

## **Comparison of Roadside and Vehicle Crash Test Injury Criteria in Frontal Crash Tests**

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**Abstract**

For full-scale crash tests involving roadside safety hardware, the flail space model is used to assess occupant risk potential. An underlying assumption of the model is that the occupant is unbelted and not airbag restrained. In the early 1980's, these were valid assumptions: cars were not equipped with airbags and belt usage rates were around 11 percent. In today's vehicle fleet, however, the flail space model assumptions are questionable: the belt usage rate is approximately 80 percent and airbags are required equipment on all cars manufactured after 1997. These changes have significant implications on injury risk as computed by the original flail space model. The objective of this study is to contrast the injury risk predictive capabilities of the flail space model with widely accepted dummy-based injury criteria in frontal crashes involving different occupant restraint conditions. In-depth crash investigation data from the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) 2000-2004 were examined to determine seatbelt usage and airbag deployment rates in longitudinal barrier crashes. Airbag deployment was found to occur in roughly half of tow-away level longitudinal barrier collisions while seatbelt usage rates are roughly 80 percent. To demonstrate the effect of vehicle restraints on resultant occupant injury risk, 30 full-scale frontal barrier vehicle crash tests and 9 roadside crash cushion tests were analyzed both in terms of vehicle crashworthiness injury criteria and roadside safety injury criteria. In frontal crash tests, the flail space model was unable to predict occupant risk for all occupant restraint conditions.

## INTRODUCTION

Full-scale crash testing is the traditional method of evaluating both vehicles and roadside safety hardware impact performance. A critical part of these evaluations is the assessment of occupant risk potential. Although the basic goal is the same, the vehicle and roadside crash safety communities approach the assessment differently. The vehicle safety community has developed impact configuration-specific crash test dummies to serve as a surrogate for the human response. Occupant risk procedures for vehicle crashworthiness are set forth in the Federal Motor Vehicle Safety Standards (FMVSS) (1-3). Frontal crash tests, for example, are described by FMVSS 208 (2).

Ideally, occupant risk in roadside barrier crash tests would be evaluated using an instrumented dummy. Several practical considerations, however, have led the roadside community to avoid this option. Crash testing of roadside hardware is more complex and must provide a structural evaluation of the device along with the occupant injury potential. Tests with longitudinal barriers, such as guardrail, are conducted at higher test speeds and oblique impact angles. In addition, the devices are typically tested in soil, which can make repeatability a challenge. A vehicle impacting one of these devices must travel over a surface sufficiently uneven to bounce a dummy out of position. As a result, the roadside safety community has developed occupant risk models, namely the flail space model. Roadside hardware occupant risk guidelines are set forth in NCHRP Report 350 (4). The guidelines attempt to indirectly predict occupant injury risk based on vehicle kinematics.

Human surrogates used in vehicle crashworthiness testing are designed to evaluate the performance of in-vehicle occupant restraints, such as seatbelts and airbags, in terms of occupant injury risk. 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 (5) and airbags were rare. Since 1997, however, airbags have become required equipment on all new vehicles. There has also been a marked increase in belt usage rates to 80 percent nationally. Despite the potentially large effect these shifts have on occupant risk, current roadside occupant risk criteria make no attempt to account for them.

## OBJECTIVE

The intent of this study is to illustrate the importance of developing roadside hardware crash test injury criteria that account for occupant restraints. Specifically, the study will examine airbag deployment and seat belt usage in collisions with roadside objects as well as injury risk variation in full-scale vehicle crashworthiness tests.

## BACKGROUND

Vehicle crashworthiness tests are intended to evaluate the performance of in-vehicle occupant restraints across the vehicle fleet spectrum. The idea is to provide a means of comparing occupant risk between vehicles for the same crash conditions. Development of roadside hardware is inherently more complex as both device performance and occupant protection must be considered. The result is a more complex set of tests, consisting of different combinations of vehicles and impact conditions, and simplified methods of computing occupant risk. The limitation of the current roadside injury criterion, the flail space model, is that it is based exclusively on vehicle accelerations. The criterion is unable to account for variations in occupant risk due to the presence and performance of seatbelts and airbags.

