss of control	Skidding	34	30,637	33.6
Collision with motor vehicle	Skidding/other	69	13,554	14.9
Ran off road	Tracking	58	12,600	13.8
Ran off road	Skidding	13	3,066	3.4
Evasive maneuver	Tracking	29	11,011	12.1
Evasive maneuver	Skidding/other	15	2,093	2.3
Drift off road	Tracking	9	3,980	4.4
Lane excursion, same direction	Tracking/unk.	6	8,769	9.6
Lane excursion, opposite direction	Tracking	8	2,260	2.5
Other	All	21	3,231	3.5
Total		262	91,202	100.0

A comment also about the coding of vehicle stability: Vehicle stability was recorded after each event in the sequence of events leading up to the rollover. The code levels available were tracking, counterclockwise rotation, clockwise rotation, skidding longitudinally, and other skidding. For the tables here, we show just tracking or skidding, combining both directions of rotation, though of course that information remains in the original data. Researchers relied on the scene diagram, photos of the crash scene, looking for skid and yaw marks on the road, and to a lesser extent the narrative summary of the NASS researcher. This approach is conservative: we looked for physical evidence of loss of control (LOC) first. But it is possible that in some cases the physical markers of LOC were too subtle or faint to be evident in the photographs of the roadway and scene. Accordingly, it is likely that skidding is underrepresented in the data.

With those cautions in mind, Table 27 presents the initiating event in the rollover sequence, along with the condition of the vehicle after that first event. Over one-third of the rollovers (33.6%) began with a loss of control due to tire saturation (presumed yaw instability), and all of these were skidding as a result. In another 14.9%, the first event was a collision with another motor vehicle, following which the SUV rolled over. A total of 21.5% of the rollovers started with the SUV going off the road, either by running off the road or drifting off the road. The distinction between run off and drift off is somewhat arbitrary, but we were trying to distinguish cases in which the SUV exited the road at a shallow angle, possibly due to driver inattention or incapacitation (e.g., asleep), from those in which the SUV drove off the road because it was unable to negotiate a curve or following an evasive maneuver. About 14.4% of the rollover sequences were initiated by an evasive maneuver, and about the same proportion (12.1%) began with a lane change of some sort.

Table 27 presents a first cut at estimating the size of the population of SUV rollovers that might be affected by vehicle stability control devices (VSC). The largest category of rollovers followed LOC due to tire saturation. VSC acts to enhance stability and control by reducing tire sideslip and vehicle yaw, which could be effective in the LOC cases. On the other hand, rollovers following a collision with another motor vehicle are unlikely to be significantly affected by VSC, unless the system aided in avoiding the collision in the first place. In the remaining rollover sequence first events, the application of VSC is less clear. In the following tables, we will discuss each of the three primary categories suggested by Table 27: LOC due to tire saturation, collisions with other motor vehicles, and all other initiating events. The discussion will focus on events and conditions that might affect the applicability of VSC to avoiding the rollover.

Where the SUV lost control as a first event in the roll sequence, the interest primarily is in the pre-event maneuver and roadway surface condition. Table 28 tabulates these two factors. Column percentages appear below the weighted frequencies and the bottom row shows row percentages for the surface condition marginal. About 75% of the LOC cases were on icy, wet, or snowy roads at the time. In comparison, roads were slick in about 30% of all SUV rollovers and about 9% of all rollover sequences that did not begin with LOC. The high proportion of low friction roads in this category certainly makes sense. It is actually the remaining 25% on dry roads that requires some explanation. Note that most of the LOC on dry roads occurred while the vehicle was rounding a curve. Only 1.5% were going straight, in comparison to 17.4% on wet surfaces, 75.7% on snowy/slushy roads, and 68.8% on icy roads. Moreover, about two-thirds of the dry road LOC cases were on dirt or gravel roads. Such roadways have a much lower friction coefficient than paved roads. However, there were some cases coded first event LOC on asphalt roads. A review of each case shows that the vehicle was traveling at such a high rate of speed for the conditions that it was unable to maintain control while negotiating a curve.

Table 28 Roadway Surface Condition and Pre-Crash Maneuver, First Event LOC Rollovers
UMTRI SUV Rollover Data

Pre-crash maneuver	Surface condition				
	Dry	Wet	Snow or slush	Ice	Total
Going straight	119	1,066	688	10,891	12,765
Negotiating curve left	540	2,178	144	4,932	7,793
Negotiating curve right	6,494	2,826	77	0	9,396
Negotiating turn left	639	0	0	0	639
Negotiating turn right	0	44	0	0	44
Total	7,792	6,113	909	15,823	30,637
Going straight	1.5	17.4	75.7	68.8	41.7
Negotiating curve left	6.9	35.6	15.8	31.2	25.4
Negotiating curve right	83.3	46.2	8.4	0.0	30.7
Negotiating turn left	8.2	0.0	0.0	0.0	2.1
Negotiating turn right	0.0	0.7	0.0	0.0	0.1
Total	100.0	100.0	100.0	100.0	100.0
Row percentages	25.4	20.0	3.0	51.6	100.0

The second primary scenario for rollovers is those that occur following a collision with a motor vehicle. In the set of cases examined, rollovers occurred following a collision with a motor vehicle in two ways: where the collision was the first event and where the collision occurred as a subsequent event. In first event collisions, there is no apparent previous evasive maneuver or LOC so it is assumed that there is little opportunity for a VSC to help avoid the collision. The 3,567 cases, 3.9% of the total here, in which the SUV lost control prior to collision with another motor vehicle are included with the LOC cases above. Since VSC works to maintain control of the vehicle, it is likely that some portion of these collisions would have been preventable had a VSC device been successful at maintaining vehicle control allowing the driver to avoid the collision. However once a collision occurs it is very speculative as to whether VSC could help avoid a subsequent rollover.

Table 29 shows the pre-crash maneuver in cases where a collision with a motor vehicle occurred as the first event in the rollover sequence. In these cases, it is assumed there was no opportunity to avoid the collision since no evasive maneuver was coded. The table shows pre-event maneuver. In almost two-thirds of the cases the SUV was essentially going straight (if we also include accelerating in lane, passing and overtaking, and changing lanes). Many of these were intersection collisions where the SUV was struck in the side. Almost 75% (73.2%) of rollovers that occurred while going straight were at intersections. The SUV was struck in the side by the other vehicle while traversing the intersection. In many cases the striking vehicle was smaller than the SUV. In these crashes, the smaller vehicle underrode and acted as a wedge to lift up and turn the larger, higher-riding SUV over. SUVs seem to be highly vulnerable to roll in this crash configuration.

Table 29 Pre-Crash Maneuver, First Event Collision with Motor Vehicle
UMTRI SUV Rollover Data

Pre-crash maneuver	Unweighted	Weighted	%
Going straight	46	8,658	63.9
Accelerating in lane	1	520	3.8
Negotiating turn left	10	1,867	13.8
Negotiating turn right	2	283	2.1
Passing or overtaking	1	225	1.7
Negotiating curve left	2	827	6.1
Negotiating curve right	3	344	2.5
Change lanes left	1	20	0.1
Change lanes right	1	608	4.5
Other	2	204	1.5
Total	69	13,554	100.0

An additional 12,986 SUVs rolled after a collision with another vehicle, but the collision with the other vehicle occurred after the first event. In these cases, there is an opportunity for VSC to prevent the rollover if enhanced stability could have helped the driver avoid the collision. The assumption is that, in those crashes where the SUV attempted an evasive maneuver and skidded as a result, VSC may be useful if it could have prevented yaw instability skidding. Obviously we cannot tell at this level of analysis whether maintaining control would have prevented the collision, but it is clear that maintaining control is essential for the driver to affect collision avoidance.

Table 30 shows the first event and resulting stability for SUVs that rolled over due to a collision with a motor vehicle following some prior event. The 12,986 cases are 14.2% of all SUV rollovers considered here. The first event is shown because in nearly all of these cases (88.4%) the second event in the rollover sequence was a collision with another motor vehicle. Note that in most cases (84.4%) the first event was a lane excursion, where the SUV changed lanes on the roadway, either into the opposing lanes (16.8%) or into another lane going the same direction. An evasive maneuver was the first event in 14.2% of the roll sequences. And note the high proportion of cases in which the vehicle was coded as tracking after the first event. The SUV was coded as tracking in over 98% of the cases. The caution offered earlier about the difficulty of coding stability with the materials at hand should be remembered, but the fact is that in almost all of these cases there was no gross evidence of skidding or sliding prior to impact with the other vehicle.

