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The Pursuit of Tangible Happiness:

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The Effects of Airbags and Seatbelts on Occupant Injury in Longitudinal Barrier Crashes

Abstract

Introduction: Longitudinal barriers, such as guardrails, are designed to prevent a vehicle that leaves the roadway from impacting a more dangerous object while minimizing the risk of injury to the vehicle occupants. Current full-scale test procedures for these devices do not consider the effect of occupant restraints such as seatbelts and airbags. The purpose of this study was to determine the extent to which restraints are used or deployed in longitudinal barrier collisions and their subsequent effect on occupant injury. *Methods:* Binary logistic regression models were generated to predict occupant injury risk using data from the National Automotive Sampling System / Crashworthiness Data System from 1997 through 2007. *Results:* In tow-away longitudinal barrier crashes, airbag deployment rates were 70 percent for airbag-equipped vehicles. Compared with unbelted occupants without an airbag available, seat belt restrained occupants with an airbag available had a dramatically decreased risk of receiving a serious (MAIS 3+) injury (odds-ratio (OR) =0.03; 95% CI: 0.004-0.24). A similar decrease was observed among those restrained by seat belts, but without an airbag available (OR=0.03; 95% CI: 0.001- 0.79). No significant differences in risk of serious injuries were observed between unbelted occupants with an airbag available compared with unbelted occupants without an airbag available (OR=0.53; 95% CI=0.10-2.68). *Impact on Industry:* This study refutes the perception in the roadside safety community that airbags rarely deploy in frontal barrier crashes, and suggests that current longitudinal barrier occupant risk criteria may over-estimate injury potential for restrained occupants involved in a longitudinal barrier crash.

Keywords: Injury, Longitudinal Barriers, Airbags, Seatbelts

Introduction

Longitudinal barriers, such as w-beam guardrails (Figure 1), are installed along a roadway or in the roadway median to prevent an errant vehicle from traversing a steep slope, impacting a more dangerous roadside object, or entering opposing vehicle travel lanes. Performance of these roadside devices is tested using controlled, full-scale crash tests prescribed by NCHRP Report 350 (Ross et al., 1993). These tests are evaluated based on the ability of the barrier to withstand the vehicle impact, the trajectory of the vehicle after the impact, and measures of occupant risk derived from measured vehicle kinematics. Occupant risk measures in NCHRP Report 350 crash tests are based on the flail space model concept (Michie, 1981). In the flail space model, the occupant is assumed to be completely unrestrained, i.e., without a seatbelt or airbag restraint. This represented a practical worst case scenario at the model's inception in the early 1980's as belt use rates were roughly 11 percent (Derrig et al., 2000) and airbags were rare. However, airbags have become required equipment on all new cars since model year 1997 and mandatory on all new light trucks and vans since model year 1998. There has also been a marked increase in belt usage rates to 80 percent nationally (Pickrell and Ye, 2008). Despite the potentially large effect these shifts have on occupant risk, the occupant risk criteria used in current roadside hardware crash tests have not been adjusted to account for them.

[Insert Figure 1 Here]

Questions have been raised within the roadside safety community regarding the effectiveness of airbags in longitudinal barrier crashes. One issue raised is whether or not an oblique impact with an energy absorbing object such as a guardrail is sufficient to deploy the frontal airbags. Assuming the frontal airbags do deploy, another issue is whether airbags designed specifically for frontal collisions are effective in reducing injury in the oblique crash mode typical of longitudinal barrier crashes.

Objective

The purpose of this study was (1) to determine the extent to which occupant restraints are used or deployed in real-world longitudinal barrier collisions and (2) to examine the effects of these restraints on occupant injury.

Previous Research

The effects of occupant restraints in preventing injury in purely frontal crashes have been well documented (Evans, 1986; Braver et al., 1997; Crandall et al., 2001; Huere et al., 2001; McGwin et al., 2003). Little is known, however, with regard to their performance in longitudinal barrier collisions. A majority of the previous longitudinal barrier research has focused on real-world crash injury prior to the widespread implementation of airbags.