### Roadside Injury Criteria

#### *Flail Space Model*

Introduced by Michie (6) in 1981, the flail space model assumes that occupant injury severity is related to the velocity at which the occupant impacts the interior and the subsequent acceleration forces. The occupant is assumed to be an unrestrained point mass that behaves as a "free-missile" inside the occupant compartment in the event of a collision. The occupant is allowed to "flail" 0.6 meters in the longitudinal direction (parallel to the typical direction of vehicle travel) and up to 0.3 meters in the lateral direction prior to impacting the vehicle interior. Measured vehicle kinematics are used to compute the difference in velocity between the occupant and occupant compartment at the instant the occupant has displaced either 0.3 meters laterally or 0.6 meters longitudinally. For ease of computations, the vehicle yaw and pitch motions are ignored, all motion is assumed to be in the horizontal plane, and the lateral and longitudinal motions are assumed to be independent. At the instant of occupant impact, the largest difference in velocity (lateral and longitudinal directions are handled independently) is termed the occupant

impact velocity (OIV). Once the impact with the interior occurs, the occupant is assumed to remain in contact with the interior and be subjected to any subsequent vehicular acceleration. The maximum 10 ms moving average of the accelerations subsequent to the occupant impact with the interior is termed the occupant ridedown acceleration (ORA). Again, the lateral and longitudinal directions are handled separately producing two maximum occupant ridedown accelerations.

Threshold values for the OIV and ORA are used to gauge occupant injury potential. TABLE 1 summarizes the current threshold values, as prescribed in NCHRP 350 (4). Although values below the “preferred” are desirable, values below the “maximum” category are considered acceptable. Note that the “maximum” thresholds correspond to serious but not life-threatening occupant injury (6). The longitudinal OIV values in TABLE 1 were developed primarily from pure frontal head impacts into windshields (7,8,9). The lateral limits were based mainly on French accident statistics (10) and research aimed at developing FMVSS 214 (3), a U.S. vehicle standard for side impact protection. As the threshold values are based independently on frontal and side impact directions, the flail space model should predict injury best in either of these directions. Note that the biomechanical data used to develop the flail space model did not include any oblique tests. The biomechanical validity of OIV in angled longitudinal barrier impacts has not been established.

**TABLE 1 Flail Space Model Thresholds**

Occupant Impact Velocity Limits		
Component Direction	Preferred Value	Maximum Value
Lateral and Longitudinal	9 m/s	12 m/s

Occupant Ridedown Acceleration Limits		
Component Direction	Preferred Value	Maximum Value
Lateral and Longitudinal	15 g	20 g

Using crash reconstruction and crash test matching methods, early research (11,12) attempted to link the flail space model to occupant injury with limited success. More recently, Gabauer and Gabler (13) evaluated OIV using crash pulse data from real-world frontal collisions coupled with occupant injury information. Although preliminary results suggested a reasonable correlation to occupant injury, the analyzed data set was small (58 cases), dealt only with the longitudinal OIV, and included only General Motors vehicles.

European test procedures (CEN) prescribe a variation of the flail space model (14), while other researchers have proposed various computational modifications (15-17). All attempted to provide a more realistic model of unrestrained point mass motion within the occupant compartment by modifying the original model assumptions. Although the improved versions better characterize unrestrained occupant motion, none attempted to account for the presence of seatbelt or airbag restraints.

**Vehicle Crashworthiness Injury Criteria**

*The Head Injury Criterion*

A refinement of the Gadd Severity Index (18), the Head Injury Criterion (HIC) was first defined in 1971 by Versace (19) as follows:

$$HIC = \frac{\left[ \int_{T_1}^{T_2} a(t) dt \right]^{2.5}}{(T_2 - T_1)}$$

where a(t) is the resultant linear acceleration time history (G’s) of the center of gravity of the head, and T<sub>1</sub> and T<sub>2</sub> are two particular time values that maximize the above expression. Traditionally, the National Highway Traffic Safety Administration (NHTSA) has limited the separation between T<sub>1</sub> and T<sub>2</sub> to no more than 36 milliseconds. Based on this separation, the maximum value for the HIC for an adult mid-size male anthropomorphic test dummy is 1000 (2). In 2000, NHTSA changed this to require a 15 millisecond HIC with a corresponding limit of 700 (20).

*Chest Injury Criteria*

Several injury criteria have been developed to predict chest injury in full-scale vehicle crashworthiness tests. Currently, NHTSA mandates limits on maximum chest acceleration and maximum chest compression. For chest acceleration, NHTSA prescribes a maximum of 60 G's, except in cases where the duration of the peak is less than 3 ms (often referred to as simply the "3 ms Clip"). For chest deflection, a maximum value of 76 mm (3 inches) was previously prescribed. This criterion is based on a study by Neathery (21) that analyzed cadaver data to estimate that a 33 percent chest compression (or 76 mm in a 50th percentile male) would result in severe but not life threatening injury. In conjunction with the update to the HIC requirements, NHTSA reduced the maximum chest compression value to 63 mm (2.5 inches) (20).

**METHODOLOGY AND RESULTS**

The general methodology for this study is twofold: (1) use available national crash statistics data to assess occupant restraint involvement in roadside hardware crashes and (2) assess the relative variation between roadside injury criteria and injury risk, as measured by human surrogates, in full-scale vehicle crashworthiness tests for differing restraint conditions.

