THE ROLE OF VERTICAL ROOF INTRUSION IN PREDICTING OCCUPANT EJECTION

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ABSTRACT

The purpose of the current study is to investigate whether there was a statistically significant relationship between vertical roof intrusion and the probability of occupant ejection in rollovers that are likely to be covered by Federal Motor Vehicle Safety Standard No. 216 (FMVSS No. 216). If such a relationship did exist, FMVSS No. 216 might affect the number of occupant ejections in rollovers.

The study applies thirty six different statistical models to crash data to model the probability of occupant ejection using a number of explanatory variables, including the amount of vertical roof intrusion. The data is on vehicle occupants who were involved in relevant rollover crashes, and is taken from NASS CDS for years 1997 to 2006 (n = 5,562). Though the study considers a number of different models, it does not find a statistically significant relationship between vertical roof intrusion in relevant rollovers and the probability of complete occupant ejection. When ejections of any degree are considered (whether complete, partial, or of unknown degree), there was a statistically significant relationship in some subpopulations.

Given that no relationship has been found between the amount of vertical roof intrusion and the probability of complete occupant ejection, increasing roof strength is unlikely to impact the number of complete occupant ejections. The study is limited to occupants in rollovers that are likely to be covered by FMVSS No. 216, and to occupants for whom key data, such as the amount of vertical roof intrusion, are available.

INTRODUCTION

Purpose. Austin et al. (2005) and Strashny (2007) have established the existence of a statistically significant relationship between the maximum severity of head, neck, and face injuries due to occupant roof contact that occurred in rollovers that were likely to be covered by Federal Motor Vehicle Safety Standard (FMVSS) No. 216 and the amount of vertical roof intrusion. The occupants considered in those reports were belted and not completely ejected. The purpose of the current report is to investigate whether there was also a statistically significant relationship between vertical roof intrusion and occupant ejection. The rollovers considered ("relevant rollovers") are those likely to be covered by FMVSS No. 216, with the exception that this report is not placing restrictions on occupant seat belt use or ejection status.

Data. The data is from the National Automotive Sampling System Crashworthiness Data System (NASS CDS) for years 1997 to 2006. NASS CDS is a complex, random sample of crashes involving at least one passenger car or "light truck or van" (LTV), defined by a gross vehicle weight rating of 4,536 kilograms (10,000 pounds) or less, that was towed due to damage. The beginning year of 1997 was selected because it was the first year that NASS CDS coded continuous vertical roof intrusion measures. Prior to that year, NASS CDS coded intrusion in categories with ranges that were too wide to be of use in this study. The ending year of 2006 was the most current year available at the time of this analysis. Note that the database codes intrusion in centimeters. For this report, measurements have been converted to inches.

This study analyzes occupants of automobiles, utility vehicles, light-duty pickup trucks, and light-duty vans that were involved in single-vehicle rollover crashes. The following vehicles were excluded from the analysis: (1) convertibles; (2) vehicles that rolled only one quarter-turn to the side, since they did not have roof-to-ground exposure; and (3) vehicles that had been towing a trailing unit or that were multistage or certified altered vehicle, because changes may have been made to the roof structure in such vehicles. To be consistent with the target population used in the FMVSS No. 216 regulatory analyses, the occupants of interest were seated in one of the two outboard front seats (seating positions 11 and 13) and were 13 years old or older. Unlike in Austin et al. (2005) and Strashny (2007), occupants were not excluded from the analysis based on their seat belt use status, ejection status, or the model year of their vehicle.

Method. Probability of ejection was analyzed using the probit model. Thirty-six statistical models were estimated. These models differed in the dependent variables, independent variables, and the data subset used. Two different dependent variables were used to indicate ejection status. These were:

1. "complete ejection" (C), indicating whether the occupant was completely ejected or not; and
2. "any ejection" (A), indicating whether the occupant was ejected (to any degree, including completely, partially, and to unknown degree) or not.

Some models contained a continuous intrusion variable, measured in inches, as an independent variable. Other models contained a dichotomous intrusion variable. In this case, the dichotomous variable was set to 0 if there was no intrusion and to 1 if there was intrusion.

