

# DEVELOPMENT OF POINT MASS OCCUPANT INJURY CRITERIA USING EVENT DATA RECORDERS

**Douglas J. Gabauer, Hampton C. Gabler**

Virginia Tech-Wake Forest Center for Injury Biomechanics, 100F Randolph Hall (MC 0238)  
Blacksburg, VA 24061

## ABSTRACT

This paper presents an estimate of the probability of serious occupant injury in frontal crashes based on vehicle kinematics information. Occupant injury risk is developed by modeling the human as a point mass and computing the occupant impact velocity (OIV) using the flail space model. Event Data Recorder data provides vehicle kinematics information for real world crashes with known injury outcomes. A data set of 211 cases is used for methodology development and preliminary insight to the injury prediction capability of the metric. Using logistic regression, injury risk curves are generated for all data, a belted occupant subset and an unbelted occupant subset. Based on the models, an occupant restrained by an airbag and safety belt is found to have a lower risk of injury than an occupant only restrained by an airbag. A 50% probability of serious injury is found to correspond to an OIV of 11.2 m/s and 15.9 m/s for unbelted and belted occupants, respectively.

**Keywords:** Crash Injury Criteria, Event Data Recorders, Flail Space Model, Thresholds

## INTRODUCTION

Point mass injury criteria are a method of using vehicle impact responses to predict the potential for occupant injury. Modeling the occupant as a point mass provides an estimate of injury potential without the use of a computationally intensive full human body model. Traditionally, point mass injury criteria have been used to assess blunt trauma injury potential in full scale crash tests with roadside hardware such as guardrails [1][2]. In 1981, Michie [3] proposed the flail space concept which models a vehicle occupant as an unrestrained point mass, positioned at the center of mass of the vehicle that acts as a “free-missile” inside the occupant compartment. Based on the deceleration of the vehicle, the velocity at which the point mass occupant impacts the vehicle interior can be computed. The assumption is that the higher this velocity, termed the occupant impact velocity (OIV), the higher the occupant injury potential. For full-scale roadside hardware tests, threshold values for the OIV are used to determine if there is risk of serious injury to a potential front seat occupant. Currently, the OIV maximum threshold in either the lateral or longitudinal direction is 12 m/s with a preferred value of 9 m/s [1].

Despite its widespread use, little is known regarding the correlation of the flail space model to actual occupant injury. Ray et al. [4] focused on linking the lateral component of the OIV to injury in seventeen real-world guardrail crashes. Council et al. [5] utilized a dataset of 62 matched cases in an attempt to link occupant risk (as calculated in crash tests) to actual injury attained in similar real-world collisions. Neither study, however, produced any significant results in terms of correlating OIV with actual occupant injury. Moreover, both studies required the researchers to estimate the deceleration

pulse of the vehicle. Our previous work [8] [9] using Event Data Recorders focused on the evaluation of the mandated thresholds for the flail space criteria.

Event Data Recorders (EDRs), installed in many late model vehicles, are similar to “black boxes” in airplanes as they record information in the event of a highway collision. Information stored by these manufacturer-specific devices includes vehicle change in velocity versus time, seat belt status, airbag deployment status, and vehicle speed prior to impact [6]. EDRs typically provide a more accurate depiction of the crash pulse with accuracy within 6% of the true delta-V [7]. The National Highway Traffic Safety Administration (NHTSA) collects EDR data in conjunction with the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) program. NASS/CDS data is collected by field investigators and provides detailed injury outcomes from a random sample of roughly 5,000 vehicular crashes in the US per year. The NHTSA EDR database is a coupling of EDR and NASS/CDS data for over 1700 crashes involving General Motors (GM) cars and light trucks.

## **OBJECTIVE**

The specific goals of this study are (1) to compute the probability of injury as a function of OIV and (2) to find threshold values that optimally discriminate between serious and non-serious injuries.

## **METHODS**

Our approach consisted of selecting suitable cases from the NHTSA EDR database, computation of the OIV, and a statistical comparison to the injuries observed. Cases suitable for analysis were chosen based on the following criteria: (1) airbag deployment, (2) comprised of only a single impact, (3) complete velocity versus time data stored in the EDR, (4) a frontal collision, and (5) injury data for either the left or right front seat occupant was known. The first two criteria ensure that the data recorded by the EDR correspond to the injury-causing event. To ensure that the EDR captured the entire crash pulse, all cases are required to have velocity profiles that converge to a constant value (i.e. zero acceleration). Only frontal collisions were considered since the GM EDR only records change in velocity information in the longitudinal direction. For the purpose of this study, a frontal collision was defined as damage to the front of the vehicle and an impulse vector direction  $\pm 10$  degrees of the vehicle’s longitudinal axis. In addition, the injury to either front seat occupant must be known. Based on these selection criteria, a total of 211 cases were available for analysis (162 drivers and 49 right front seat occupants). The final data set consisted of 170 belted occupants and 41 unbelted occupants.