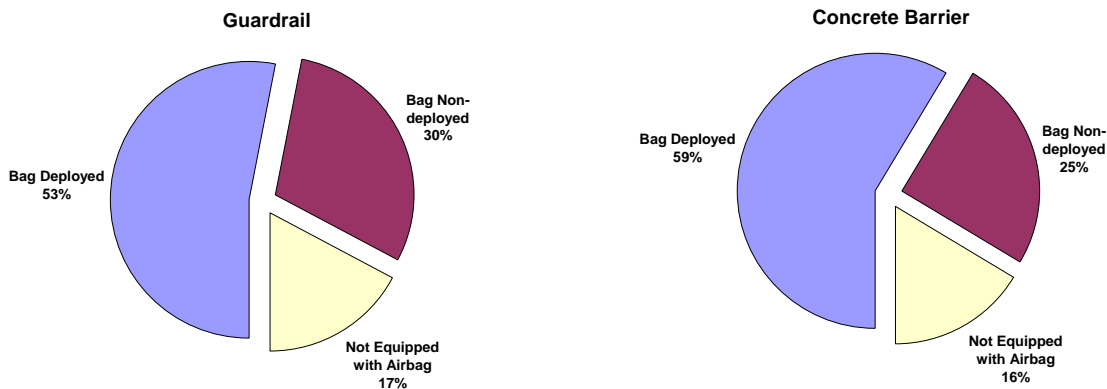
**Advanced Restraints in Collisions with Roadside Safety Hardware**

*Methodology*

Data from the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) was analyzed to provide an estimate of airbag deployment and seatbelt usage rates in roadside hardware crashes. NASS/CDS provides detailed information, including restraint usage and performance, for a random sample of approximately 5,000 U.S. crashes every year. Our analysis focused on the most recent 5 years of the database: years 2000 through 2004, inclusive. Suitable cases were those comprising only a single event involving a longitudinal barrier. Inclusion of only single event crashes ensures that the object struck caused (or did not cause) the deployment of the airbag. In addition, single impact crashes are more characteristic of NCHRP 350 crash tests. Longitudinal barriers, for the purpose of the analysis, include concrete barrier and guardrail. A total of 315 NASS/CDS cases were suitable for analysis and, after application of NASS national weights, represent over 150,000 longitudinal barrier collisions.

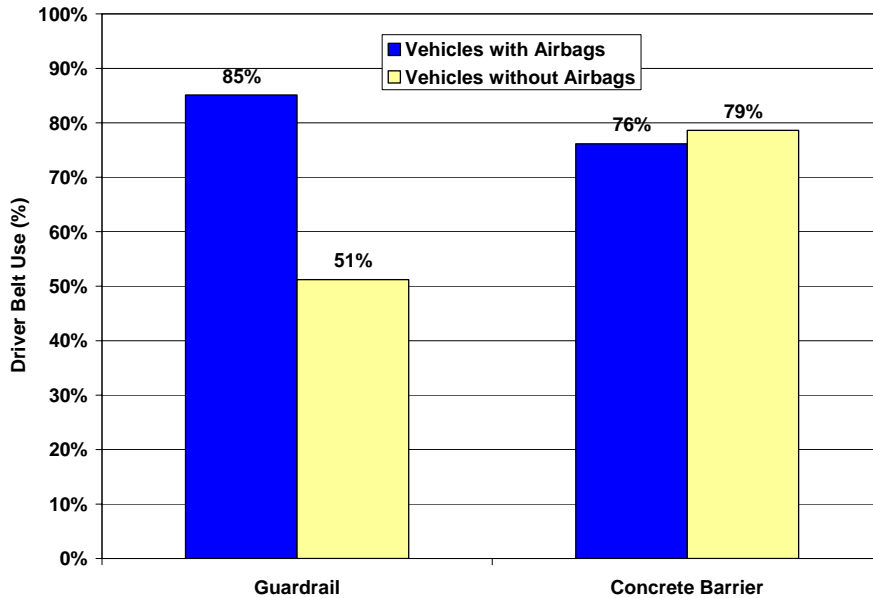
*Results*

Based on the NASS/CDS 2000-2004 data, the deployment of airbags appears to be a common event in single event tow-away level crashes involving longitudinal barriers. Airbag-equipped vehicles accounted for 80 percent of all vehicles striking longitudinal barrier. In these vehicles, the driver bag deployed approximately two-thirds of the time in collisions with either concrete barrier or guardrail. Considering both vehicles equipped and not-equipped with airbags, driver airbags deployed in more than 50 percent of the longitudinal barrier collisions, as evident in FIGURE 1. Less than 20 percent of tow-away longitudinal barrier crashes involved vehicles not equipped with airbags.