Table 30 First Event, Rollover Followed Collision with Motor Vehicle
UMTRI SUV Rollover Data

First event	Stability after first event	Unweighted	Weighted	%
Lane excursion, same dir.	Skidding	1	25	0.2
Lane excursion, same dir.	Tracking/unk.	5	8,758	67.4
Lane excursion, opp. dir.	Tracking	6	2,183	16.8
Evasive maneuver	Skidding	3	203	1.6
Evasive maneuver	Tracking	14	1,633	12.6
Ran off road right	Tracking	1	163	1.3
Negotiate turn right	Tracking	1	21	0.2
Total		31	12,986	100.0

Thus, most rollovers that occurred after collision with another vehicle, either as a first or subsequent event, did not appear to experience any skidding or lateral loss of control prior to the collision. Obviously a few did, but they amounted to fewer than 2% of the cases where roll was not immediate, and fewer than 1% of all rollovers in collisions with motor vehicles.

Note that a weighted estimate of 3,567 rollovers occurred when the SUV lost control due to reduced road friction, collided with a motor vehicle and overturned. These cases are included with the LOC cases discussed above and tabulated in Table 28, not with the cases where rollover followed collision with another vehicle.

The third category of rollover sequences to be considered comprises all the rollovers that do not fall into the first two categories. These are cases where there was no loss of control from reduced road friction and no collision with another motor vehicle. In these cases, there were a large number of different sequences. Of the original 262 cases selected from the NASS CDS file for clinical examination, 127 fell into this category. And of these 127, there were 90 different rollover sequences, taking into account both events and vehicle stability after the event.

Given the complexity of these rollovers, two approaches are taken. In the first, the largest categories of rollover sequences are identified and then the roll sequence is traced through. The purpose is to construct a coherent story of how the rollover occurred, along with the vehicle's stability at different points. In the second approach, we address the question of vehicle stability more directly. The cases are classified by whether the SUV left the roadway or not. In crashes where the SUV left the roadway prior to rollover (whether the vehicle returned to the roadway or not), we tabulate vehicle stability as it left the roadway. And in those crashes in which the vehicle did not leave the roadway at any point in the rollover sequence, we tabulate the SUV's stability prior to rollover.

Table 31 shows the distribution of first event and stability where the rollover did not follow LOC or a collision with another motor vehicle. Fortunately, there were three primary events here: drift off road, evasive maneuver, and ran off road. There was also a number of other first events in the crash sequence, but they accounted for only a minority of the cases. The three primary events account for 91.1% of the rollover sequences.

Table 31 Rollovers Not Following Collision with Motor Vehicle or LOC
UMTRI SUV Rollover Data

	Stability after first event			
First event	Tracking	Skidding	Other	Total
Drift off road	3,980	0	0	3,980
Evasive maneuver	9,430	1,827	10	11,267
Hit nonfixed object	0	767	0	767
Lane excursion, opp. dir.	77	539	0	616
Lane excursion, same dir.	11	608	0	619
Ran off road	12,437	3,326	0	15,763
Tire failure	46	11	51	108
Turning left or right	0	114	0	114
Other vehicle failure	0	638	0	638
Adverse ground contour	0	46	0	46
Other	0	106	0	106
Total	25,981	7,984	61	34,024
	Distribution by stability			Total
Drift off road	15.3	0.0	0.0	11.7
Evasive maneuver	36.3	22.9	16.0	33.1
Hit nonfixed object	0.0	9.6	0.0	2.3
Lane excursion, opp. dir.	0.3	6.7	0.0	1.8
Lane excursion, same dir.	0.0	7.6	0.0	1.8
Ran off road	47.9	41.7	0.0	46.3
Tire failure	0.2	0.1	84.0	0.3
Turning left or right	0.0	1.4	0.0	0.3
Other vehicle failure	0.0	8.0	0.0	1.9
Adverse ground contour	0.0	0.6	0.0	0.1
Other	0.0	1.3	0.0	0.3
Total	100.0	100.0	100.0	100.0

It is worth noting the small number of rollovers initiated by tire failure. We had expected to find a significant number of cases in which the rollover sequence was initiated by tire failure. But in the event, only three of the 262 rollovers began with a tire failure. Those three cases account for a weighted 0.12% of the weighted total of rollovers. While this study was not designed to measure the incidence of tire failure as a roll precursor, we were surprised to find so few.

Drift off road accounts for a weighted estimate of 3,980 cases, but these are based on only nine actual cases, so any conclusions are very tentative. One case has a weight of 2,563; it accounts for about 65% of the drift off road estimate. All drift off cases were tracking on exit from the road. As noted earlier, identification of drift off cases is difficult, but the intent of the code is to identify cases with a shallow departure angle, indicating the driver was inattentive or even asleep. Given this definition of drift off the road, all the vehicles would be tracking as they went off the road. Of the nine cases that drifted off, four either rolled over immediately or hit a fixed object and rolled. The other five returned to the road and rolled there, or continued across the road and rolled. Of the five that returned to the road, three were coded as tracking and two as skidding upon return to the road. However, when the appropriate case weights are applied, the estimated population totals are 2,673 tracking and 461 skidding. Since the number of cases on which the estimated totals are based is so small, the reliability of the population estimates is low. This rollover scenario should possibly be combined with the ran off road category.

Rollover sequences initiated by a ran off road event can get very complicated. Of the 15,763 SUVs that ran off road as the first event in the rollover sequence, 7,378 or 46.8% returned to the road at some point in the crash sequence. Table 32 shows the breakdown of these cases by whether they returned to the road and their stability at the first excursion off the road. It is interesting to note that almost half of the vehicles that exited the road returned to the road at some point in the sequence of events leading up to the rollover. Of the weighted 15,763 cases that fall into this category, 7,378 or 46.8% returned to the road prior to rollover. An estimated 3,326 were skidding as they ran off the road, while 12,437 (78.9%of the total) were tracking as they exited the roadway. Vehicles that were skidding at roadway exit were much less likely to return to the roadway. Only 26.5% of the skidding SUVs managed to return to the roadway, compared with 52.2% of the SUVs coded as tracking.

Table 32 First Event Ran Off Road, Stability and Return
UMTRI SUV Rollover Data

Stability at road exit	Returned		No return		Total	
	N	%	N	%	N	%
Tracking	6,498	52.2	5,939	47.8	12,437	100.0
Skidding	880	26.5	2,446	73.5	3,326	100.0
Total	7,378	46.8	8,385	53.2	15,763	100.0

The diagrams in Figure 2 and Figure 3 show what happened to the SUVs that ran off the road as a first event and later returned. The boxes show the estimated number of cases and the percentage of all 15,763 cases that exited the road. The largest group returned to the road, accounting for a weighted total of 5,100 cases and 32.4% of all those that exited the road. Most of those vehicles were skidding upon return (top branch of the diagram in Figure 2). Of the 4,908 that returned skidding, 1,603 rolled over on the road, and 3,306 went off the road again and rolled. The 4,908 cases that were tracking when they left the road had enough control to return to the road without an intervening event, such as collision with a fixed object or rollover. But the steering maneuver to return to the road was abrupt enough to put the vehicle into yaw-related loss of control. These rollovers are another potential opportunity for vehicle control enhancement technologies.