To compute the OIV for each case, EDR relative velocity data was first numerically integrated to obtain relative occupant position as a function of time. Following the flail space methodology, the occupant was assumed to strike the vehicle interior after traveling 60 cm [1]. The impact time and EDR relative velocity were then used to obtain the longitudinal OIV. Gabauer and Gabler [8] provides a more detailed description of the computational procedure.

The OIV threshold limits were originally proposed to correspond to an Abbreviated Injury Severity (AIS) value between 3 and 4 [3]. The AIS scale is an injury severity metric that measures threat to life based on a 0 to 6 scale; zero corresponding to no injury while six corresponds to maximum or fatal injury [10]. In NASS/CDS, each injury is rated according to this scale and the highest AIS value of all injuries to an occupant is referred to as the maximum occupant AIS (MAIS) value. Note that the

original OIV model was developed for the unrestrained occupant (i.e. no airbag or seat belt) and the suitable cases in this analysis involve at least an airbag restraint, and in a majority of cases, both seat belt and airbag. In light of this, the grouping of the data included MAIS values of 0, 1, and 2 for the “not serious” injury group and MAIS values of 3, 4, 5, and 6 for the “serious” injury group. Using the OIV as a predictor, a binary logistic regression model was fit first to the entire data set and then fit separately to the belted and unbelted data subsets.

## RESULTS

The results of the binary logistic regressions fit for the entire data set, the belted subset, and the unbelted subset are shown in Figure 1, Figure 2, and Figure 3, respectively. All figures show the model predicted cumulative probability of “serious” injury (as defined above) as a function of longitudinal OIV. The upper and lower 95 percentile confidence bounds on the predicted are shown as dashed lines. Also, the data points are plotted as a function of longitudinal OIV; note that a value of “1” corresponds to the “serious” injury group. The deviance goodness-of-fit statistics are 0.9909, 0.9999, and 0.9190 for all suitable cases, the belted subset, and the unbelted subset model, respectively. For the entire dataset and the belted subset, all tests for the global null hypothesis were significant to the 0.0001 level while the unbelted subset was significant to the 0.001 level or better.

Table 1 presents a summary of the model results for probability of serious injury using the current OIV threshold values. Figure 4 provides an overlay of the three injury risk curves shown in Figure 1 through Figure 3. A fifty percent probability of “serious” injury corresponds to an occupant impact velocity of 11.2 m/s, 15.9 m/s, and 14 m/s for the unbelted, belted, and all case models, respectively. Table 2 presents proposed values for OIV thresholds based on a 25 and 50 percent chance of serious occupant injury.