Some models contained intrusion, whether continuous or dichotomous, as the only independent variable. These are called "unadjusted" as they have not been adjusted for potentially confounding factors. "Adjusted" models, on the other hand, control for a number of potentially confounding factors. The following independent variables were used in all of the adjusted models: occupant age, whether the vehicle was an LTV or a passenger car; and whether the rollover was end-over-end or to the side. For sideways rollovers, rollover severity was controlled by using either the number of quarter turns or the number of roof-to-ground exposures.

There does not appear to be a logical connection between occupant age and ejection status. Indeed, occupant age was not statistically significant in most of the models. In the models in which it was statistically significant, it is possible that the statistical significance was due to an artifact of the data, as discussed below. Thus, the only reason that occupant age is included as an independent variable is for consistency with other recent reports that included it in their models of occupant ejection, such as Lund (2008) and Padmanaban and Moffatt (2008), and because it was statistically significant in some models.

Occupant sex was not statistically significant in any of the estimated models. Because of this, and because there does not appear to be a logical connection between occupant sex and ejection status, this independent variable was not used in the final versions of any of the models.

According to Eigen (2003), while there is no universally accepted measure of sideways rollover severity, some studies use the number of quarter turns for this purpose. Digges and Eigen (2003) and Eigen (2005) found that, in some cases, the number of roof-to-ground exposures is a good measure of sideways rollover severity. Specifically, Digges and Eigen (2003) found that "for belted occupants and unbelted ejected occupants in single vehicle crashes, the number of [roof-to-ground exposures] is an appropriate severity indicator." Following Eigen (2005) and Strashny (2007), the number of roof-to-ground exposures in a sideways rollover is defined as the number of times that the vehicle roof faced downward, toward the ground, regardless of the number of times that the roof physically contacted the ground. Strashny (2007) found that, other things being equal, as the number of quarter turns or the number of roof-to-ground exposures increased, the severity of injuries considered by that report also tended to increase. Therefore, the current report uses both of these measures to control for sideways rollover severity.

Some models were estimated using all the occupants. In these cases, the adjusted models controlled for seat belt use. Other models were estimated only on the subpopulation of belted occupants or on the subpopulation of unbelted occupants. Note that only the occupants who are known to have been belted are considered as such, whereas the occupants who were either unbelted or whose seat belt use status is unknown are considered to be unbelted.

Thus, there were two possible dependent variables (C and A), two possible intrusion variables (continuous and dichotomous), three possible types of models (unadjusted, quarter turns adjusted, and roof-to-ground exposure adjusted), and three data subsets (all occupants, belted occupants only, and unbelted occupants only), leading to a total of 36 models.

DATA DESCRIPTION

Error! Reference source not found. is a description of the variables used in this report. The first sub-table shows the sample size and the weighted annual average of all occupants, as well as the unbelted and the belted subsets. The second sub-table describes categorical variables. As all of the categorical variables used in this report only have two categories, the table shows only one category for each variable. Values for the other category can be obtained by subtraction. For example, among all occupants, 4.3 percent were complete ejected. This means that 95.7 percent [= 100% - 4.3%] were not completely ejected. The third sub-table describes interval scale variables. For each variable, it gives the minimum, maximum, and the weighted mean.

Table 1.

A description of the variables used in this report

Occupants	**All**	**Unbelted**	**Belted**
Sample size	5,562	1,951	3,611
Weighted annual average	251,245	51,297	199,949

	All occupants			**Unbelted occupants**			**Belted occupants**		
Variable	WP	WAA	Sample	WP	WAA	Sample	WP	WAA	Sample
Intrusion > 0 (vs. no intrusion)	58.2%	146,205	3,686	59.4%	30,461	1,290	57.9%	115,744	2,396
Complete ejection (C) (vs. partial or no ejection)	4.3%	10,863	793	20.0%	10,252	765	0.3%	612	28
Any ejection (A) (vs. no ejection)	6.9%	17,250	1,199	25.4%	13,009	948	2.1%	4,241	251
End-over-end rollovers (vs. lateral rollovers)	0.7%	1,689	76	1.5%	779	34	0.5%	910	42
Vehicle = LTV (vs. vehicle = passenger car)	54.8%	137,729	3,135	47.9%	24,553	1,086	56.6%	113,177	2,049
Belted occupants (vs. unbelted or unknown)	79.6%	199,949	3,611						

		All occupants			**Unbelted occupants**			**Belted occupants**		
Variable		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Intrusion	(inches)	0	44.1	3.5	0	44.1	3.7	0	38.6	3.4
# roof exposures	(end-over-end = 0)	0	4	1.2	0	4	1.2	0	4	1.2
# quarter turns	(end-over-end = 0)	0	17	3.6	0	17	3.8	0	17	3.6
Occupant age	(years)	13	95	29.6	13	93	28.5	13	95	29.9

Note: "WP" = weighted percent; "WAA" = weighted annual average; "Sample" = sample size.
Source: NHTSA, NCSA, NASS CDS 1997-2006.