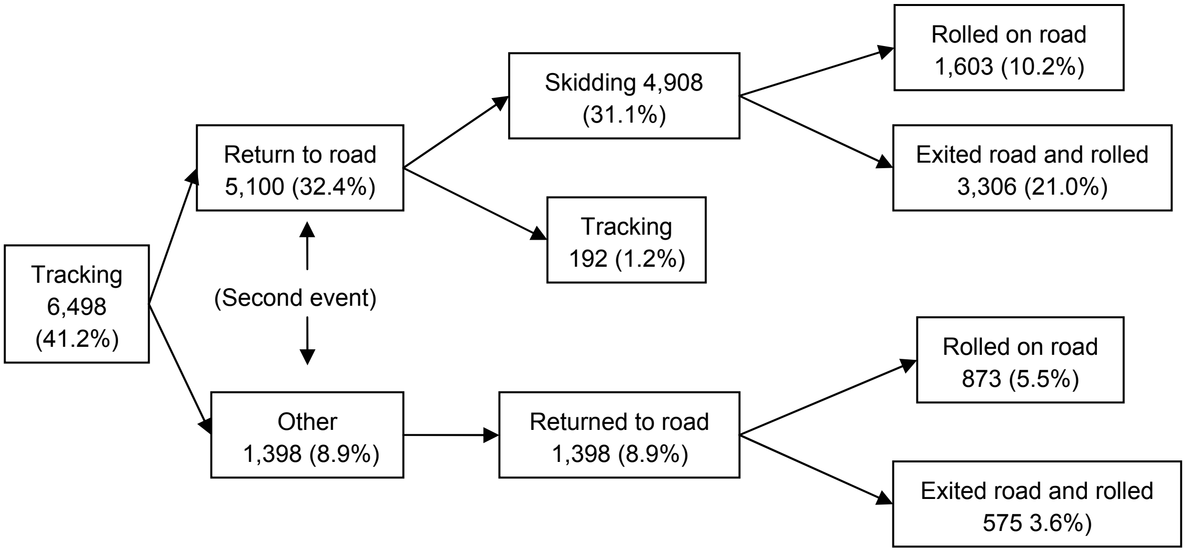


Figure 2 Sequence of events, First Event Ran Off Road Tracking, Later Returned UMTRI SUV Rollover Data

Cases on the bottom branch of the diagram in Figure 2 did not return to the road as the second event, though they did so later. Often the second event was a collision with a fixed object, and the SUV was skidding upon return to the road. This branch is based on only thirteen cases, however.

Figure 3 provides a compact diagram of the sequence of events for SUVs that exited the road while skidding and later returned. It is based on only two cases, and is present for the sake of completeness only.

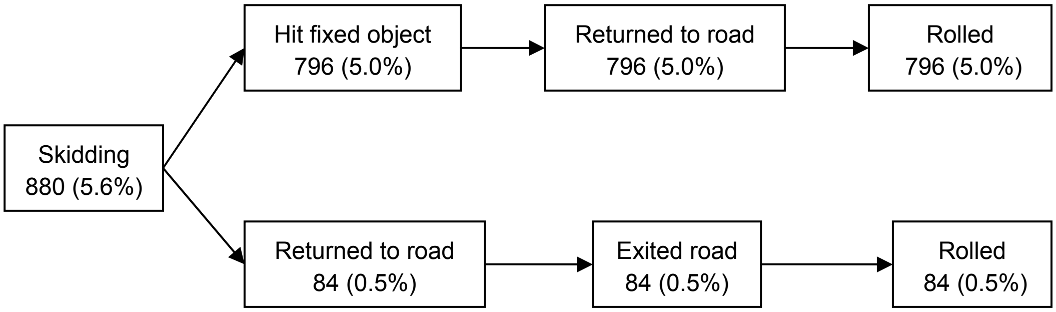


Figure 3 Sequence of Events, Ran Off Road Skidding, Later Returned UMTRI SUV Rollover Data

Evasive maneuver accounts for 11,269 of the weighted total of 91,202 SUV rollovers represented by the cases clinically examined by UMTRI. An estimated 12.4% of all rollover sequences are initiated by an evasive maneuver. These rollovers account for 33.1% of the cases that do not fall into the first two groups in this discussion (LOC and collision with motor vehicle).

Figure 4 shows the primary sequences of events for the weighted 9,430 rollovers where the first event was an evasive maneuver and the SUV was still tracking after the maneuver. Cases where the SUV was tracking after the evasive maneuver represent almost 84% of all the first event evasive maneuver cases. The percentages in parentheses in the diagram show the proportion of all 11,269 first event rollovers. Only 3.4% of the first event evasive maneuvers stayed on the road and rolled over there. The diagrams in Figure 4 and Figure 5 show that most of those that went off the road were tracking at the time. Considering those that were tracking after the evasive maneuver (Figure 4), 7,282 ran off the road and later returned. Given the return to the roadway, they represent a potential target for VSC. However, of the 7,282 that ran off the road, 2,983 returned to the road immediately and were coded as tracking upon return, and 4,299 hit a fixed object prior to return and were coded as skidding on return. So for the cases represented in Figure 4, if vehicle stability is coded correctly and the vehicle was tracking after the maneuver, it does not appear that there is an opportunity for VSC to reduce rollover significantly.

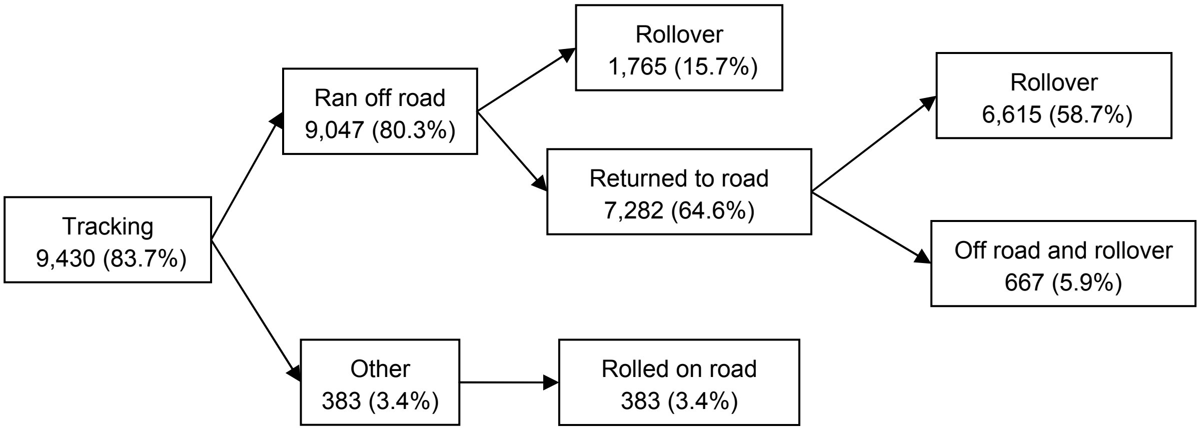


Figure 4 Sequence of Events, Evasive Maneuver Tracking

Figure 5 shows the outcome for first event evasive maneuver where the vehicle was skidding following the maneuver. Most of those cases ran off the road where they rolled over. A small number, each represented by one case, either rolled over on the road without exiting the road or returned to the road after exiting it and rolling on the road. In any case, if VSC could help maintain the stability of these vehicles, it may reduce the probability of rollover.

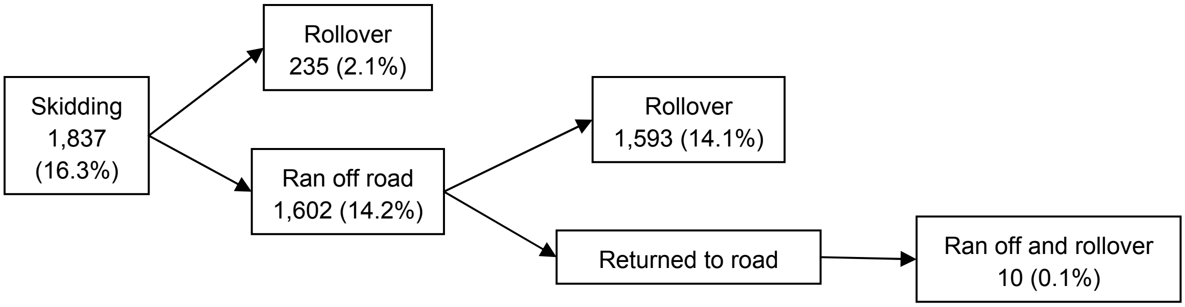


Figure 5 Sequence of Events, Evasive Maneuver Skidding

Summary

To this point, the analysis has focused on the chronology of events leading to rollover. An alternative approach would be to identify a "critical event" in the rollover sequences and to record the stability of the vehicle at that point. What is meant by the critical event is simply the point in the sequence in which it is reasonable to think that a VSC device could have some affect. For example, where the SUV collides with another vehicle as a first event, and there is no intervening LOC, it is unlikely that any stability enhancing device could have much affect on the probability of rollover. On the other hand, since VSC is intended to enhance vehicle stability where there is some loss of control, it is more likely to be effective where the crash was initiated by a loss of control due to yaw-induced tire saturation.

Table 33 shows a method of sorting the rollover sequences in an effort to isolate the critical event and record the vehicle's stability at that point. Two critical events have already been mentioned: loss of control and collision with another motor vehicle. The remaining cases are classified into three groups: stayed on the road and rolled; exited the road and rolled over without returning, and exited the road, returned, and rolled.