Several studies were conducted in New York state examining injury and fatality in crashes with various types of roadside and median barriers (Carlson, Allison and Bryden, 1977; Zweden and Bryden, 1977; Hiss and Bryden, 1992). Viner (1995) used national data from 1985 to examine the costs of various roadside crash types, including guardrail impacts. Ray et al. (1986; 1987) investigated occupant injury mechanisms in longitudinal barrier collisions with a focus on secondary collisions. Perhaps the most in-depth longitudinal barrier crash data, the Longitudinal Barrier Special Study (LBSS), was collected in tandem with the National Automotive Sampling System (NASS) / Crashworthiness Data System (CDS) for approximately 600 barrier crashes occurring between 1982 and 1986. NASS/CDS provides detailed information, including restraint performance and occupant injury, for a sample of U.S.

police-reported crashes where at least one vehicle sustained damage that required it to be towed from the scene (NCSA, 2005). Researchers (Erinle et al., 1994; Hunter, Stewart and Council, 1993) used this specialized database primarily to investigate injury differences between different barrier systems and investigate the performance of barrier end terminals. Elvik (1995) performed a meta-analysis of previous guardrail literature published between 1956 and 1993 to evaluate the safety effects of guardrails.

There have been a limited number of studies that have assessed the performance of occupant restraints in these collisions. Council and Stewart (1996) and Council et al. (1997) examined state accident data to determine the effect of airbags on average injury severity in collisions with various roadside objects and safety devices. Airbags were found to decrease the average severity of roadside object collisions by 10 to 50 percent, but in most cases the decrease was not statistically significant due to small sample sizes. In this case, the average severity was gauged primarily by the proportion of fatal and/or incapacitating driver injury. The study included data from only three states (North Carolina, Illinois and Utah), excluded pickup trucks and vans, and included only data through 1994, which was prior to the widespread implementation of airbags. Holdridge et al. (2005) used multivariable nested logit models to investigate the performance of roadside hardware on urban state highways in Washington State. Although airbags and seatbelts were found to reduce the severity of roadside fixed object crashes, the analysis was not specific to longitudinal barriers, was based on data from only a single state, and was limited to urban state highways.

Grzebieta et al. (2002) performed several full-scale crash tests with a small car impacting various roadside barriers to examine airbag performance and driver injury potential. The researchers demonstrated that advanced vehicle restraints, including airbags and seat belt pretensioners, can fire under certain barrier impact conditions. In terms of investigation of injury, however, the study was limited by the number of impact conditions and the use of a single vehicle type. Other researchers have suggested that impacts with the relatively flexible barriers may actually cause the late deployment of an airbag, which may increase the propensity for occupant injury (Grzebieta et al, 2005). With the exception of the Grzebieta et al study, there is little full-scale roadside hardware crash test data to study airbag performance. In the US, the current NCHRP Report 350 crash testing procedures (Ross et al, 1993) do not specify that the airbags need to be turned on during the test. As a result, these devices are usually disabled prior to the crash test and the deployment characteristics are not measured.

Methods

Data from NASS/CDS was used to determine occupant restraint usage and deployment rates as well as compare injury based on occupant restraint condition. NASS/CDS provides a detailed record of approximately 5,000 crashes investigated each year (NCSA, 2005). To be included in NASS/CDS, at least one of the vehicles in the crash had to have been towed from the scene. The NASS/CDS database includes only crashes involving cars, light trucks, vans and sport utility vehicles. Heavy vehicles and motorcycles are not included as subject vehicles in the NASS/CDS database. Cases are selected for NASS/CDS investigation using a complex sampling strategy which oversamples certain types of crashes including fatal crashes, crashes involving hospitalized occupants, and crashes involving late model year vehicles among other factors (NHTSA, 2005). To permit nationally representative estimates to be computed, NASS/CDS provides weighting factors which account for this sampling scheme. These weights were applied in the analysis which follows. All statistical analyses were performed using the SAS V9.1.3 software package.

Case Selection

Cases were selected from an 11-year NASS/CDS data set spanning 1997 to 2007, inclusive. Cases were selected from NASS/CDS based on the following criteria:

- Single event crash where a single passenger vehicle impacts a longitudinal barrier and the vehicle was inspected by a NASS investigator.
- Damage to the front of the vehicle
- Occupant is seated in the front left or front right seating position (or both)
- No occupant ejection or vehicle rollover
- Known occupant belt and airbag status.