Both complete ejection and any ejection were much more likely among unbelted occupants as compared to belted occupants. One way of measuring differences in probabilities is using odds ratios (OR). The odds ratio for complete ejection for unbelted occupants as compared to belted occupants was 81.4 [=(0.2 / (1-0.2)) / (0.003 / (1-0.003))]. For any ejections, the odds ratio was 15.7.

For categorical variables, the sample sizes of some of the categories were relatively small. For example, for unbelted occupants, the sample size of those who were in the end-over-end rollover vehicles was 34; for belted occupants, the sample size of those who were completely ejected was 28.

One potential issue with models of belted occupants is that there were few belted occupants who were ejected. This could affect the accuracy of these models. That is why Padmanaban and Moffatt (2008) only develop models of ejection for unbelted drivers. Table 2 shows selected variables and statistics for the subpopulation of belted occupants.

Table 2.

Selected variables and statistics for the subpopulation of belted occupants

	WP	WAA	SP	Sample
Complete ejection (C)	0.31%	612	0.78%	28
Any ejection (A)	2.12%	4,241	6.95%	251
End-over-end	0.46%	910	1.16%	42
Complete ejection (C) and end-over-end	0%	0	0%	0
Any ejection (A) and end-over-end	0%	0	0%	0

Odds ratio for age >= 50	WAA	Sample

Complete ejection (C)	12.71	0.59
Any ejection (A)	2.17	1.08

Note: "WP" = weighted percent; "WAA" = weighted annual average; "SP" = sample percent; "Sample" = sample size.
Source: NHTSA, NCSA, NASS CDS 1997-2006.

As the table shows, annually, only an estimated 0.31 percent of belted occupants were completely ejected. End-over-end rollovers were a rare event in belted occupants as well – only an estimated 0.46 percent of belted occupants were in such rollovers annually. Finally, there were no occupants who were belted, involved in an end-over-end rollover, and ejected, either completely or to any degree.

The second sub-table of Table 2 shows the odds ratios of ejection for older occupants (50 years old or older) as compared to younger occupants. The first column gives the odds ratios based on the weighted annual averages, while the second column gives them based on the sample. The table shows that, while there were relatively few belted older occupants who were ejected in the sample, the weighting was such that the estimated annual average for these occupants was large. This means that, in the belted subpopulation, the observations of a few older occupants could have a large effect in modeling the probability of ejection.

For example, consider complete ejections. In the sample, there were only 3 older occupants who were completely ejected, as compared to a total of 28 occupants who were completely ejected, giving odds of ejection of 0.12 [=(3/28)/(1-3/28)] for older occupants. Among the occupants who were not completely ejected, the odds were 0.20. Thus, the odds ratio was 0.59 [=0.12/0.20], indicating that relatively more occupants in the sample were younger than 50. However, using the estimated annual averages, the odds ratio was 12.71, indicating that, based on the weighting, there were relatively many more older ejected occupants. For instance, while the estimated annual average of completely ejected occupants was 612 based on 28 observed occupants, just one observation of an occupant who was 59 years old had a weighted annual average of 310, or about 50 percent of the total.

It might appear that the number of quarter turns variable and the end-over-end indicator might be highly correlated and that using both of them as explanatory variables in the same model might cause near multicollinearity. This is because there is a relationship between the two variables: whenever the end-over-end indicator is equal to 0, the number of quarter turns is greater than or equal to 2; whenever the end-over-end indicator is equal to 1, the number of quarter turns is equal to 0. In fact, the correlation coefficient between the two variables is just -0.20, which means that the variables are not strongly correlated at all and using both of them as explanatory variables at the same time would not cause near multicollinearity. Likewise, the correlation coefficient between the number of roof exposures and the end-over-end indicator is -0.26, which means that these two variables are not strongly correlated either and can both be used in the same model as explanatory variables without causing near multicollinearity.