Table 33 Rollover Sequence Type and Stability Prior to Critical Event
UMTRI SUV Rollover Data

Stability at critical event	Crash type and stability	Unweighted	Weighted	%
	LOC due to reduced friction	35	30639	
Stability prior to rollover	*skidding*	*35*	*30,639*	*33.6*
	tracking	*0*	*0*	*0.0*
	Collision with motor vehicle	100	26,540	
Stability prior to collision	*skidding*	*3*	*228*	*0.2*
	tracking	*97*	*26,312*	*28.9*
	Stayed on road and rolled	12	1,529	
Stability prior to rollover:	*skidding*	*12*	*1,529*	*1.7*
	tracking	*0*	*0*	*0.0*
	Exited road and rolled	64	13,862	
Stability at roadway exit:	*skidding*	*27*	*5,235*	*5.7*
	tracking	*37*	*8,627*	*9.5*
	Exit road, return, roll	51	18,633	
Stability at roadway exit:	*skidding*	*6*	*1,719*	*1.9*
	tracking	*45*	*16,914*	*18.5*
	Total	262	91,202	100.0

In the case of SUVs that stayed on the road and rolled, the critical event is the one preceding the rollover. In the data we reviewed, all were skidding prior to rollover. In most of these cases there was an evasive maneuver prior to the rollover. These cases relatively rare, accounting for only 1.7% of all rollovers.

The next category is rollovers in which the SUV exited the road and rolled. In these cases, the critical point is the stability of the SUV as it went off the road. If the vehicle was tracking normally, there is no opportunity for VSC to improve stability. But VSC has the potential to improve stability where the vehicle is skidding. Of the 13,962 cases where the SUV exited the road and rolled, in 5,235 cases (weighted) the SUV was skidding at roadway exit, which accounts for 5.7% of all rollovers.

And the final category is cases where the SUV exited the road, returned, and rolled subsequently, either on road or exiting the road again and rolling. These cases are examined separately simply because the return to the road suggests some control on roadway exit. In the event, of the estimated 18,633 rollovers that followed this path, 16,914 were tracking at roadway exit, 18.5% of all rollovers. Note that among these cases where the SUV was tracking at roadway exit, are 4,908 cases where the driver likely vehicle overcorrected and immediately returned to the roadway skidding (Figure 2). VSC may be relevant in these cases, which account for 5.4% of all rollovers examined here.

The cases where the vehicle was skidding prior to the critical event may be taken as an estimate of the upper limit to the effect of VSC on preventing rollover. When the percentages from the different subcategories of rollover are summed, the result is a total of 43.1% where there is an opportunity for VSC to affect the outcome of the rollover sequence. If we include the cases where the vehicle was tracking on roadway exit, immediately overcorrected back on the road and re-entered skidding, the total percentage of SUV rollovers potentially addressable by stability enhancement amounts to 48.5% of all SUV rollovers. This finding is highly significant and supports the argument that vehicle stability control devices have the potential to significantly reduce SUV rollovers by increasing vehicle yaw stability control limits. It is also significant that the majority of SUV rollovers are linked to yaw-induced loss of control events rather than high lateral acceleration curve radius induced rollovers. These findings therefore strongly support the argument that evaluation procedures for VSC devices should focus on yaw stability enhancement associated with driver steer over correction. The tests would be most effective if they considered oversteer scenarios attributed to road surface friction differences consistent with high-speed return to road maneuvers.

While this study only considered rollover crashes and focused exclusively on SUVs, it did show that yaw instability was a significant precursor to rollover. It is likely that crashes not involving rollover are also highly associated with yaw instability particularly when vehicles with lower center of mass are involved. This suggests that vehicle stability control systems have the potential to prevent other types of crashes independent of vehicle type. The analysis used in this work could be applied across all vehicle types to provide estimates of the potential benefit for the broad application of this technology.

There may be interest in additional analysis to refine this estimate further or to more precisely define rollover scenarios. The purpose of the present effort is to define the major rollover scenarios, and it has done so. In the process we have also illustrated the amount of detailed information obtained through UMTRI's review of the NASS CDS cases. It is hoped that it will stimulate readers of this report to ask other questions of the data and to further explore specific paths of the rollover sequences in greater detail. Any review here could not possibly be exhaustive. But the goal is to define the major outline here, and then let further analysis fill in the details as needed.

Selected literature

1. 1992. Rollover prevention and roof crush report to Congress. National Highway Traffic Safety Administration, Washington, D.C. 73 p. UMTRI-83096
2. 2003. Initiatives to address the mitigation of vehicle rollover. National Highway Traffic Safety Administration, Washington, D.C. 21 p. Report No. NHTSA-2003-14622. UMTRI-97470
3. Aga, Masami; Okada, Akio.2003. Analysis of Vehicle Stability Control (VSC)'S Effectiveness From Accident Data. Presented at 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan.7 p.
4. Altman, S.; Santistevan, D.; Hitchings, C.; Wallingford, J. G.; Greenlees, B. 2002. A comparison of rollover characteristics for passenger cars, light duty trucks and sport utility vehicles. 9 p. Automotive crash research: side impact, rollover, and vehicle aggressivity. Warrendale, SAE, 2002, p. 23-31. Report No. SAE 2002-01-0942. UMTRI-95607 A03
5. Cooperrider, N. K.; Thomas, T. M.; Hammoud, S. A. 1990. Testing and analysis of vehicle rollover behavior. Failure Analysis Associates. 10 p. Accident Reconstruction: Human, Vehicle, and Environmental Factors. Warrendale, Pa., SAE, 1990, p. 125-134. Report No. SAE 900367. UMTRI-79890 A03
6. Deutermann, W. 2002. Characteristics of fatal rollover crashes. National Highway Traffic Safety Administration, Washington, D.C./ Department of Transportation, Washington, D.C./ National Center for Statistics and Analysis, Research and Development, Washington, D.C. Published by Washington, D.C.: National Center for Statistics and Analysis, Research and Development ; Springfield, Va.: National Technical Information Service. 54 p. Report No. DOT-HS-809-438. UMTRI-95913
7. Eigen, Ana Maria. 2003. Examination of Rollover Crash Mechanisms and Occupant Outcomes, National Center for Statistics and Analysis.Traffic Safety Facts, Research Note, 8p. Report No. DOT-HS-809-692.
8. Farmer, C. M.; Lund, A. K. 2002. Rollover risk of cars and light trucks after accounting for driver and environmental factors. Insurance Institute for Highway Safety, Arlington, Va. 11 p. Accident Analysis and Prevention, Vol. 34, No. 2, Mar. 2002, p. 163-173. UMTRI-62664 See Journal
9. Harwin, E. A.; Brewer, H. K. (1987) Analysis of the relationship between vehicle rollover stability and rollover risk using the NHTSA CARDfile accident database. National Highway Traffic Safety Administration, Washington, D.C. 36 p. UMTRI-78527
10. Hendricks, D., Scheifflee, T., Page, J., Bellis, E. "Analysis of Untripped Rollovers, Final Report, Technical Findings," CALSPAN, Buffalo, 1998.
11. Jones, I. S.; Wilson, L. A. 2000. Techniques for the reconstruction of rollover accidents involving sport utility vehicles, light trucks and minivans. Jones, Ian S. and Associates. 21 p. Accident Reconstruction: Analysis, Simulation, and Visualization. Warrendale, SAE, 2000, p. 401-421. Report No. SAE-2000-01-0851. UMTRI-93282 A20.

