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16. Abstract

This analysis established the univariant occupant injury risk predictive models (or injury probability curves) through logistic regression using delta V as the predictor. Delta V is a measure of crash severity. Occupant injury severity was based on the Maximum Abbreviated Injury Scale (MAIS), 2005 revision, 2008 update, which is noted as MAIS(05/08) in this report. The analysis used crash data from the 2010–2015 National Automotive Sampling System Crashworthiness Data System. The injury probability curves were developed for three crash modes: "all crashes," "frontal crashes," and "rear-end crashes."

There are some notable limitations with the occupant sample that would affect the use of the established probability curves. One is that CDS collects relatively more severe crashes. The second one is that the 2010–2015 CDS recorded AIS injury information only for occupants in vehicles 10 years old and newer. This resulted in occupants in older vehicles with missing MAIS value. The third one is that there are a sizeable number of cases with missing delta V's. Thus, the established injury probability curves might not properly reflect the injury probabilities for occupants from older vehicles nor for occupants in a crash sample that is very different from that in the CDS.

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1. Executive Summary

This analysis develops injury probability curves for all crash conditions as well as for frontal crashes and rear-end crashes. The injury probability curves predict occupant injury risk outcome using delta V. Delta V is the total change in vehicle velocity over the duration of the crash event[1] and serves as the proxy for crash severity. Therefore, these curves can be used to estimate safety countermeasures that reduce delta V. Injury severity is measured by the Maximum Abbreviated Injury Scale score (MAIS)[2] that an occupant received during a crash. AIS has been revised several times over the years. The MAIS which this analysis focuses on is based on the AIS 2005 revision, updated 2008 and is noted as MAIS(05/08) in this report. This MAIS version was recorded only in the 2010–2015 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS).[3] Therefore, this period of CDS was used for analysis. Overall, the analysis developed the occupant injury probability curves for three types of crashes modes: "all crashes," "frontal crashes," and "rear-end crashes."[4]

The logistic regression technique was used. The regression models the probability of having MAISi+ injuries as a function of delta V where MAISi+ means MAIS i and higher level of injuries and "i" ranges from 1 (minor) to 6 (representing fatality in this report).[5] For sample size concern, non-fatal MAIS 5 (critical) and MAIS 6 (maximal) injuries were combined into MAIS 5 injuries. All fatalities regardless of the MAIS scale were grouped together in this analysis. The notation MAIS6 and MAIS6+ represent these fatalities. In other words, MAISi injuries were non-fatal MAIS i injuries for i less than 6. These MAISi+ probability curves were used to derive individual MAIS level non-fatal injury probability curves, noted as MAISi. For example, the MAIS2 injury probability curve was derived from MAIS2+ and MAIS3+ injury probability curves and expressed as MAIS2+ minus MAIS3+. MAIS(05/08) injury probability curves were established also for each of the three crash types.

Occupants with known recorded MAIS and delta V's were included in the logistic regression analysis. There are some notable limitations with the occupant sample that would affect the use of the established probability curves. CDS collects crash data involving passenger vehicles

[1] Generally, delta V was estimated manually or using computer programs through crash construction techniques. Delta V used here was estimated from a Microsoft Window version of Simulating Motor Vehicle Accident Speeds on the Highway program (WinSMASH). Estimates might have relatively wider variations for certain type of crashes such as rollovers, narrow object impact, and sideswipe due to the number of variables considered.

[2] The Abbreviated Injury Scale (AIS) is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive Medicine and is used for coding single injuries, assessing multiple injuries, or for assessing cumulative effects of more than one injury. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable). MAIS represents the maximum injury severity of an occupant at an AIS level, i.e., the highest single AIS for a person with one or more injuries. MAIS 0 means no injury.

[3] In 2016 CDS was transitioned into the Crash Investigation Sampling System (CISS) that employs a different sampling design and records only AIS 2015 version.

[4] Frontal crashes and rear-end crashes are subsets of all crashes. As defined here, they are not mutually exclusive.

[5] The original AIS scale 6 (i.e., AIS 6) represents maximum (untreatable) injuries. In his analysis, due to sample size concern, non-fatal MAIS 5 and MAIS 6 injuries were consolidated into MAIS 5 injuries while all fatalities, regardless of their recorded AIS levels, were combined. In other words, fatalities can be rated as MAIS 5 or MAIS 6 injuries. These fatalities were represented by MAIS6+ and MAIS6 in the report.