Table 3 shows the ejection route for ejected occupants as a function of ejection degree, seat belt use, and rollover type. The table shows weighted annual averages and weighted percents. The patterns shown in the table might help explain the results of the statistical analysis below. For example, it is at least conceivable that some routes could be enlarged during some rollovers, while other routes could be restricted.

Table 3.

Ejection route for ejected occupants as a function of ejection degree, seat belt use, and rollover type

Ejection	Complete		Partial	
Windshield	1,398	12.9%	166	2.6%
Side window	5,708	52.5%	5,096	79.8%
Backlight	582	5.4%	74	1.2%
Roof window	585	5.4%	707	11.1%
Door	1,178	10.8%	69	1.1%
Other/ Unknown	1,412	13.0%	275	4.3%

Seat belt use	Unbelted		Belted	
Windshield	1,253	9.6%	311	7.3%
Side window	7,441	57.2%	3,364	79.3%
Backlight	593	4.6%	64	1.5%

Roof window	1,161	8.9%	132	3.1%
Door	1,141	8.8%	106	2.5%
Other/ Unknown	1,421	10.9%	266	6.3%

Ejection type	End-over-end		Sideways	
Windshield	278	54.6%	1,286	7.7%
Side window	134	26.4%	10,670	63.7%
Backlight	7	1.3%	650	3.9%
Roof window	0	0.0%	1,292	7.7%
Door	10	1.9%	1,237	7.4%
Other/ Unknown	80	15.8%	1,607	9.6%

Source: NHTSA, NCSA, NASS CDS 1997-2006.

The distribution of ejection routes varied by the categories considered in the table. For example, of the occupants who were completely ejected, 10.8 percent were ejected through the door, while of those who were ejected but not completely, only 1.1 percent were ejected through the door. For ejections through the door, the odds ratio for complete ejections versus ejections that were not complete was 11.1 [= (0.108 / (1-0.108)) / (0.011 / (1-0.011))]. As another example, considering end-over-end rollovers as compared to sideways rollovers, relatively more of the ejected occupants were ejected through the windshield in end-over-end rollovers (OR = 14.5).

ANALYSIS RESULTS

Table 4 shows the statistical significance of the coefficient on the vertical roof intrusion variable in the models analyzed in this report. In the table, "yes" means that the coefficient is statistically significant at the 0.05 level; "weak" means that the coefficient is statistically significant at the 0.10 level, but not at the 0.05 level; and "no" means that the coefficient is not statistically significant, even at the 0.10 level.

Table 4.

Statistical significance of the coefficient on the vertical roof intrusion variable in several probit models of occupant ejection.

	Intrusion:		Continuous		Dichotomous	
	Ejection:		Complete (C)	Any (A)	Complete (C)	Any (A)
All occupants	Adjustment	# roof exp.	No	Weak	No	No
		# q.t.	No	Yes	No	No
	Unadjusted model		No	Yes	No	No
Unbelted occupants	Adjustment	# roof exp.	No	No	No	No
		# q.t.	No	No	No	No
	Unadjusted model		No	Weak	No	No
Belted occupants	Adjustment	# roof exp.	No	Yes	No	No
		# q.t.	No	Yes	No	No
	Unadjusted model		No	Yes	No	Weak

Yes = statistically significant at the 0.05 level.
Weak = statistically significant at the 0.10 level, but not at the 0.05 level.
No = not statistically significant, even at the 0.10 level.
Source: NHTSA, NCSA, NASS CDS 1997-2006.

As the table shows, in the 18 models of complete ejection, the coefficient on the vertical roof intrusion variable was never statistically significant. This means that this report does not find evidence of a statistical relationship between the vertical roof intrusion in relevant rollovers and complete occupant ejection. As for the statistical relationship between the vertical roof intrusion and any occupant ejection, it varies depending on the statistical model used. For example, among belted occupants, the report does find such a statistical relationship. However, among unbelted occupants, it does not.