12. Kahane, C. J. 1993. Effect of car size on the frequency and severity of rollover crashes. National Highway Traffic Safety Administration, Washington, D.C. 6 p. International Technical Conference on Experimental Safety Vehicles. Thirteenth. Proceedings. Volume II. Washington, D.C., NHTSA, 1991, p. 765-770. UMTRI-85232 A07
13. Krull, K. A.; Khattak, A. J.; Council, F. M. 2000. Injury effects of rollovers and events sequence in single-vehicle crashes. North Carolina University, Chapel Hill, Highway Safety Research Center. 9 p. Transportation Research Record, Vol. 1717, 2000, p. 46-54. Sponsor: Federal Highway Administration, Washington, D.C. Report No. 00-0662. UMTRI-62134 See Journal
14. Malliaris, A. C.; DeBlois, J. H. 1993. Pivotal characterization of car rollovers. DeBlois and Associates, Washington, D.C. 8 p. International Technical Conference on Experimental Safety Vehicles. Thirteenth. Proceedings. Volume II. Washington, D.C., NHTSA, 1991, p. 721-728. Sponsor: Centers for Disease Control, Atlanta, Ga. UMTRI-85232 A01
15. Parenteau, C. S.; Shah, M.; Tieman, C. 1999. Common rollover characteristics in US rollovers [sic] crashes; Common rollover characteristics in US rollover crashes. Delphi Automotive Systems. 12 p. Journal of Traffic Medicine, Vol. 27, No. 3-4, 1999, p. 97-106. UMTRI-61688
16. Parenteau, C. S.; Viano, D. C.; Shah, M.; Gopal, M.; Davies, J.; Nichols, D.; Broden, J. 2003. Field relevance of a suite of rollover tests to real-world crashes and injuries. Delphi Automotive Systems, Troy, Mich./ Saab Automobile AB (Sweden) 8 p. Accident analysis and prevention. Vol. 35, no. 1 (Jan. 2003) p. 103-110. UMTRI-63068 See Journal
17. Pittle, R. David. 2000. SUV Rollover and Stability Control – A Consumer View. Presented at SAE Conference on Rollover and Stability Control. Troy, Michigan, May 16, 2000.
18. Robertson, L. S.; Maloney, A. 1997. Motor vehicle rollover and static stability: an exposure study. Yale University, New Haven, Conn./ Nanlee Research, Branford, Conn./ Indian Health Service, Tuba City, Ariz. 2 p. American Journal of Public Health, Vol. 87, No. 5, May 1997, p. 839-841. UMTRI-90584
19. Viano, D. C.; Parenteau, C. 2003. Case study of vehicle maneuvers leading to rollovers: need for a vehicle test simulating off-road excursions, recovery and handling. ProBiomechanics, Bloomfield Hills, Mich./ General Motors Corporation, Vehicle Structure and Safety Integration/ Delphi Corporation, Troy, Mich. 12 p. Biomechanics. Warrendale, SAE, 2003, p. 135-146. Report No. 2003-01-0169. UMTRI-96373 A14
20. Wielenga, T. J. 1999. A method for reducing on-road rollovers -- anti-rollover braking. Dynamotive. 12 p. Vehicle dynamics and simulation 1999 (SAE-SP-1445). Warrendale, SAE, 1999, p. 87-98. Report No. SAE 1999-01-0123. UMTRI-91880 A06
21. Wielenga, T. J. 1999. Tire properties affecting vehicle rollover. Chace and Associates Engineering, Inc., Ann Arbor, Mich. 9 p. Vehicle dynamics and simulation 1999 (SAE-SP-1445). Warrendale, SAE, 1999, p. 129-137. Report No. SAE 1999-01-0126. UMTRI-91880 A09

Appendix A

Definitions and Code Levels for SUV Data Collection

Coding manual for TRW SUV Rollover data collection

This manual presents a proposed methodology to collect information on pre-roll events for a set of rollover crashes involving selected SUVs (Ford Explorer, Chevy Blazer, GMC Jimmy, Toyota 4Runner, and Jeep Cherokee).

We will select rollover cases from the NASS Crashworthiness Data System (CDS) file and then review the NASS investigation of the crash to code additional information about the sequence of events prior to the rollover. The data coded covers all the events and conditions we currently think are relevant to the rollover process, constrained by what is feasible to extract from the NASS CDS investigations.

The general purpose of the data collection is to accomplish two things:

1. Collect data on pre-roll conditions that are relevant to the rollover.
2. Collect a relatively complete sequence of events leading up to the rollover, including the immediate cause of the rollover.

It is intended that these data will allow the full characterization of the rollover sequence from “normal” driving to the rollover. The data collected will be joined to the data collected by the NASS for comprehensive coverage of the events.

The first section covers the approach to the data collection. The second section provides definitions for each coded field.

General approach to the data collection

1. Code our own judgment and conclusions. In some cases, similar variables are coded by the NASS researcher. Our obligation is to make an independent judgment on that. It is known, and not surprising, that there are errors in the NASS CDS file. We need to make sure that we bring our own observation and judgment to bear. In some cases our coded data will differ from the NASS researcher. Use the “UMTRI summary” field to discuss.
2. Use all the evidence and best judgment. We need to be sure we are reviewing all the available evidence on a case, including the scene diagram, coded information, and photographs.
3. The standard for judgment is the preponderance of evidence, not beyond a reasonable doubt. We are making judgments from photos, narratives, and scene diagrams. We can’t “prove” much. But we can make a reasonable argument. However, there must be some evidence that you can point to in making a call.
4. If there is no evidence or you are unable to make a judgment, we will have to rely on the NASS researcher’s information. This will be particularly true for quarter turns. Direction of roll we can verify from photos. And we can verify the number of turns when less than

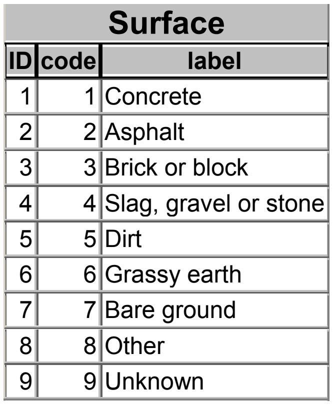
4, by looking for damage on the vehicle. I think we can also get guidance from the roll type coded by the researcher, but this should be guidance only.

5. We are only interested in events up to the rollover. Once the wheels leave the ground, events coding ends.

Definitions of fields collected

Capture the scene diagram to a file name Scene_IDXXXX where XXXX is the ID number automatically generated by Access for the case. Capture this file to the same file where your database lives. If you need help with this, ask me.

Road surface type: (This table includes a number of different surfaces, off-road as well as on.) Codes the road the vehicle was on prior to rollover. These code levels are also used to capture roll surfaces.



Surface

ID	code	label
1	1	Concrete
2	2	Asphalt
3	3	Brick or block
4	4	Slag, gravel or stone
5	5	Dirt
6	6	Grassy earth
7	7	Bare ground
8	8	Other
9	9	Unknown

Road surface condition: Again, this is the general condition of the roadway, not at the point of roll or loss of control.

Road surface condition

ID	code	Label
1	1	Dry
2	2	Wet
3	3	Snow or slush
4	4	Ice
5	5	Sand, dirt, or oil
8	8	Other
9	9	Unknown

Split surface: This is a yes/no variable. It will be used to record cases where, at the time of rollover initiation, the SUV has two wheels on the road and two on the shoulder, or two on the shoulder and two on the roadside. Note this is at rollover initiation.

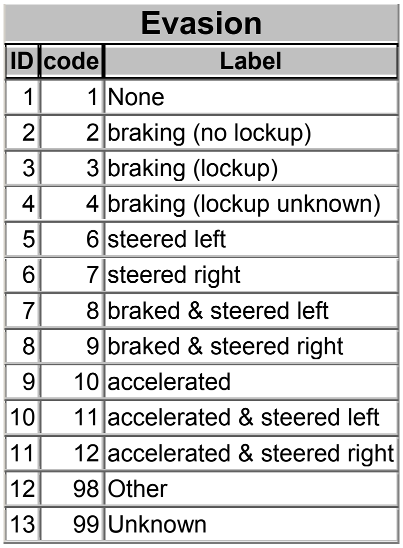
Surface, left; Surface right: Same code levels as for road surface type. Note that the surface table includes a number of different surfaces, off road as well as on road.

Elevation change: This variable is used to record changes in road level, as when there is a drop off from the road surface to the shoulder or roadside, or the shoulder to the roadside. The researcher will enter a value in inches. Does not include curbs. Enter a negative number when the second surface is below the first. Enter a positive number if the second surface is above. We are looking for a drop off, not a slope.

This one will be somewhat hard to judge in many cases. The following table provides codes to be used when there is a change in elevation, but no precise estimate can be made:

Code	Label
-98	Drop off of more than 3 inches
-97	Drop of less than 3 inches
0	No drop off (default)
97	Bump up of less than 3 inches (but more than 0)
98	Bump up of more than 3 inches

Evasion: Records the first evasive maneuver, if any. If there is no evasion, code “not applicable.” The evasion can be to **maneuver to avoid collision with another vehicle, debris in the road, pedestrian/bicyclist, animal, etc.** These are not attempts to regain control, etc. The idea is to capture an evasive maneuver that may have precipitated or contributed to loss of control. But loss of control doesn’t have to follow the evasion.