Inclusion of single event crashes ensures that the longitudinal barrier caused (or did not cause) the deployment of the airbag. Only passenger vehicles and light trucks and vans (LTVs) were included; all heavy vehicles were excluded from the analysis. For the purpose of this study, a longitudinal barrier included concrete barriers, metal beam guardrails, and cable barriers. Longitudinal barriers in NASS/CDS are grouped into one of two categories: (1) concrete barriers, and (2) other barriers. The latter category includes all types of steel guardrail systems such as w-beam guardrails, box beam barriers, and cable barriers. Each case was checked for proper barrier type coding using crash scene photographs available online for the NASS/CDS years 1997 through 2007. Any concrete barriers miscoded as "other barrier" were reclassified accordingly and any steel barrier systems miscoded as a concrete barrier were reclassified accordingly. Any cases which were incorrectly coded as a barrier impacts, e.g. pole, curb, or bridge structure impacts, were omitted from the data set.

As the focus of this study was on frontal airbag deployment, side impacts and rear impacts with longitudinal barriers have been excluded. Only non-ejected front seat occupants were selected for analysis as current longitudinal barrier occupant risk criteria focus only on the injury to these occupants. Another stipulation was that occupant belt and airbag status was known. For this study, only unbelted occupants or those restrained by a 3-point seatbelt were included. As with seat belt status, airbag status was determined separately for each occupant. Only occupants with no airbag available, airbag available but not deployed, or airbag deployed during the crash were included. Occupants with unknown belt use were excluded.

Restraint Usage and Airbag Deployment Rates

Restraint usage and airbag deployment proportions were determined directly from the suitable NASS/CDS cases after the application of the associated statistical weighting factors. In the analysis which follows, the term 'airbag restrained' indicates that an airbag was available to the occupant, not that the airbag necessarily deployed. Seat belt usage rates were determined for the entire data set and two subsets: (1) airbag restrained occupants and (2) non-airbag restrained occupants. Airbag deployment rates in crashes with longitudinal barrier were determined using the airbag restrained occupant data subset. Airbag deployment rates were also examined as a function of crash severity using the equivalent barrier speed (EBS) metric. Although delta-V is the preferred measure of crash severity, delta-V is difficult to estimate for longitudinal barrier crashes (Smith and Noga, 1982). In addition, delta-V was not available for a majority of the suitable cases. Due to the uncertainty in the delta-V estimates for this crash mode, the authors opted not to pursue a multiple imputation approach involving vehicle delta-V. Instead, for this portion of the analysis, cases were only included if the EBS was known. EBS can be determined based on the crush of the subject vehicle. EBS avoids many of the difficulties associated with delta-V computations for vehicles impacting objects of unknown stiffness such as guardrails. Two airbag restrained occupant subgroups were also analyzed based on type of barrier impacted: (1) concrete barrier or (2) other barrier. Data from these subgroups were then used in a two-way contingency table analysis to determine if differences in airbag deployment rates existed by barrier type.

Injury Risk Comparison by Restraint Type

To provide a comparison of injury risk by occupant restraint status, odds ratios were compared from developed binary logistic regression models. Each of the models predicted occupant injury based on occupant restraint status and possible confounding factors while considering the complex sampling design of NASS/CDS. This analysis considered four occupant restraint conditions: (1) airbag available, belted occupant, (2) airbag available, unbelted occupant, (3) no airbag, belted occupant, and (4) no airbag, unbelted occupant.

Potential confounding factors were vehicle, occupant and barrier related variables including vehicle type, occupant gender, occupant age, seating position, crash severity and type of barrier impacted. Vehicle type was grouped into one of two categories, passenger car or LTV, based on the "bodytype" variable in NASS/CDS. Seating position was also considered a dichotomous variable: driver or right front passenger. Occupants were grouped into three categories based on age: up to and including 24, 25 to 54, or 55 and older. Equivalent barrier speed (EBS) was used to account for crash severity with three distinct categories: up to 16 km/hr (10 mph), 16 km/hr to 40 km/hr, and greater than 40 km/hr (25 mph).