Table 5 and **Error! Reference source not found.** show the coefficient estimates for the models analyzed in this report. Estimates in bold are statistically significant at the 0.05 level. Percent concordant and c are two popular measures of association between estimated probabilities and observed outcomes. Percent concordant can be anywhere between 0 and 100; c can be anywhere between 0 and 1. Higher values of each measure indicate better association.

Table 5.

Coefficient estimates for probit models of occupant ejection in relevant rollover crashes (continuous intrusion).

		Complete ejection (C)			Any ejection (A)		
		All	Unbelted	Belted	All	Unbelted	Belted
Intercept		**-1.77**	**-0.91**	**-2.64**	**-1.60**	**-0.74**	**-2.22**
Intrusion	(inches)	0.0146	0.0184	-0.0406	**0.0285**	0.0205	**0.0428**
% concordant		44.1	47.1	40.3	47.9	47.4	50.8
c		0.529	0.535	0.573	0.544	0.538	0.572
Sample size		5,562	1,951	3,611	5,562	1,951	3,611

Complete ejection (C)		All occupants		Unbelted occupants		Belted occupants	
Adjustment		Roof exp	QT	Roof exp	QT	Roof exp	QT
Intercept		**-1.88**	**-1.91**	**-1.73**	**-1.77**	**-4.14**	**-4.19**
Intrusion	(inches)	-0.0038	-0.0009	0.0040	0.0074	-0.0628	-0.0591
# quarter turns	(end-over-end = 0)		**0.172**		**0.173**		**0.181**
# roof exposures	(end-over-end = 0)	**0.549**		**0.553**		**0.584**	
End-over-end	(1 = yes/0 = no)	**1.52**	**1.54**	**1.67**	**1.68**	**-1.98**	**-1.91**
Occupant age	(years)	0.0003	0.0011	-0.0087	-0.0076	**0.0197**	**0.0193**
Seat belt status	(1 = belted/0 = not belted)	**-2.01**	**-2.09**				
Vehicle	(1 = LTV/0 = car)	**0.592**	**0.563**	**0.701**	**0.675**	0.089	0.040
% concordant		87.8	89.7	63.8	68.9	51.5	53.2
c		0.888	0.903	0.643	0.691	0.640	0.667
Sample size		5,562	5,562	1,951	1,951	3,611	3,611

Any ejection (A)		All occupants		Unbelted occupants		Belted occupants	
Adjustment		Roof exp	QT	Roof exp	QT	Roof exp	QT
Intercept		**-1.66**	**-1.59**	**-1.60**	**-1.54**	**-3.10**	**-3.02**
Intrusion	(inches)	0.0245	**0.0273**	0.0083	0.0125	**0.0395**	**0.0415**
# quarter turns	(end-over-end = 0)		**0.149**		**0.170**		**0.129**
# roof exposures	(end-over-end = 0)	**0.528**		**0.607**		**0.463**	
End-over-end	(1 = yes/0 = no)	**1.46**	**1.39**	**2.00**	**1.91**	**-2.84**	**-2.91**
Occupant age	(years)	0.0029	0.0033	-0.0078	-0.0068	**0.0109**	**0.0106**
Seat belt status	(1 = belted/0 = not belted)	**-1.40**	**-1.42**				
Vehicle	(1 = LTV/0 = car)	**0.248**	**0.206**	**0.608**	**0.563**	-0.104	-0.145
% concordant		81.0	81.7	62.7	66.2	59.9	60.5
c		0.814	0.821	0.631	0.664	0.618	0.622
Sample size		5,562	5,562	1,951	1,951	3,611	3,611

Note: Bolded estimates are statistically significant at the 0.05 level.
QT = quarter turns adjusted model.
Source: NHTSA, NCSA, NASS CDS 1997-2006.

Table 6.

Coefficient estimates for probit models of occupant ejection in relevant rollover crashes (dichotomous intrusion).