Evasion

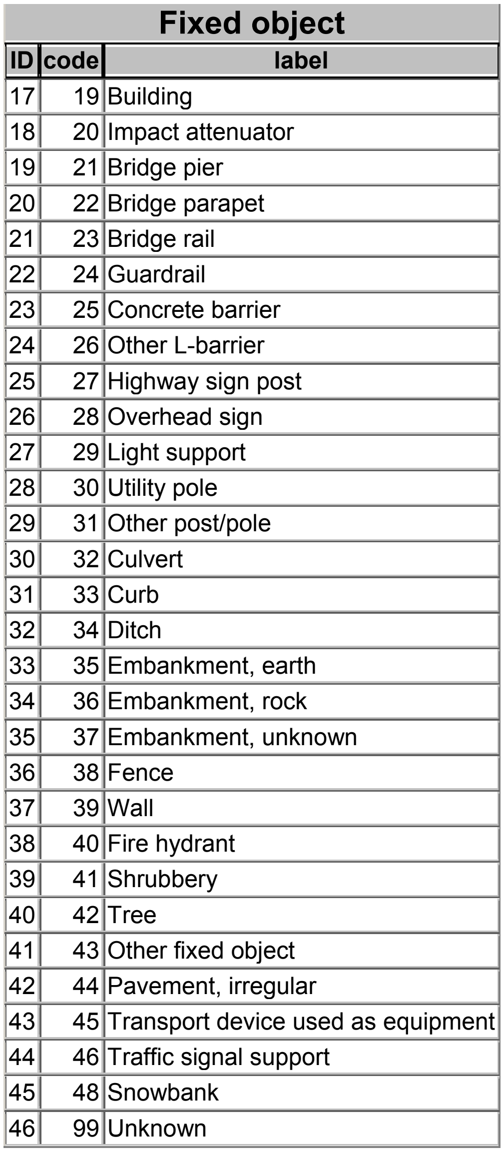
ID	code	Label
1	1	None
2	2	braking (no lockup)
3	3	braking (lockup)
4	4	braking (lockup unknown)
5	6	steered left
6	7	steered right
7	8	braked & steered left
8	9	braked & steered right
9	10	accelerated
10	11	accelerated & steered left
11	12	accelerated & steered right
12	98	Other
13	99	Unknown

Recovery maneuver: Code the first recover maneuver. Recovery maneuvers occur after the vehicle either leaves the road or becomes unstable. Code “not applicable” if no recovery maneuver is attempted. The recovery maneuvers are the same as the evasive maneuvers.

Note that we might need to amend the list. We may not know about braking or steering. May know some details but not all. We can revisit this one after reviewing a few cases.

Recovery followed: Code the number of the event the recovery maneuver followed. Code “no recovery” if no recovery was attempted. Same as “not applicable.”

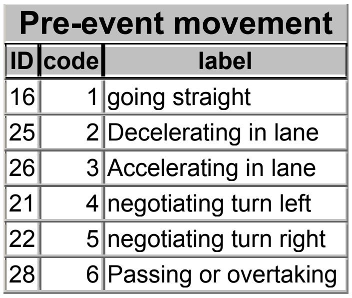
Fixed object: Records the first fixed object struck. If no fixed object is struck, code "not applicable." Later these values can be aggregated to identify point objects such as trees or bridge piers and horizontal objects, such as guardrail ends.



Fixed object

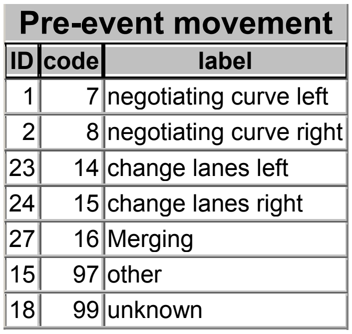
ID	code	label
17	19	Building
18	20	Impact attenuator
19	21	Bridge pier
20	22	Bridge parapet
21	23	Bridge rail
22	24	Guardrail
23	25	Concrete barrier
24	26	Other L-barrier
25	27	Highway sign post
26	28	Overhead sign
27	29	Light support
28	30	Utility pole
29	31	Other post/pole
30	32	Culvert
31	33	Curb
32	34	Ditch
33	35	Embankment, earth
34	36	Embankment, rock
35	37	Embankment, unknown
36	38	Fence
37	39	Wall
38	40	Fire hydrant
39	41	Shrubbery
40	42	Tree
41	43	Other fixed object
42	44	Pavement, irregular
43	45	Transport device used as equipment
44	46	Traffic signal support
45	48	Snowbank
46	99	Unknown

Pre-event maneuver: This variable records the maneuver of the vehicle prior to the rollover sequence. It records the last equilibrium state before the rollover sequence began.



Pre-event movement

ID	code	label
16	1	going straight
25	2	Decelerating in lane
26	3	Accelerating in lane
21	4	negotiating turn left
22	5	negotiating turn right
28	6	Passing or overtaking



Pre-event movement		
ID	code	label
1	7	negotiating curve left
2	8	negotiating curve right
23	14	change lanes left
24	15	change lanes right
27	16	Merging
15	97	other
18	99	unknown

Events one through six: These are the events the lead up to the rollover. The last event will always be the rollover. Six events seems like enough, but if there are any cases where there are seven events, the seventh event is implied as a rollover. (LOC means loss of control.) Once rollover occurs, code all subsequent events “no other.”

Note that we separate stability from events. Events occur and then after each event, the stability of the vehicle is judged. So rotating, spinning, sliding, etc., are not events but the result of events, either a maneuver or something else.

Drift off road means a gradual departure, usually related to fatigue or inattention. Ran off road can occur because of loss of control, or an evasive maneuver, or attempting to negotiate a curve too fast. In drift off road, basically the driver is not engaged and the vehicle drifts off. In ran off road, the driver is engaged and goes off, whether intentionally or not.

Lane excursion means to move from one lane to another travel lane, either into a lane going the same direction or a lane going in the opposite direction. Usually precedes another non-roll event. If the vehicle goes straight off the road, use that code instead.

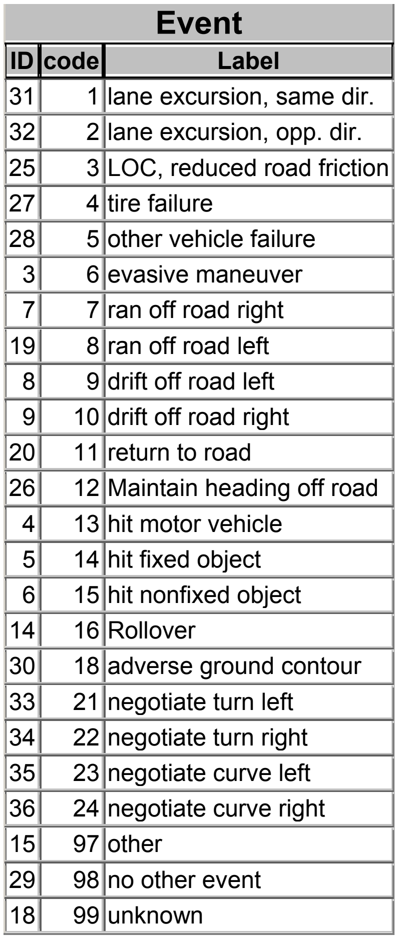
LOC, reduced road friction means loss of control due to reduced road friction. Don’t record other LOC events here.

Negotiate turn refers to a turn from one roadway to another, such as at an intersection or driveway.

Negotiate curve refers to following curves in the roadway itself, not transitioning from one roadway to another.

Fixed objects will generally be off the roadway, so fixed object events should be preceded by a ran or drift off road event.

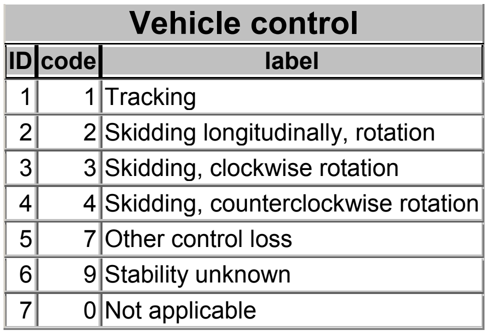
An adverse ground contour is for sudden changes in the ground contour that severely challenge handling or stability with an impact with the front of the vehicle. If the front bumper strikes a ditch side, then code fixed object and record the object type. But if the vehicle bounces over the ditch, without actually striking it with a body part, record adverse ground contour.