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

Occupant injury severity was described using the Abbreviated Injury Severity (AIS) scale (AAAM, 1998). The AIS scale methodically rates injury on a discrete 0 to 6 scale based on threat to life, where 0 represents no injury and 6 represents a fatal injury. In NASS/CDS, each injury acquired by an occupant is rated based on this scale. The most severe of all the injuries is termed the maximum AIS (MAIS) score. Two injury thresholds were used to provide a binary (injury/no injury) response: (1) a maximum AIS value of 2 or greater (MAIS 2+) and, (2) MAIS 3+. The MAIS 2+ and MAIS 3+ thresholds were selected to determine the effects of restraints on more serious occupant injuries. For this portion of the analysis, cases with unknown or missing occupant injury data were excluded.

Results

Restraint Usage and Deployment Rates

There were a total of 757 NASS/CDS cases initially suitable for analysis. After application of the NASS weights, these cases represent more than 395,000 occupants exposed to a longitudinal barrier collision. The crash scene photographs were examined for each case to determine if the object struck was properly coded. A total of 8 cases were excluded from the analysis as they did not fall in the concrete or other barrier category (2 poles, 1 curb, and 5 bridge rails), reducing the suitable number of cases to 749. A total of 28 cases were then reclassified; 24 miscoded "other barriers" were reclassified to the concrete barrier category and 4 miscoded concrete barriers were reclassified to the "other barrier" category. Based on this analysis, the predominant barrier in the "other barrier" category was the strong post w-beam (65 %) followed by the strong post thrie beam barrier (12 %), weak post w-beam barrier (6 %), and box beam barrier (3 %). Table 1 shows the actual and weighted cases by restraint type. Note that these cases represent approximately 79 percent of unweighted (75 percent weighted) front seat occupants involved in a longitudinal barrier crash. A majority of the remaining cases (15 percent unweighted and 17 percent weighted) had an unknown belt use; these cases were excluded from the analysis.

[Insert Table 1 Here]

A total of 70 percent of occupants involved in a tow-away level longitudinal barrier impact between 1997 and 2007 had an airbag available (30 percent did not have an airbag available). For those occupants where an airbag was present, the airbag deployed 67 percent of the time. This percentage is nearly identical when only drivers are considered (68 percent). For all occupants, lap and shoulder belt usage rates were 79 percent. For the airbag restrained and non-airbag restrained data subsets, the lap and shoulder belt use rates were 86 percent, and 62 percent, respectively (data not shown).

Figure 2 shows weighted airbag deployment rates as a function of the NASS investigator determined EBS. This was based on 322 raw cases (178,835 weighted cases) with a minimum of 31 raw observations in each EBS category. Figure 3 shows the weighted distribution of EBS for all 749 barrier crashes. There were a total of 276 (37%) cases with no estimate of EBS.

[Insert Figure 2 Here]

[Insert Figure 3 Here]

Table 2 shows the occupant airbag deployment rate by barrier type for airbag equipped occupants in the available data. The weighted values and associated percentages are shown along with the 95 percent confidence intervals for the weighted proportions. Based on the Rao-Scott modified likelihood ratio chi-squared test, a statistically significant difference was found between airbag deployment rates for different barrier types ($p = 0.033$).

[Insert Table 2 Here]

Injury Risk Comparison by Restraint Type

A slightly smaller data set of 686 cases (363,484 weighted) was available for the injury analysis as detailed injury data was unknown in 63 cases. There were two cases (145 weighted) where the injury severity was unknown but the NASS/CDS treatment variable indicated a fatality; these cases were assigned an MAIS value of 6. A total of 421 of the available cases (245,009 weighted) had known EBS. The distribution of occupant injury for this smaller EBS-known data set was very similar to that of the injury-known data set (686 raw cases) with approximately 96 percent of the occupants having no injury or only minor (MAIS 1) injuries. A smaller 413 case data set (both EBS and injury severity known) was used for the remainder of the injury risk analysis.