**FIGURE 1 Airbag Deployment in Crashes with Longitudinal Barriers**

Belt usage rates were approximately 80 percent for drivers, although this varied according to the presence of an airbag within the vehicle (see FIGURE 2). Drivers of non-airbag equipped (presumably older) vehicles appeared to be less likely to wear their seatbelts. It is unclear why this difference is more apparent in guardrail collisions than in concrete barrier collisions. This may be due to the fact that concrete barrier is more prevalent in urban areas; occupants may be more inclined to use their belts as enforcement of the mandatory seatbelt laws is likely more strict.



**FIGURE 2 Seat Belt Use in Longitudinal Barrier Collisions**

**Correlation of Roadside Safety and Vehicle Crashworthiness Injury Criteria**

*Case Selection*

For frontal collisions, there are four primary occupant restraint scenarios: (1) no restraint, (2) three-point belt restraint only, (3) airbag restraint only, and (4) three-point belt and airbag restraint. Since roadside hardware crash tests rarely employ an instrumented anthropometric test device (ATD), finding roadside crash tests to satisfy all four restraint categories was not feasible. Roadside hardware crash tests using a fully instrumented Hybrid II ATD, however, have been reported by Hinch et al. (22). The dummy was completely unrestrained in several high speed tests involving sand-filled crash cushions. Nine of these tests (11 occupant responses), as reported by Hinch et al. (22), were selected to compare roadside injury criteria to human surrogate occupant risk for unrestrained occupants.

For the remainder of the restraint scenarios, full scale vehicle crash tests were used as an alternate means of comparing roadside and ATD-based occupant risk. NHTSA maintains an electronic database of full-scale vehicle crashworthiness tests performed for Federal Motor Vehicle Safety Standards (FMVSS) compliance as well as various other research purposes. All cases selected from the NHTSA database were frontal barrier collisions and had an impact speed of 25, 30, or 35 mph. For the airbag only restraint and belt and airbag restraint scenarios, additional restrictions included airbag presence and proper deployment, vehicle model year 2000 or newer, and use of Hybrid III 50<sup>th</sup> percentile male ATDs. For the belted only restraint scenario, additional requirements included no frontal airbags and the use of Hybrid II 50<sup>th</sup> percentile male ATDs. Particular emphasis was placed on frontal crashes due to the plethora of test data in the frontal crash mode. Proper deployment of the airbag ensures that any variation in injury risk measured by the ATD cannot be attributed to airbag malfunction. Tests selected for each restraint scenario use the same ATD and impact conditions to further reduce the variability of injury risk measured between tests.

A total of 30 vehicle crash tests were evaluated which resulted in a total of 60 occupant responses (ATDs in right and left front seats). For each of the three restraint conditions remaining, 10 tests were used to provide a comparison of roadside and ATD-based occupant risk. The airbag only restraint condition used tests with 25 mph impact speed and Hybrid III 50<sup>th</sup> percentile male ATDs while the airbag and belt restraint condition used tests with

35 mph impact speed and Hybrid III 50<sup>th</sup> percentile male ATDs. Finally, the belt only scenario used tests with a 30 mph impact speed and Hybrid II 50<sup>th</sup> percentile male ATDs.

*Flail Space Model Computations*

As measured vehicle kinematics information is provided for rigid frontal barrier crash tests, the computation of OIV and ORA is identical to the longitudinal portion of the procedures outlined in NCHRP Report 350 (4). In the tests, both the dummies and vehicle structure are instrumented with accelerometers. For computation of OIV and ORA, accelerometer data was chosen as close to the vehicle center of gravity as possible to best describe the occupant compartment movement. Sensors used in our calculation included those attached to the vehicle rear floor pan, rear sill, or rear seat, all of which were aligned in the longitudinal direction. Any errors incurred due to use of acceleration data not at the vehicle center of gravity are expected to be negligible as only minor roll and yaw motions are experienced by the vehicle during these perpendicular frontal-barrier tests. All data traces used were checked against redundant sensor traces to ensure data accuracy; corrections for sensor bias were made as necessary. The raw acceleration data from the selected channel was filtered to CFC 180, as prescribed in NCHRP 350, prior to integrating for velocity or position. Numerical integration was accomplished via the trapezoidal rule, as recommended in NCHRP 350.

*Vehicle Injury Criteria and Injury Risk Computations*

Injury criteria reported in the NHTSA database include 36 ms HIC and chest 3 ms clip. The 15 ms HIC and maximum chest deflection were computed using the Signal Browser software, available from NHTSA. All head center of gravity acceleration traces were filtered at CFC 1000 prior to computation of the 15 ms HIC, as prescribed by SAE-J211 (23). Similarly, the chest deflection traces were filtered at CFC 600 prior to determining the maximum deflection. Also, any sensor bias problems were corrected prior to analysis.