Event

ID	code	Label
31	1	lane excursion, same dir.
32	2	lane excursion, opp. dir.
25	3	LOC, reduced road friction
27	4	tire failure
28	5	other vehicle failure
3	6	evasive maneuver
7	7	ran off road right
19	8	ran off road left
8	9	drift off road left
9	10	drift off road right
20	11	return to road
26	12	Maintain heading off road
4	13	hit motor vehicle
5	14	hit fixed object
6	15	hit nonfixed object
14	16	Rollover
30	18	adverse ground contour
33	21	negotiate turn left
34	22	negotiate turn right
35	23	negotiate curve left
36	24	negotiate curve right
15	97	other
29	98	no other event
18	99	unknown

Post-event stability one through six: Records the stability of the vehicle after each respective event. Once rollover occurs, code “not applicable.”

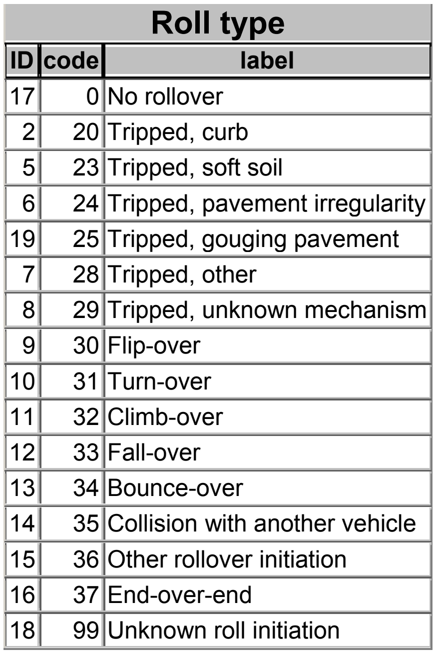


Vehicle control

ID	code	label
1	1	Tracking
2	2	Skidding longitudinally, rotation
3	3	Skidding, clockwise rotation
4	4	Skidding, counterclockwise rotation
5	7	Other control loss
6	9	Stability unknown
7	0	Not applicable

Roll initiation: The immediate cause of the rollover. This primarily characterizes the rollover mechanism. Definitions are the same as in the NASS CDS coding manual, that has been distributed. We’ve broken up tripped into subcategories. Note in the NASS CDS manual that turn-over requires justification. Turnover occurs when the lateral forces on the tire from contact with the road is sufficient to turn the vehicle over. No tripping from a curb or roadway ruts or gouges is present. I infer from the manual and the fact that this code requires special justification that turn-over is infrequent. We should be aware of this when coding.

Look for scuffs, gouge marks, contact marks with fixed object, and so on, in judging this. We will occasionally have to use information from the NASS CDS researchers judgment, but the first priority is to use our own judgment, and to base our judgment on reasoning from evidence.



Roll type

ID	code	label
17	0	No rollover
2	20	Tripped, curb
5	23	Tripped, soft soil
6	24	Tripped, pavement irregularity
19	25	Tripped, gouging pavement
7	28	Tripped, other
8	29	Tripped, unknown mechanism
9	30	Flip-over
10	31	Turn-over
11	32	Climb-over
12	33	Fall-over
13	34	Bounce-over
14	35	Collision with another vehicle
15	36	Other rollover initiation
16	37	End-over-end
18	99	Unknown roll initiation

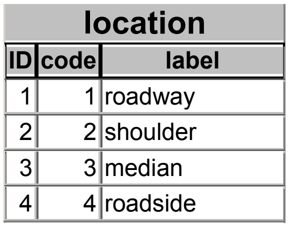
Number of quarter turns of roll. We will code up to 12, and 12+. Try to verify by looking at the vehicle damage pictures. We will have to rely on NASS researchers judgment for numbers greater than 4.

Direction: Direction of roll. Verify from photos of the vehicle and scene, from the scene diagram, and the NASS summary. Make sure the story makes sense and is self-consistent.

direction

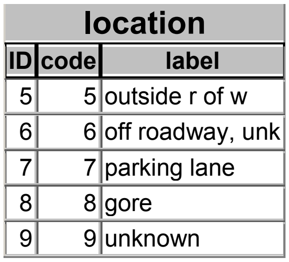
ID	number	label
1	1	Left
2	2	Right
5	3	End-over-end
3	8	Other
4	9	Unknown

Location of roll: Verify from scene photos and scene diagram. I can supply definitions for each category, if desired. Don't guess. Ask if you need definitions.



location

ID	code	label
1	1	roadway
2	2	shoulder
3	3	median
4	4	roadside



location

ID	code	label
5	5	outside r of w
6	6	off roadway, unk
7	7	parking lane
8	8	gore
9	9	unknown

Roll type surface: Type of surface at roll initiation. Takes same values as “road surface type.”

Surface condition roll: Surface condition at the point of rollover initiation. Takes on the same values as roadway surface condition above.

Surface condition LOC: Surface condition at the point of loss of control, if any. The purpose of this is to capture events where the vehicle losses control at an icy patch, and then rolls when it hits dry pavement.

UMTRI summary: This is a text area where the UMTRI researcher will enter a description of the rollover, along with any discussion of unusual, pertinent events. Use this to describe events, point to evidence used in your judgment, and address any anomalies in the case (e.g., disagreements with NASS, unusual events, etc.) A little extra time spent here will be useful later. Write as if you will be looking at these summaries long after you’ve forgotten the details of the case, because you will.

NASS summary: Another text area where we will copy the NASS CDS researchers summary of the crash (not just the rollover).

Appendix B

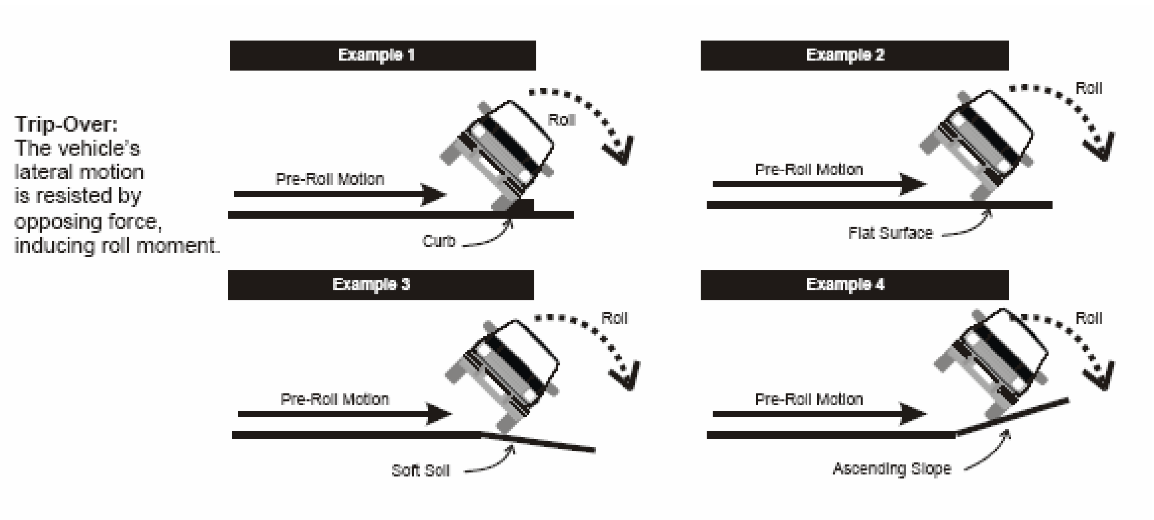
NASS CDS Roll Initiation Type Definitions

NASS CDS definition of rollover initiation type.

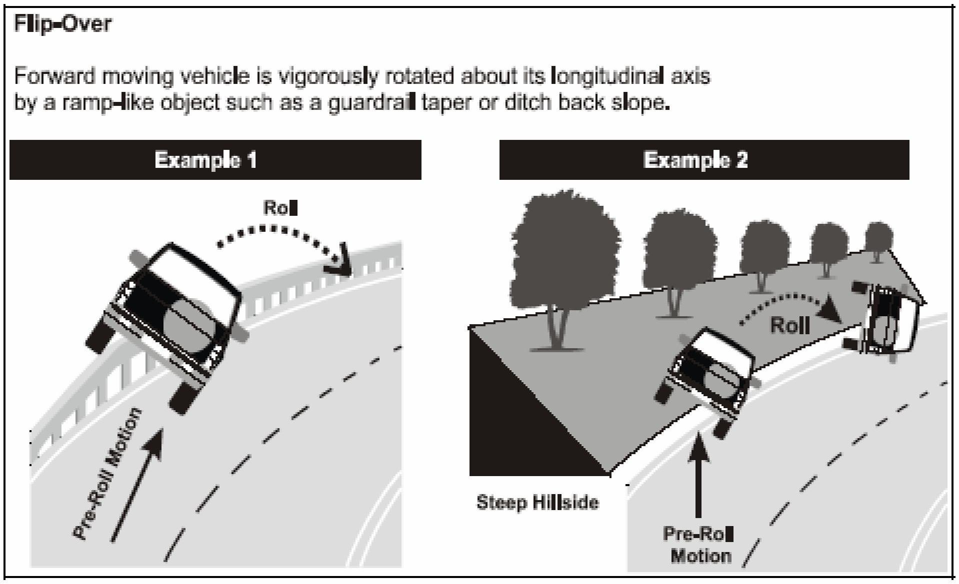
Quoted from **Nation Automotive Sampling System Crashworthiness Data System 2000 Coding and Editing Manual.** United States Department of Transportation, National Highway Traffic Safety Administration. pp 230-235.