A summary of the binary logistic regression model parameters is shown in Table 3. A total of two models were developed based on the two injury thresholds (MAIS 2+ and 3+) using EBS as a proxy for crash severity. For each parameter, the Wald Chi-Square statistic and associated *p*-value has been included as well as the C-statistic for each model. The C-statistic represents the area under the Receiver Operator Characteristic (ROC) curve and provides a single numerical value of how well the model distinguishes between the response variable, in this case, occupant injury versus no injury. EBS was significantly associated with both MAIS 2+ and MAIS 3+ occupant injury ($p \leq 0.001$). The following variables were significantly associated with MAIS 3+ injury only: restraint condition, occupant location, occupant age, and vehicle type. Barrier type was found to be significantly associated with MAIS 2+ injury only and was nearly significant at the MAIS 3+ level ($p = 0.063$). The effect of vehicle type was also found to be nearly significant at the MAIS 2+ level ($p = 0.054$). Drivers, older occupants, and concrete barriers were found to be associated with higher odds of occupant injury. Occupant gender differences were not found to be statistically significant. Interactions between the model parameters were also tested. With the exception of airbag deployment and barrier type interaction at the MAIS 3+ injury level ($p < 0.001$), there was no other statistically significant interactions found between model parameters.

[Insert Table 3 Here]

Table 4 shows the odds ratios for occupant restraint condition and barrier type for both models. For the occupant restraint condition, the odds ratio represents a comparison to a completely unrestrained occupant, i.e. no belt used and no airbag available. For the barrier type, the odds ratio represents a comparison to rigid barriers, i.e. concrete barriers and bridge rails combined. The 95 percent confidence bounds on each ratio are also shown.

[Insert Table 4 Here]

With the exception of the airbag only restrained occupants at the MAIS 2+ level, all restraint conditions show a decrease in the odds of injury compared to the unrestrained condition. The decrease was statistically significant for the fully restrained occupant at the MAIS 3+ injury level. For the belt only restrained occupant, the decrease was statistically significant at the MAIS 3+ injury level. In terms of barrier type, the odds of occupant injury were decreased when impacting a non-rigid barrier. These decreases, however, were statistically significant only at the MAIS 2+ level but nearly statistically significant at the MAIS 3+ level (upper 95% confidence bound = 1.08).

Figure 4 shows the odds ratio results for the four occupant restraint conditions based on the EBS adjusted model. All odds ratios are with respect to the unrestrained condition and the error bars represent the 95 percent confidence bounds on the point estimates. Statistically significant differences from the completely unrestrained condition are noted by an asterisk (*).

[Insert Figure 4 Here]

Discussion

Restraint Usage and Deployment Rates

The available data suggest that a majority of occupants exposed to a longitudinal barrier collision were restrained by a lap and shoulder belt. If the vehicle was equipped with an airbag, the airbag deployed in almost three-fourths of tow-away severity crashes. Lap and shoulder belt usage rates were consistent with the current US national average of approximately 83 percent (Pickrell and Ye, 2008), especially with respect to airbag restrained occupants. The belt use rate for non-airbag restrained occupants was found to be somewhat lower at 62 percent. One explanation for this observation could be that non-airbag equipped vehicles tend to be older model year vehicles; other researchers have linked non-use of seatbelts to older vehicles (Reinfurt et al., 1996). These results confirm that airbag deployment is not a rare event in tow-away longitudinal barrier collisions and that a majority of occupants wear safety belts. Although the flail space model continues to be used to evaluate occupant risk in full-scale roadside hardware tests, it does not account for either of these occupant restraint types.

Concrete barriers were found to have a significantly increased propensity for airbag deployment compared to other metal beam or cable barriers. Based on the weighted data, the airbag deployment rates were 72 percent for concrete barriers compared to 61 percent for other longitudinal barriers. Concrete barriers are more rigid than the metal beam and cable barriers typically classified as "other barriers" in NASS/CDS. These deployment differences are also consistent with the limited amount of longitudinal barrier crash testing conducted with the airbag systems activated. Grzebieta et al (2002; 2005) found that concrete barriers caused airbag deployment for all high speed impact conditions investigated while only one of the two impact tests with w-beam barrier resulted in airbag deployment.

Figure 2 shows that the probability of airbag deployment in longitudinal barrier collisions increased with increasing equivalent barrier speed. Based on the available data, it appears that airbag deployment occurs in all barrier collisions with an equivalent barrier speed greater than 35 km/hr (21 mph). Approximately 83 percent of occupants exposed to a tow-away longitudinal barrier collision were in vehicles where the equivalent barrier speed was at or below 24 km/hr (15 mph).