**TABLE 2 Computation of Injury Risk Based on Injury Criteria Values (24)**

Body Region	Injury Criteria	Probability of AIS 3+ Injury
Head	15 ms HIC	$p(AIS \geq 3) = \frac{1}{1 + e^{((3.39+200/HIC)-0.00372HIC)}}$
Chest	3 ms Chest Clip (G)	$p(AIS \geq 3) = \frac{1}{1 + e^{(3.1493-0.0630Ac)}}$

TABLE 2 summarizes the relations used to compute human injury risk potential based on the ATD-based injury criteria values (24). The occupant risk probability is gauged by the Abbreviated Injury Severity (AIS) scale (25), which methodically rates injury on a discrete 0 to 6 scale based on threat to life. Injury levels are summarized in TABLE 3. The original intent of the flail space model is to indicate the transition between AIS 3 and AIS 4 level injury (6). As such, injury risk computed for this analysis is the probability of AIS 3 or greater occupant injury.

**TABLE 3. Abbreviated Injury Severity (AIS) Scale Summary**

AIS Value	Injury Description
0	No Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum/Fatal

*Risk Comparison*

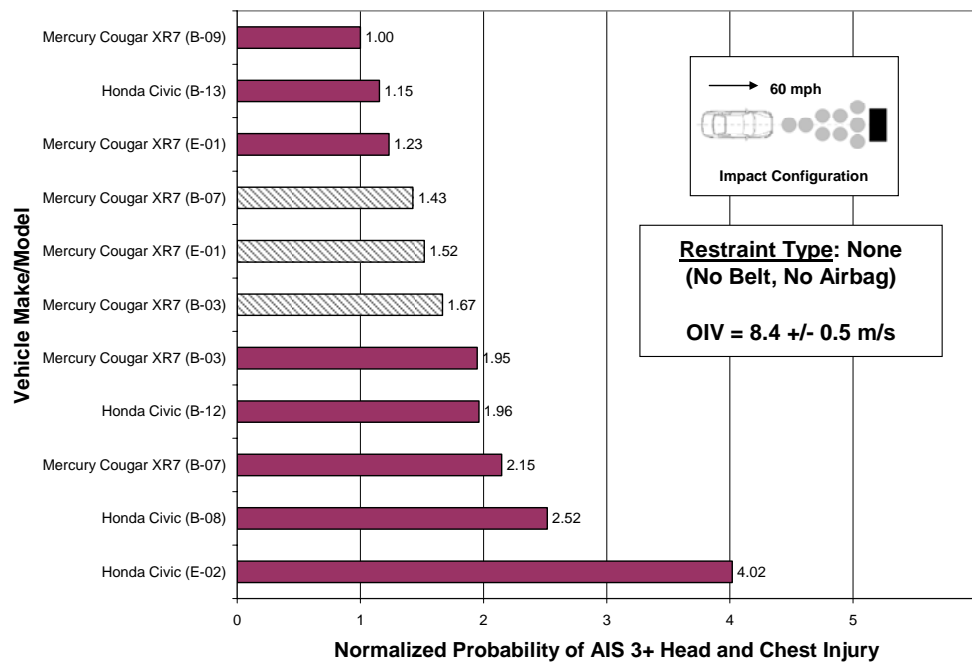
Roadside and ATD-based occupant risk is first compared graphically for each occupant restraint scenario. As roadside occupant risk is intended to predict overall occupant injury, the combined probability of AIS 3+ head and chest injury is used as an analogous ATD metric. The combined probability is computed by adding the AIS 3+ head and chest injury (based on 3 ms clip) probability and then subtracting the product; a procedure similar to how NHTSA determines vehicle star safety ratings. Each plot is then normalized based to the probability of injury of the

best performer (lowest injury risk assumes a value of unity). Since each restraint scenario uses crash tests of nearly identical impact speeds, there is only small variation in roadside occupant risk values, especially the OIV. The mean OIV value and approximate range are noted on each plot.

Linear regression analysis is used to provide further comparison. Ideally, if the roadside injury criteria are indeed good predictors of occupant risk, we would expect strong linear correlations to the ATD-based injury criteria. This should be especially evident in the unrestrained scenario, as the flail space model assumes this restraint condition.  $R^2$  values are indicated for each available roadside-ATD criteria combination for each restraint condition.