		Complete ejection (C)			Any ejection (A)		
		All	Unbelted	Belted	All	Unbelted	Belted
Intercept		**-1.71**	**-0.85**	**-2.56**	**-1.54**	**-0.68**	**-2.15**
Intrusion?	(1 = yes/0 = no)	-0.005	0.009	-0.403	0.094	0.036	0.197
% concordant		N/A	22.9	28.5	23.3	23.2	24.7
c		N/A	0.506	0.546	0.512	0.508	0.533
Sample size		5,562	1,951	3,611	5,562	1,951	3,611

Complete ejection (C)		All occupants		Unbelted occupants		Belted occupants	
Adjustment		Roof exp	QT	Roof exp	QT	Roof exp	QT
Intercept		**-1.82**	**-1.85**	**-1.70**	**-1.74**	**-4.10**	**-4.13**
Intrusion?	(1 = yes/0 = no)	-0.179	-0.128	-0.090	-0.036	-0.648	-0.612
# quarter turns	(end-over-end = 0)		**0.171**		**0.173**		**0.185**
# roof exposures	(end-over-end = 0)	**0.554**		**0.559**		**0.617**	
End-over-end	(1 = yes/0 = no)	**1.51**	**1.53**	**1.66**	**1.67**	**-1.93**	**-1.88**
Occupant age	(years)	0.0005	0.0012	-0.0083	-0.0073	**0.0214**	**0.0212**
Seat belt status	(1 = belted/0 = not belted)	**-2.02**	**-2.09**				
Vehicle	(1 = LTV/0 = car)	**0.621**	**0.587**	**0.728**	**0.697**	0.040	-0.015
% concordant		87.8	89.8	64.0	68.5	42.8	44.4
c		0.888	0.903	0.644	0.688	0.596	0.620
Sample size		5,562	5,562	1,951	1,951	3,611	3,611

Any ejection (A)		All occupants		Unbelted occupants		Belted occupants	
Adjustment		Roof exp	QT	Roof exp	QT	Roof exp	QT
Intercept		**-1.65**	**-1.58**	**-1.58**	**-1.53**	**-3.04**	**-2.94**
Intrusion?	(1 = yes/0 = no)	0.038	0.092	-0.028	0.032	0.100	0.155
# quarter turns	(end-over-end = 0)		**0.153**		**0.172**		**0.135**
# roof exposures	(end-over-end = 0)	**0.557**		**0.615**		**0.506**	
End-over-end	(1 = yes/0 = no)	**1.48**	**1.40**	**2.00**	**1.91**	**-2.53**	**-2.62**
Occupant age	(years)	0.0032	0.0034	-0.0075	-0.0065	**0.0103**	**0.0097**
Seat belt status	(1 = belted/0 = not belted)	**-1.39**	**-1.41**				
Vehicle	(1 = LTV/0 = car)	**0.283**	**0.234**	**0.632**	**0.582**	-0.065	-0.109
% concordant		80.6	81.5	62.4	65.9	57.6	58.3
c		0.813	0.819	0.629	0.662	0.602	0.603
Sample size		5,562	5,562	1,951	1,951	3,611	3,611

Note: Bolded estimates are statistically significant at the 0.05 level.
QT = quarter turns adjusted model.
Source: NHTSA, NCSA, NASS CDS 1997-2006.

The intercept is lower in models of belted occupants as compared to corresponding models of unbelted occupants. Also, in the adjusted models of all occupants, the seat belt status indicator is negative. Both of these factors indicate that, other things being equal, the probability of ejection for belted occupants was lower than for unbelted occupants.

In the cases when it is statistically significant, the coefficient of the vertical roof intrusion variable is positive, indicating that greater vertical roof intrusion was associated with a greater probability of ejection. Note again, however, that the coefficient is not statistically significant in any of the models of complete ejection. In fact, in several of the models of complete ejection, the coefficient estimate is negative. Thus, if these models were used to describe the relationship between intrusion and complete ejection, which they shouldn't be because of the lack of statistical significance, they would be saying that greater vertical roof intrusion is associated with a *lower* probability of ejection.

The coefficients on both the number of quarter turns and the number of roof exposures are positive and statistically significant in all of the adjusted models. This means that in sideways rollovers, occupant ejection was more likely in more severe rollovers, as measured by these criteria.

The coefficients on the end-over-end indicator are statistically significant in all of the adjusted models. In the models of all occupants and unbelted occupants, the coefficients are positive. Let β_E be the coefficient on the end-over-end indicator; let S be a sideways rollover severity measure (that is, either the number of quarter turns or the number of roof-to-ground exposures); and let β_S be the coefficient on S. Then, the rollover severity measured in terms of occupant ejection S^* for which, other things being equal, an end-over-end rollover is hypothetically equivalent to a sideways rollover is

$$S^* = \frac{\beta_E}{\beta_S}.$$

See Strashny (2007) for a more detailed discussion of this calculation. Thus, for example, considering the continuous intrusion/complete ejection/all occupants/quarter turns adjusted model, the number of quarter turns that would make a rollover hypothetically equivalent to an end-over-end rollover in terms of occupant ejections, other things being equal, was 9.0 [=1.54/0.172].