Injury Risk Comparison by Restraint Type

In terms of occupant injury risk, the first observation is the overall low injury risk in the vehicle to barrier crashes. There were few high severity occupant injuries present in the available single event longitudinal barrier collisions. Approximately 96 percent of the weighted cases were occupants that sustained either no injury or an MAIS 1 level injury. Based on the weighted data available, approximately 1 percent of occupants exposed to a tow-away longitudinal barrier collision sustained potentially life threatening injuries (MAIS 3 or greater). These results are consistent with the findings of previous researchers combining results from several studies using police-reported injury data from guardrail crashes (Michie and Bronstad, 1994).

In terms of occupant injury risk by restraint condition, the results of the binary logistic regression models indicate a decrease in the odds of occupant injury for occupants that are restrained with an airbag, a seatbelt, or both. Compared with completely unrestrained occupants, occupants restrained with both airbags and seat belts had a dramatically decreased risk of receiving serious injury, especially at the MAIS 3+ injury level. A similar decrease was observed among those restrained only by seat belts. The similarity between the odds ratios for the fully restrained occupants and the belt only restrained occupants suggests that airbags only have a relatively small incremental safety benefit in longitudinal barrier crashes. No significant differences in serious injury risk were observed between occupants restrained only by an airbag compared with completely unrestrained occupants, again suggesting airbags alone have a relatively small effect on occupant injury in these collisions. There was also a slight increase in odds of injury for airbag only restrained occupants at the MAIS 2+ level, although not statistically significant. Barrier type was also found to have a statistically significant effect. The odds of occupant injury in collisions with metal barriers were between 4 and 5 times lower than in collisions with a concrete barrier.

Limitations

The primary limitation of this study was the relatively small number of suitable raw barrier crashes available in NASS/CDS database. The confidence intervals were relatively wide and overlapped each other in most cases suggesting that sample size may have reduced the power to detect differences between the groups. Also, despite the use of procedures to account for the complex sampling design of NASS/CDS, extrapolating the raw cases to a nationally representative sample adds some inherent uncertainty to the conclusions. Also, missing data in the form of unknown restraint usage and occupant injury increases uncertainty associated with the findings and may affect the associations found with injury risk if non-random in nature. For restraint usage, approximately 11 percent of available raw cases had missing or unknown airbag deployment status (8 percent weighted) while approximately 15 percent of available raw cases had missing or unknown seat belt status (16 percent weighted). For occupant injury, approximately 11 percent of available cases had missing or unknown occupant injury severity (13 percent weighted).

For this study, equivalent barrier speed is used as a measure of crash severity. Vehicle delta-V is commonly associated with occupant injury potential and would have been a preferred crash severity metric, but delta-V is frequently unavailable in NASS/CDS for longitudinal barrier crashes. Coon and

Reid (2005; 2006) have developed a longitudinal barrier-specific methodology for determining vehicle delta-V in these collisions. These procedures are currently not incorporated into the NASS/CDS delta-V estimates.

Conclusions

This study has investigated occupant restraint use and airbag deployment in longitudinal barrier collisions. In real world longitudinal barrier collisions, airbags were found to deploy in 70 percent of all tow-away collisions when the vehicle was equipped with an airbag. Concrete barriers were also found to be associated with a higher airbag deployment rates compared to metal barriers. Seat belt usage rates in longitudinal barrier collisions were found to be 86 percent in airbag-equipped vehicles.

When adjusting for other confounding effects, seatbelts and airbags are found to reduce the odds of serious occupant injury in single event longitudinal barrier crashes. Compared with completely unrestrained occupants, occupants restrained with both airbags and seat belts had a dramatically decreased risk of receiving a serious (MAIS 3+) injury (odds-ratio (OR) =0.03; 95% CI: 0.004-0.24). A similar decrease was observed among those restrained only by seat belts (OR=0.03; 95% CI: 0.001-0.79). No significant differences in risk of serious injuries were observed between occupants restrained only by an airbag compared with completely unrestrained occupants (OR=0.53; 95% CI=0.10-2.68).