*Unrestrained Occupant Risk Comparison*

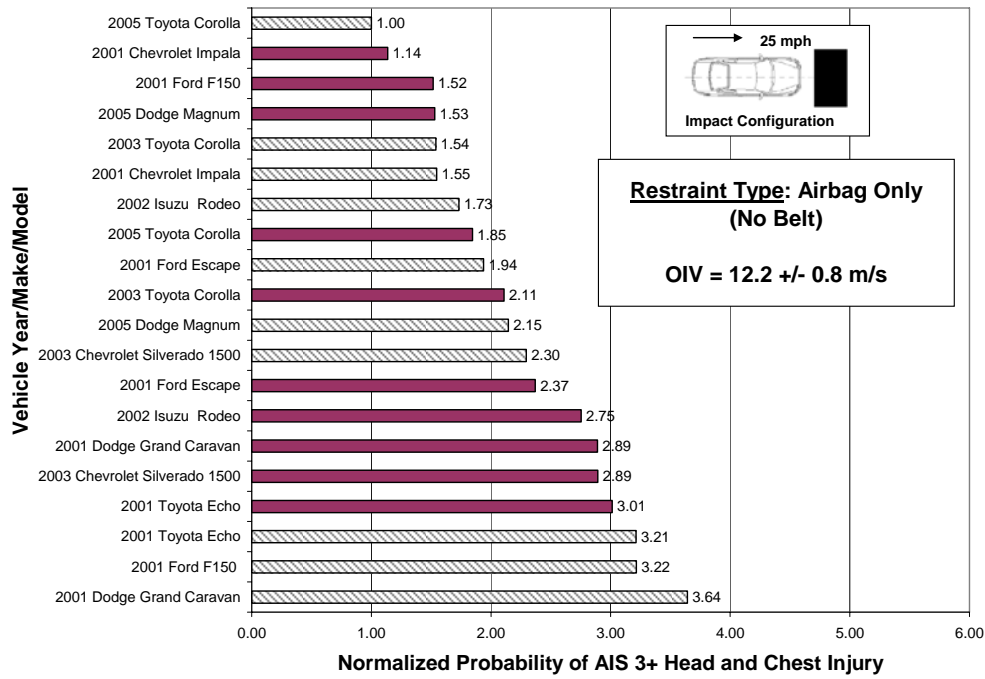
FIGURE 3 is a chart showing AIS 3+ head and chest normalized injury risk for the selected 60 mph frontal crash cushion tests. The vehicle make and model are shown with driver indicated by a solid bar and right front seat passenger indicated with a hatched bar. All vehicles were model year 1979 and the corresponding test designation reported by Hinch et al. (22) is indicated in parentheses. All ATD occupants are Hybrid II 50<sup>th</sup> percentile males with no restraints. Probability of injury has been normalized to the Mercury Cougar driver in test B-09, which has a combined head and chest injury probability of 14 percent. The OIV varies within a small 1 m/s range suggesting a relatively constant risk whereas ATD occupant risk varies as much as four-fold in relation to the best performer. Although this variation is striking, there is the possibility that small changes in roadside risk criteria correlate to larger changes in ATD-based occupant risk. Note that the tests selected include two different crash cushion types (Energite III and Fitch System) under variable conditions (bagged sand or frozen sand in some instances), which may account for some of the variation in addition to vehicle interior differences.



**FIGURE 3 Probability of Serious Injury to Unrestrained Occupants Normalized to Best Performer**

*Airbag-Only Restrained Occupant Risk Comparison*

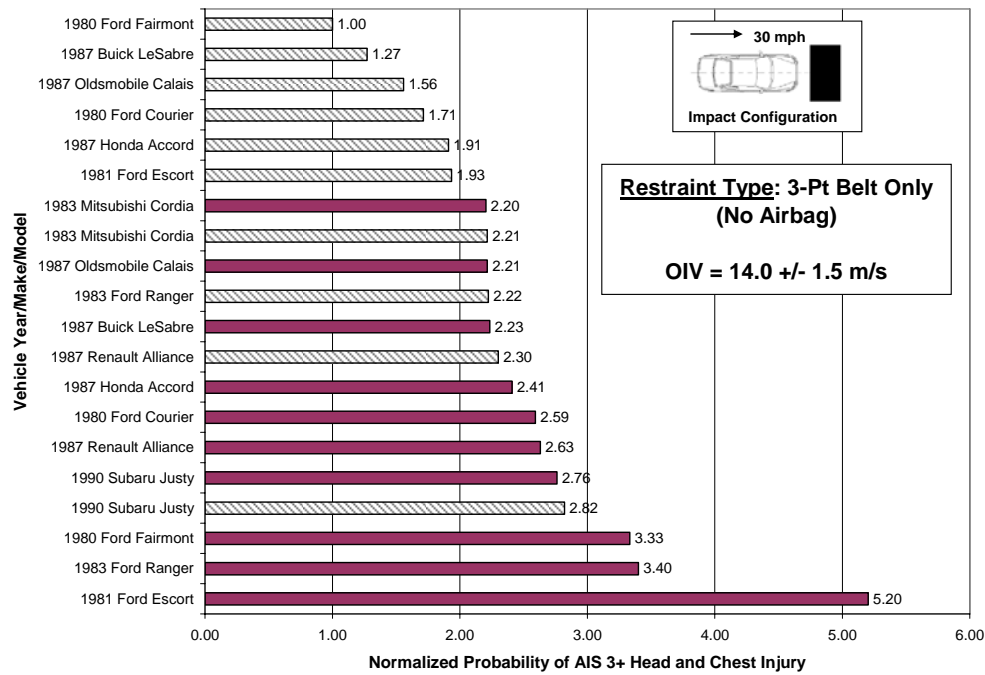
FIGURE 4 is a chart showing AIS 3+ head and chest normalized injury risk for the selected 25 mph frontal barrier vehicle crash tests. Again, drivers are indicated by a solid bar and right front seat passengers are indicated with a hatched bar. Both front seat ATD occupants are Hybrid III 50<sup>th</sup> percentile males with only an airbag restraint. Probability of injury has been normalized to the right front passenger of the 2005 Toyota Corolla, which has a combined head and chest injury probability of 16 percent. The OIV varies within a range of 1.5 m/s whereas ATD occupant risk varies as much as 3.6 times the injury probability of the best performer. Also note differences within the same vehicle where the roadside criteria are identical by design; for the same OIV, the Ford F150 driver has an injury probability 1.5 times that of baseline while the right front passenger risk exceeds 3 times the baseline.