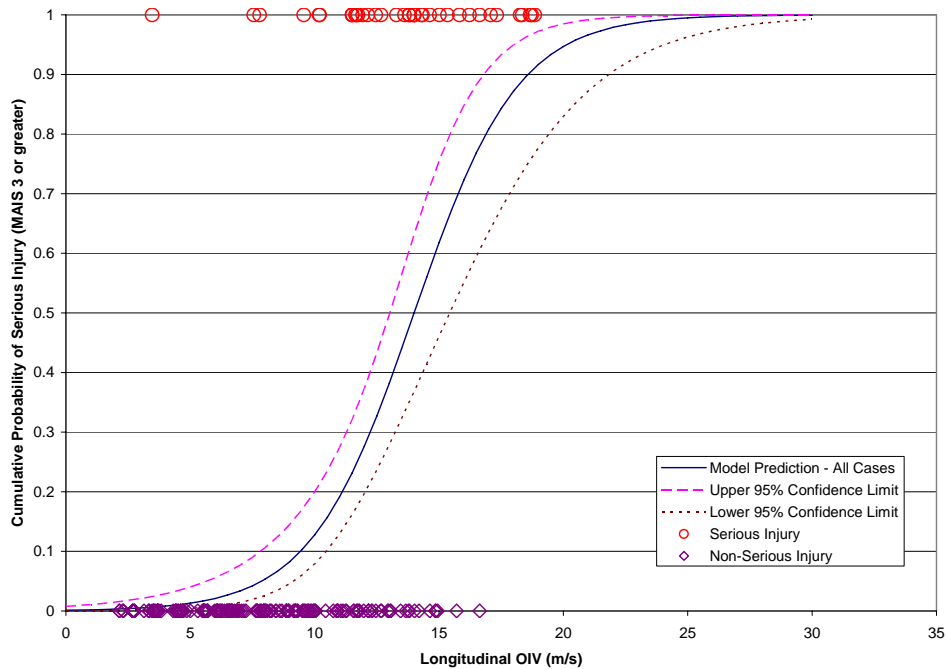


Figure 1. Probability of Serious Occupant Injury – All Occupants

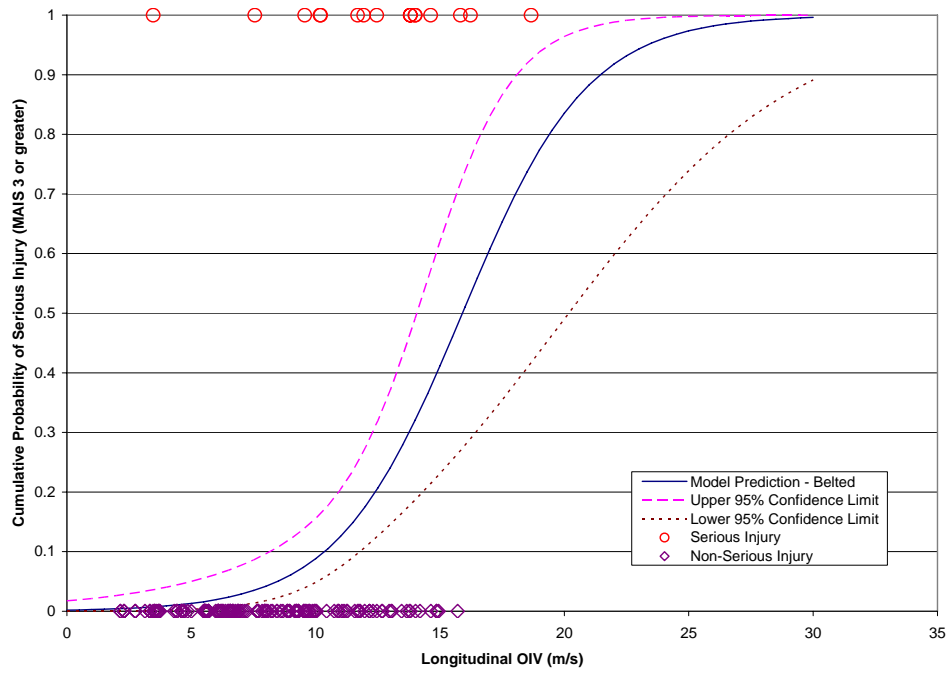


Figure 2. Probability of Serious Occupant Injury – Belt and Airbag Restrainted Occupants

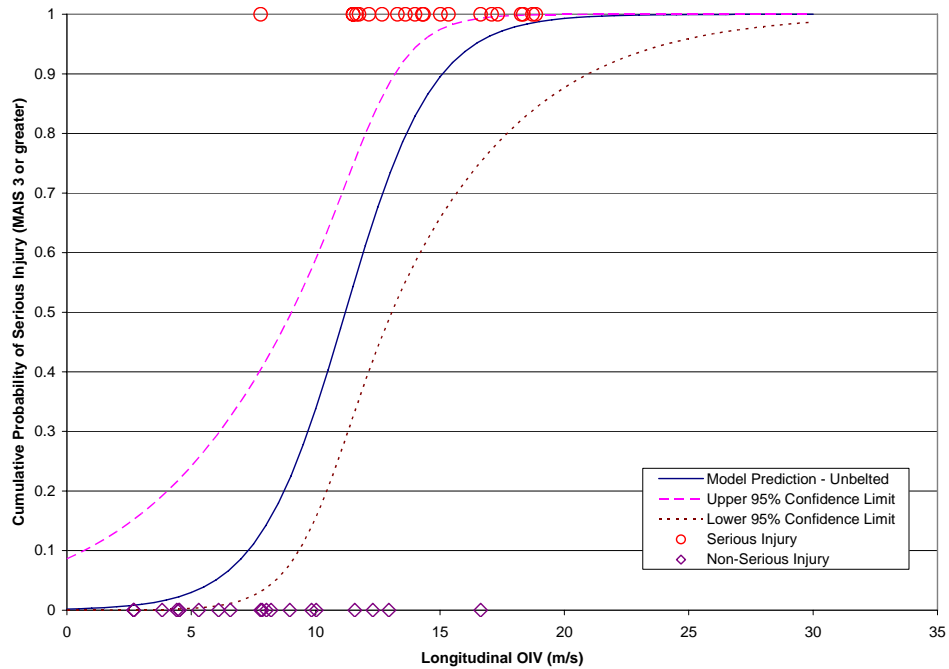


Figure 3. Probability of Serious Occupant Injury – Unbelted (Airbag Restrainted Only) Occupants