Impact on Industry

Currently, occupant risk procedures for longitudinal barrier crash tests do not include the effects of occupant restraints such as seatbelts and airbags. The results of this study suggest that these restraints are effective in reducing occupant injury in collisions with longitudinal barrier. This study also refutes the perception in the roadside safety community that airbags rarely deploy in frontal barrier crashes and need not be turned on in crash tests. Existing longitudinal barrier occupant risk criteria appear to over-estimate injury potential in passenger vehicle-barrier crashes for those occupants with any type of restraint, but especially for those occupants restrained by a seat belt or restrained by both a seat belt and airbag.

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Figures and Tables

Figure 1. W-Beam Guardrail along Interstate 87, New York State

Table 1 Tow-Away Longitudinal Barrier Crashes by Occupant Belt Usage and Airbag Status: Raw and Weighted Data [NASS/CDS 1997-2007, inclusive]

Belt Usage	Airbag Status	Raw Data		Weighted	
		Occupants	% of Total	Occupants	% of Total
Lap and Shoulder	Bag Deployed	253	34	156,310	40
	Non-Deployed	141	19	80,017	20
	Not Equipped	97	13	72,249	19
No Belt	Bag Deployed	101	13	23,087	6
	Non-Deployed	31	4	15,993	4
	Not Equipped	126	17	44,194	11

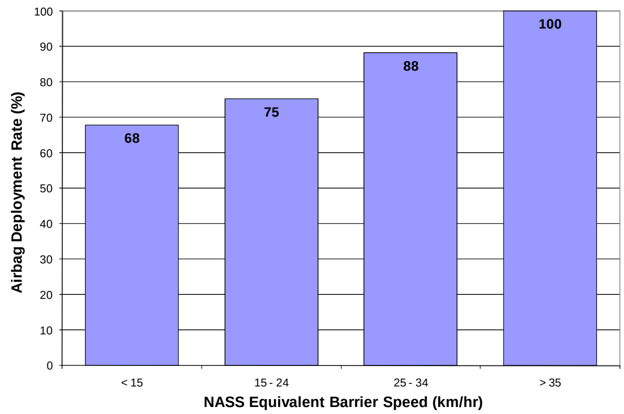

Figure 2. Airbag Deployment as a Function of Equivalent Barrier Speed in Longitudinal Barrier Crashes involving only Airbag-Equipped Vehicles. [NASS/CDS 1997-2007, inclusive]

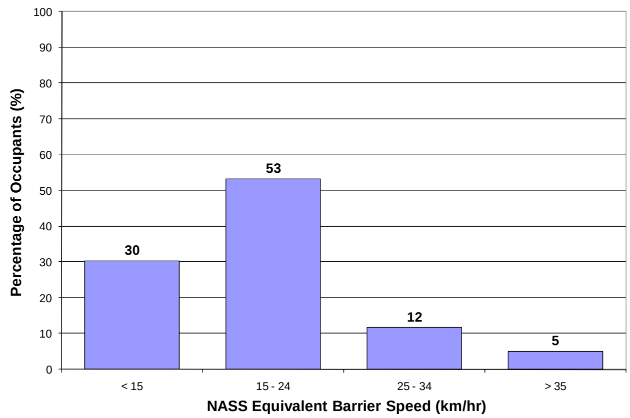

Figure 3 Distribution of Equivalent Barrier Speeds for All Available Longitudinal Barrier Crashes. [NASS/CDS 1997-2007, inclusive]

Table 2 Longitudinal Barrier Crash Airbag Deployment Rates and 95% Confidence Intervals by Type of Barrier Impacted, [NASS/CDS 1997-2007, inclusive]

Object Struck	**Airbag Status**	**Raw Cases**	**Weighted**		**95% Confidence Bounds**	
			Occupants	**Percent**	**Lower**	**Upper**
Concrete Barrier	Bag Deployed	211	78,254	72	57	87
	Non-Deployed	59	30,449	28	13	43
Other Barrier	Bag Deployed	135	101,144	61	44	78
	Non-Deployed	113	65,561	39	22	56