This manual is available at http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Manuals/CDSAUM02.pdf

Trip-over is selected when the vehicle's lateral motion is suddenly slowed or stopped, inducing a rollover. The opposing force may be produced by a curb, pot-holes, or pavement/soil dug into by a vehicle's wheels.



Flip-Over is selected when the vehicle is rotated about its longitudinal axis by a ramp-like object may be in a yaw when it comes in contact with the ramp-like object. For example, if the vehicle traveling forward climbs the down turned end of a guardrail and rolls over about its longitudinal axis, use this code. To use this, the vehicle's roll need not begin on the ramp-like structure or object, For example, if the vehicle transverses the turned-down end of a guardrail, continues along the level portion, then rolls back toward the side of the guardrail from which it came, use this code.

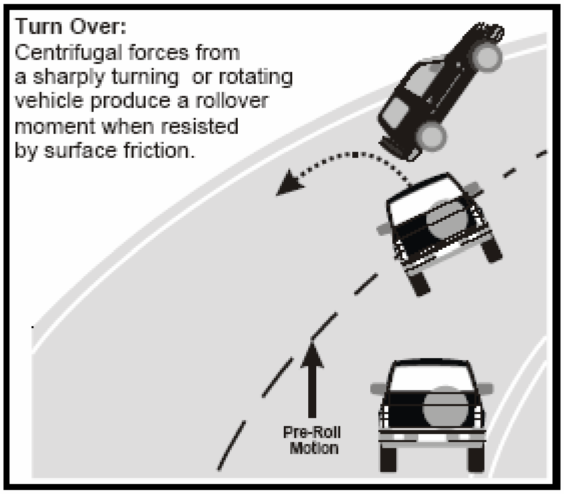


Flip-Over

Forward moving vehicle is vigorously rotated about its longitudinal axis by a ramp-like object such as a guardrail taper or ditch back slope.

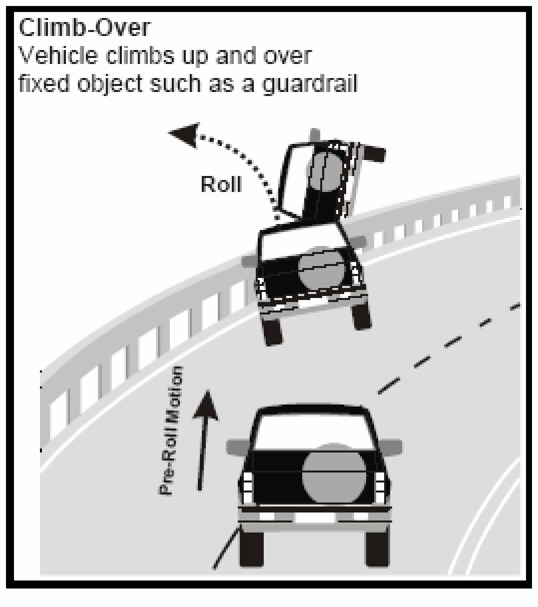
Turn Over: Centrifugal forces from a sharply turning or rotating vehicle produce a rollover moment when resisted by surface friction.

Turn-Over is selected when centrifugal forces from a sharply turning or rotating vehicle produce a rollover when resisted by normal surface friction. This type of rollover is more likely to occur in vehicles with a higher center of gravity than most passenger vehicles. The surface type includes pavement surfaces plus gravel, grass, dirt, etc. The distinction between **Turn-over** and **Trip-over** is that no furrowing, gouging, etc. occurs to the surface at the point of trip. In addition, see remarks for **Fall-over** below. When turnover is selected, the justification **must be entered**.

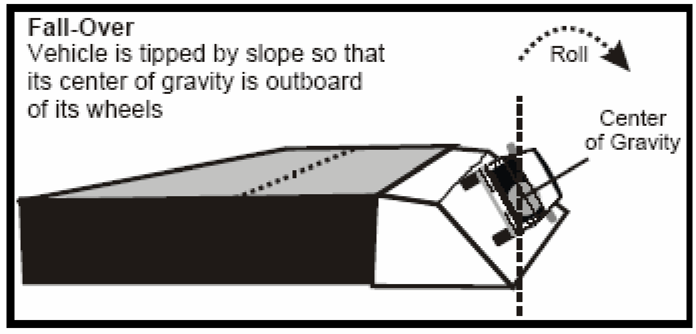


Turn Over:
Centrifugal forces from a sharply turning or rotating vehicle produce a rollover moment when resisted by surface friction.

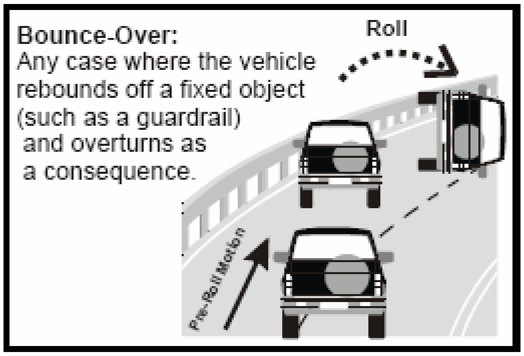
Climb-Over is selected when a vehicle climbs up and over a fixed object such as a barrier or guardrail. The object should be high enough to lift the vehicle completely off the ground (*i.e.*, the height should exceed the radius of the vehicle's largest diameter wheel). The vehicle must roll to the opposite side from which it approached the object.



Fall-Over Vehicle is tipped by slope so that its center of gravity is outboard of its wheels. **Fall-Over** is selected when the surface the vehicle is traversing slopes downward in the direction of movement of the vehicle's center-of-gravity such that the vehicle's center of gravity becomes outboard of its wheels. The distinction between this and **Turn-over** above involves the negative slope of the traversed surface. If the rotation and/or the surface friction causes the trip, then use **Turn-over,** however, if the slope is so negative that a line straight downward through the vehicle's center-of-gravity (as shown in the illustration) would fall outside the vehicle's track, then use this attribute. For example, if a vehicle goes off the road and encounters a substantial surface drop off because of the elevated nature of the road in relation to its environment (*e.g.*, cliff, ditch, etc.), then use this attribute.



Bounce-Over is selected when a vehicle deflects off of a fixed object (such as a guardrail, barrier, tree, or pole) or a not-in-transport vehicle such that the vehicle's rotation causes it to overturn. The deflection momentum contributes to a rollover. To use this attribute, the rollover must occur in close proximity to the object from which it deflected. For example, if a vehicle strikes a center median barrier and rotates across two traffic lanes prior to the vehicle rolling over, then **Trip-over** or **Turn-over** would apply.



Collision with another vehicle is selected when an impact with another vehicle causes the rollover. The rollover must be the immediate result of the impact between the vehicles (*e.g.*, intersection crashes where a vehicle is struck in the side and the momentum of the struck vehicle results in the rollover, or offset end-to-end type crashes when one vehicle will vault over the tapered end of another vehicle resulting in a rollover). Otherwise use attributes above. For example, if a vehicle is struck in the side ***and*** the vehicle rotates ***and*** does not produce any wheel/rim gouges or furrows in the surface nor encounters any prominent raised objects (*e.g.*, a high curb) ***and*** overturns in close proximity to the point of impact, then use this attribute.

Other rollover initiation type is selected when this vehicle's rollover initiation type cannot be described above. Whenever this is used, the researcher is required to ***specify*** the type of rollover which occurred.

Unknown is selected when the type of rollover initiation is unknown

[End-over-end] is automatically entered when the type of rollover is end-over-end.