**FIGURE 4 Probability of Serious Injury to Airbag-Restrained Occupants Normalized to Best Performer**

*Belt-Only Restrained Occupant Risk Comparison*

FIGURE 5 is a chart showing AIS 3+ head and chest normalized injury risk for the selected 30 mph frontal barrier vehicle crash tests.

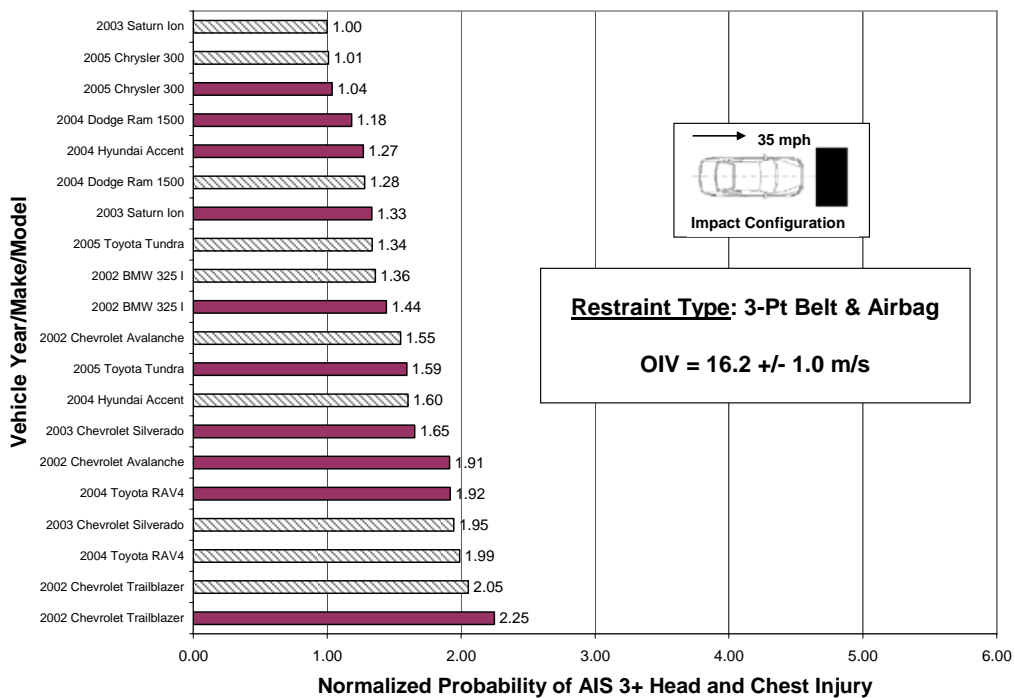


**FIGURE 5 Probability of Serious Injury to Belt-Restrained Occupants Normalized to Best Performer**

Both front seat ATD occupants are Hybrid II 50<sup>th</sup> percentile males with only a three-point belt restraint. Probability of injury has been normalized to the right front passenger of the 1980 Ford Fairmont, which has a combined head and chest injury probability of 18 percent. The OIV varies within a range of 3 m/s whereas ATD occupant risk varies as much as five-fold. Again, note the differences within the same vehicle. In the Fairmont test, both dummies experienced the same OIV but the driver has more than a three-fold risk compared to the right front passenger.