Table 3 Binary Logistic Regression Models Summary – Parameter Significance and Overall Model Fit for MAIS 2+ and MAIS 3+ Occupant Injury Levels. Includes Occupants exposed to a Longitudinal Barrier Crash where Equivalent Barrier Speed and Injury Level was Known (*n* = 413) [NASS/CDS 1997-2007, inclusive]

Injury Level	**Parameter**	**Wald χ^2**	***P***	**C Statistic**
MAIS 2+	Restraint Condition	4.380	0.223	0.790
	Gender	0.348	0.555	
	Vehicle Type	3.705	0.054	
	Occupant Location	3.066	0.080	
	Age Group	2.061	0.357	
	Barrier Type	4.054	0.044	
	Equivalent Barrier Speed	18.485	<0.001	
MAIS 3+	Restraint Condition	15.341	0.002	0.812
	Gender	0.179	0.673	
	Vehicle Type	17.592	<0.001	
	Occupant Location	5.986	0.014	
	Age Group	15.611	<0.001	
	Barrier Type	3.465	0.063	
	Equivalent Barrier Speed	15.294	0.001	

Table 4 Odds Ratios and 95% Confidence Intervals for Longitudinal Barrier Crash Occupant Injury by Restraint Condition and Barrier Impacted [NASS/CDS 1997-2007, inclusive]*

Injury Level	Parameter	Value	Reference Group	Odds Ratio	95% Confidence Bounds	
					Lower	Upper
MAIS 2+	Restraint Condition	Airbag, Belted	No Airbag, No Belt	0.17	0.02	1.43
		No Airbag, Belted		0.22	0.02	2.41
		Airbag, No Belt		1.33	0.34	5.22
	Barrier Type	Other Barrier	Concrete Barrier	0.22	0.05	0.96
MAIS 3+	Restraint Condition	Airbag, Belted	No Airbag, No Belt	0.03	0.004	0.24
		No Airbag, Belted		0.03	0.001	0.79
		Airbag, No Belt		0.53	0.10	2.68
	Barrier Type	Other Barrier	Concrete Barrier	0.24	0.05	1.08

*Adjusted for Vehicle Type, Seating Position, Age, Gender, and Equivalent Barrier Speed

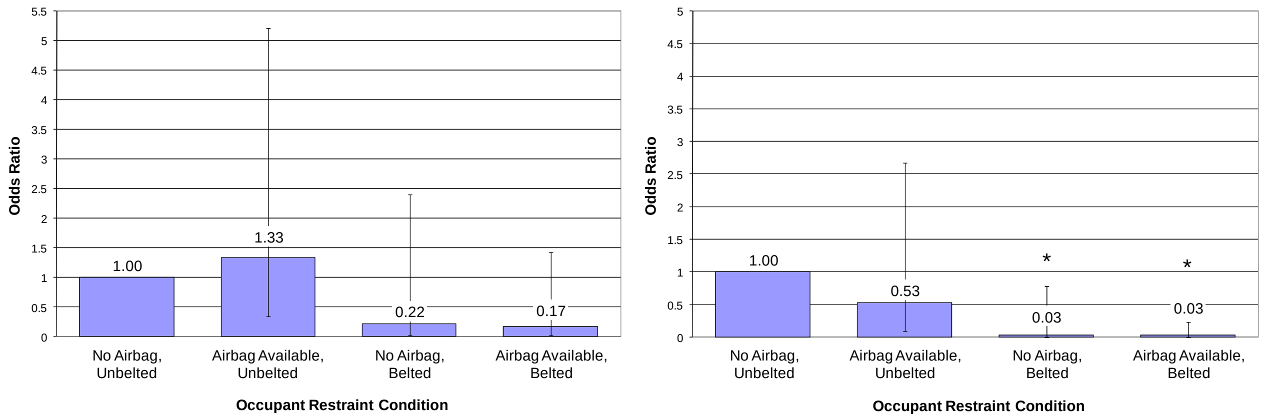

Figure 4. Equivalent Barrier Speed Adjusted Odds Ratio and 95% Confidence Interval Plot for Longitudinal Barrier Crash Occupant Injury by Restraint Condition (n = 413): MAIS 2+ (left) and MAIS 3+ (right). [NASS/CDS 1997-2007, inclusive]