Table 1. Summary of Injury Probabilities Based on Existing OIV Threshold Values

Occupants	OIV Threshold (m/s)	Probability of Serious Injury (%)	95% Confidence Intervals	
			Lower	Upper
All	9 m/s	8	5	15
	12 m/s	28	20	37
Belted + Airbag	9 m/s	6	3	12
	12 m/s	18	11	27
Unbelted (Airbag Only)	9 m/s	23	8	50
	12 m/s	61	38	80

Table 2. OIV Thresholds for Serious Injury

Occupants	Probability of Serious Injury (%)	OIV Value (m/s)
Belted + Airbag	25	13.1 m/s
	50	15.9 m/s
Unbelted (Airbag Only)	25	9.2 m/s
	50	11.2 m/s

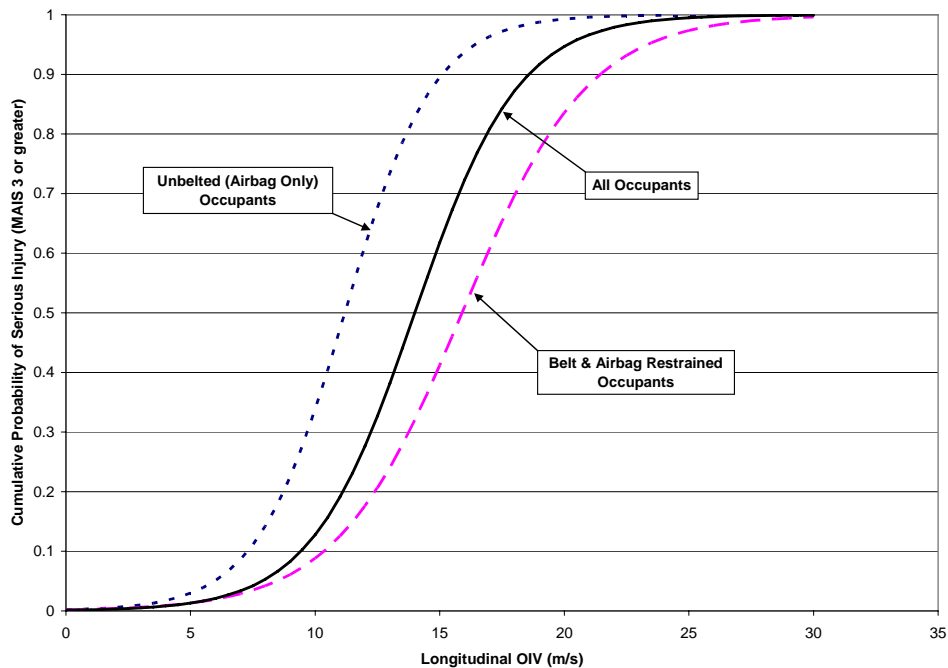


Figure 4. Probability of Serious Occupant Injury by Restraint

## DISCUSSION

Three binary logistic models were used to correlate occupant injury in frontal crashes to a simplified point mass injury criterion. Correlation to the data appeared best in the model which included all cases. A weaker correlation was observed in the belted subset models presumably due to the lack of high severity injury cases involving belted occupants. A weaker correlation was also observed for the unbelted cases due to a general lack of cases involving unbelted occupants. The lack of higher severity

belted cases is especially evident in the lower 95 percent confidence bound. Other uncertainties in the models could be explained by variables that contribute to injury tolerance that were not included in the analysis. These include, but are not limited to, occupant gender, age and stature. Also note that the accuracy of the models is impeded by a general lack of data at higher AIS levels; only 37 of the 211 cases have an MAIS  $\geq$  3. Despite these limitations, however, the models provide some useful insight into the correlation of the OIV criterion to actual occupant injury. As expected, occupants restrained by both a belt and airbag have a higher threshold for injury while occupants restrained only by an airbag have a lower threshold. Also, the fifty percent probability of serious occupant injury in the unbelted subset corresponded closely to the original maximum OIV threshold of 12 m/s. These occupants, however, are restrained by an airbag and not completely unrestrained as assumed in the original formulation of the flail space model.

## CONCLUSIONS

This paper has developed a correlation between probability of serious injury and occupant impact velocity based on the injury outcomes 211 occupants subjected to a frontal crash. The fifty percent probability of serious occupant injury in the current fleet is found to be 11.2 m/s and 15.9 m/s for unbelted and belted occupants, respectively. The current maximum OIV threshold of 12 m/s is found to correspond to an 18 percent chance of serious injury for belted occupants and a 61 percent chance of serious injury for unbelted occupants. Also, for a given OIV value, occupants restrained by both airbags and safety belts are found to have a lower risk of serious injury than those occupants restrained by airbags only.

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