*Belt and Airbag Restrained Occupant Risk Comparison*

FIGURE 6 is a chart showing AIS 3+ head and chest normalized injury risk for the selected 35 mph frontal barrier vehicle crash tests. Drivers are indicated by a solid bar and right front seat passengers are indicated with a hatched bar. Both front seat ATD occupants are Hybrid III 50<sup>th</sup> percentile males with airbag and three-point belt restraints. Probability of injury has been normalized to the right front passenger of the 2003 Saturn Ion, which has a combined head and chest injury probability of 30 percent. The OIV varies within a range of 2 m/s whereas ATD occupant risk varies as much as two-fold.



**FIGURE 6 Probability of Serious Injury to Belt and Airbag Restrained Occupants Normalized to Best Performer**

*Linear Regression Comparison*

The preceding plots showed wide variation in ATD-based risk for tests experiencing essentially the same OIV. There is still the possibility, however, that small changes in roadside criteria correlate to large changes in ATD-based risk. If this is the case, a strong linear regression correlation (e.g. R<sup>2</sup> value approaching unity) should be evident between the roadside and ATD-based criteria. TABLE 4 provides a summary of the linear regression analysis for each of the restraint scenarios analyzed. The slope of the regression line is indicated in parentheses for stronger fits (R<sup>2</sup> value above 0.20).

**TABLE 4 Summary of Linear Regression Analysis**

Configuration	Vehicle Injury Criteria	R <sup>2</sup> Values	
		OIV	ORA
No Occupant Restraint (60 mph)	HIC	0.315 (+)	0.079
	3 ms Clip	0.280 (+)	0.094
	Head/Chest	0.326 (+)	0.088
Airbag Only (25 mph)	HIC	<0.001	<0.001
	3 ms Clip	<0.001	0.106
	Chest Deflection	0.031	0.004
	Head/Chest	<0.001	0.092
Belt Only (30 mph)	HIC	0.011	0.006
	3 ms Clip	<0.001	0.122
	Head/Chest	0.007	0.010
Airbag and Belt (35 mph)	HIC	0.488 (-)	0.025
	3 ms Clip	0.061	0.197
	Chest Deflection	0.225 (-)	0.002
	Head/Chest	0.174	0.120

As expected, the strongest correlations are evident for the unrestrained occupant, especially the OIV. All unrestrained occupant correlations were positive indicating direct proportionality (increasing ATD risk with increasing OIV). The lack of correlation in the ORA for the unrestrained condition was not expected and cannot be fully explained. In general, there appears to be virtually no correlation between roadside injury criteria and ATD-based criteria at a given test speed for any of the restraints considered. This is especially evident with the OIV and ORA for belted only occupants and airbag restrained only occupants. The negative correlations obtained for airbag and belt restrained occupants was also not expected. It may be an artifact of the relatively small data set or be a result of a tendency of vehicle manufacturers to design aggressive restraints for vehicles with stiffer front ends.

**CONCLUSIONS**

This study highlights the importance of considering vehicle restraints, from advanced passive restraints such as airbags to simplistic active restraints such as seatbelts, in injury criteria used in full-scale crash tests with roadside hardware. Specific conclusions and recommendations include:

1. Current injury criteria are out of step with current restraint usage in the U.S. In a fleet with 80% belt usage and 100% airbags installation, an unbelted occupant without an airbag is no longer the practical worst case. Even the 20% of occupants who are hard core non-belt users are protected by an airbag. At a minimum, the roadside criteria should be updated to reflect the presence of airbags in all cars and light trucks manufactured since 1998.
2. In frontal crash tests, current roadside occupant risk criteria are not an accurate measure of occupant risk for individual vehicles. The flail space algorithm was unable to predict the variation in occupant risk for unbelted, belted, airbag only, or belt and airbag restrained occupants.
3. The objective of this paper was to evaluate roadside injury criteria not the use of crash test dummies in roadside hardware tests. Although it is difficult to measure occupant risk without measuring anything on the occupant, it may still be possible to conduct occupant risk assessment with an improved vehicle-acceleration based metric. Alternatives such as a modified OIV or other vehicle-acceleration based metric should be explored. It is clear however that current vehicle-acceleration based metrics, e.g. OIV, do not provide an accurate measure of occupant injury.
4. Airbag deployment in collisions with longitudinal barriers is not a rare event; roughly two-thirds of all tow-away barrier collisions involving airbag-equipped vehicles result in airbag deployment. For vehicles used in future roadside hardware crash tests, we recommend that the airbag remain on. This will allow for monitoring of airbag performance in these crashes and check for late deployments. Anecdotal evidence suggests that airbags may deploy late in guardrail crashes, causing injury.
5. At a given impact speed, variation in ATD-based risk between occupants in the same vehicle can be vastly different in some instances; all roadside criteria, however, are the same for a particular vehicle and crash event.

## ACKNOWLEDGEMENTS

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