Interestingly, the coefficients on the end-over-end indicator in models of belted occupants were negative. The reason for this is that there were no belted occupants in end-over-end rollovers who were also ejected. See Table 2 and its discussion. Because of this, the presence of an end-over-end rollover in belted occupants indicated the absence of ejection, producing a relatively large negative coefficient on the end-over-end indicator.

The coefficient on occupant age is positive and statistically significant in models of belted occupants. This means that, according to the models, for belted occupants, higher occupant age was associated with a greater probability of ejection in a relevant rollover. Lund (2008) found the opposite effect in a model of any ejections of drivers regardless of seat belt use. However, the model in that report did not control for rollover severity, with which driver age could be correlated. One explanation for why the coefficient is positive in the current report is that the weights on a few belted ejected older occupants were relatively large. See Table 2 and its discussion.

The coefficient on the vehicle indicator is statistically significant and positive in the models of all occupants and unbelted occupants, indicating that, for these occupant groups, being in a relevant rollover in an LTV as opposed to a passenger car was associated with a higher ejection probability.

According to both the percent concordant measure and the c measure, of the models considered, the models that have the best association between estimated probabilities and observed outcomes are the quarter turns adjusted/all occupants/complete ejection models. Among models of any ejection, the models that have the best association between estimated probabilities and observed outcomes are the quarter turns adjusted/all occupants/any ejection models.

CONCLUSION

This report does not find evidence of a statistical relationship between vertical roof intrusion in relevant rollovers and complete occupant ejection. The report models the probability of occupant ejection in relevant rollovers as a function of vertical roof intrusion using 36 different statistical models. According to the models considered, there was no statistically significant relationship between complete ejection and vertical roof intrusion. However, in some cases, a statistically significant relationship did exist between any ejection and vertical roof intrusion.

The report finds that, other things being equal, an increase in the number of quarter turns or an increase in the number of roof-to-ground exposures increased the probability of both complete and any ejection. This finding lends further support to using either the number of quarter turns or the number of roof-to-ground exposures as a measure of sideways rollover severity.

REFERENCES

Austin, R., Hicks, M., & Summers, S., "The Role of Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck, or Face During FMVSS No. 216 Rollovers," August 30, 2005, unpublished but available in NHTSA dockets NHTSA-2005-22143-52 and NHTSA-2005-22154-1. Washington, DC: National Highway Traffic Safety Administration.

Digges, K. H., & Eigen, A. M., "Crash Attributes That Influence the Severity of Rollover Crashes," Proceedings of the 18th ESV Conference, No. 231, Nagoya, Japan, 2003.

Eigen, A. M., "Examination of Rollover Crash Mechanisms and Occupant Outcomes," DOT HS 809 692, December 2003. Washington, DC: National Highway Traffic Safety Administration.

Eigen, A. M., "Rollover Crash Mechanisms and Injury Outcomes for Restrained Occupants," DOT HS 809 894, July 2005. Washington, DC: National Highway Traffic Safety Administration.

Lund, A. K., "Logical and Statistical Errors in Comments by Padmanaban and Moffatt on the Insurance Institute for Highway Safety Study, 'Roof Strength and Injury Risk in Rollover Crashes'," May 13, 2008, unpublished but available in NHTSA docket NHTSA-2008-0015-0088. Washington, DC: National Highway Traffic Safety Administration.

Padmanaban, J., & Moffatt, E. A., "JP Research's Response to IIHS Docket Submission of May 13, 2008," May 30, 2008, unpublished but available in NHTSA docket NHTSA-2008-0015-0091.1. Washington, DC: National Highway Traffic Safety Administration.

Strashny, A., "The Role of Vertical Roof Intrusion and Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck, or Face During FMVSS No. 216 Rollovers: An Updated Analysis," October 2007, DOT HS 810 847. Washington, DC: National Highway Traffic Safety Administration.