(PVs), with at least one PV towed due to damage. These crashes were relatively more severe than the overall crash population.[6]

Second, 2010-2015 CDS recorded AIS injury information only for occupants in vehicles 10 years old and newer. Third, many CDS cases are missing either MAIS or delta V values. Thus, the established injury curves might not properly reflect injury risks for a sample containing a sizeable number of older vehicles nor for a sample having a crash profile that is vastly different from the base sample. The larger number of cases with missing values were not included in the model fitting might also bias the estimated risks.

Table 1-1 presents the mathematical formulas for MAISi+ probability curves by crash modes. These formulas were derived from the logistic regression models developed with consideration of CDS sample design. Figure 1-1 depicts two types of probability curves: MAISi+ probability curves on the left half and the derived MAISi curves in the right half. Please consult Chapter 4 for values of MAISi probability curves tabulated by delta V's and separately by the crash modes.

Table 1-1. Mathematical Formula for MAIS+(05/08) Injury Probability Curves by Crash Modes

	All Crashes	Frontal Crashes	Rear-End Crashes
MAIS 1+	$p(D)=\frac{e^{-1.3925+0.0815*D}}{1+e^{-1.3925+0.0815*D}}$	$p(D)=\frac{e^{-1.4930+0.0854*D}}{1+e^{-1.4930+0.0854*D}}$	$p(D)=\frac{e^{-1.8199+0.0671*D}}{1+e^{-1.8199+0.0671*D}}$
MAIS 2+	$p(D)=\frac{e^{-5.1331+0.1479*D}}{1+e^{-5.1331+0.1479*D}}$	$p(D)=\frac{e^{-4.9429+0.1425*D}}{1+e^{-4.9429+0.1425*D}}$	$p(D)=\frac{e^{-6.1818+0.1482*D}}{1+e^{-6.1818+0.1482*D}}$
MAIS 3+	$p(D)=\frac{e^{-6.9540+0.1637*D}}{1+e^{-6.9540+0.1637*D}}$	$p(D)=\frac{e^{-6.9774+0.1620*D}}{1+e^{-6.9774+0.1620*D}}$	$p(D)=\frac{e^{-8.0329+0.1793*D}}{1+e^{-8.0329+0.1793*D}}$
MAIS 4+	$p(D)=\frac{e^{-8.2070+0.1564*D}}{1+e^{-8.2070+0.1564*D}}$	$p(D)=\frac{e^{-8.4254+0.1586*D}}{1+e^{-8.4254+0.1586*D}}$	$p(D)=\frac{e^{-11.8787+0.2210*D}}{1+e^{-11.8787+0.2210*D}}$
MAIS 5+	$p(D)=\frac{e^{-8.7927+0.1598*D}}{1+e^{-8.7927+0.1598*D}}$	$p(D)=\frac{e^{-8.8355+0.1566*D}}{1+e^{-8.8355+0.1566*D}}$	$p(D)=\frac{e^{-12.1944+0.2276*D}}{1+e^{-12.1944+0.2276*D}}$
Fatality	$p(D)=\frac{e^{-8.9819+0.1603*D}}{1+e^{-8.9819+0.1603*D}}$	$p(D)=\frac{e^{-9.0422+0.1571*D}}{1+e^{-9.0422+0.1571*D}}$	$p(D)=\frac{e^{-12.1982+0.2255*D}}{1+e^{-12.1982+0.2255*D}}$

P(D): probability at delta V D; D: delta V in mph.
Data source: 2010-2015 CDS.

Judging visually from the shape, peak and the rise of the MAISi probability curves shown in Figure 1-1 and the gaps and interaction amongst them, all-crash and frontal-crash probability curves are very similar. The discernable differences between these two sets of probability curves are the peaks for MAIS2 and MAIS4 curves although they are occurring at slightly different delta V's. The peaks of these two curves were slightly higher for frontal crashes compared to those for all crashes. The similarity of these two sets of probability curves likely was influenced by the fact that frontal crashes comprised 70 percent of the "all-crash" group. In contrast, the

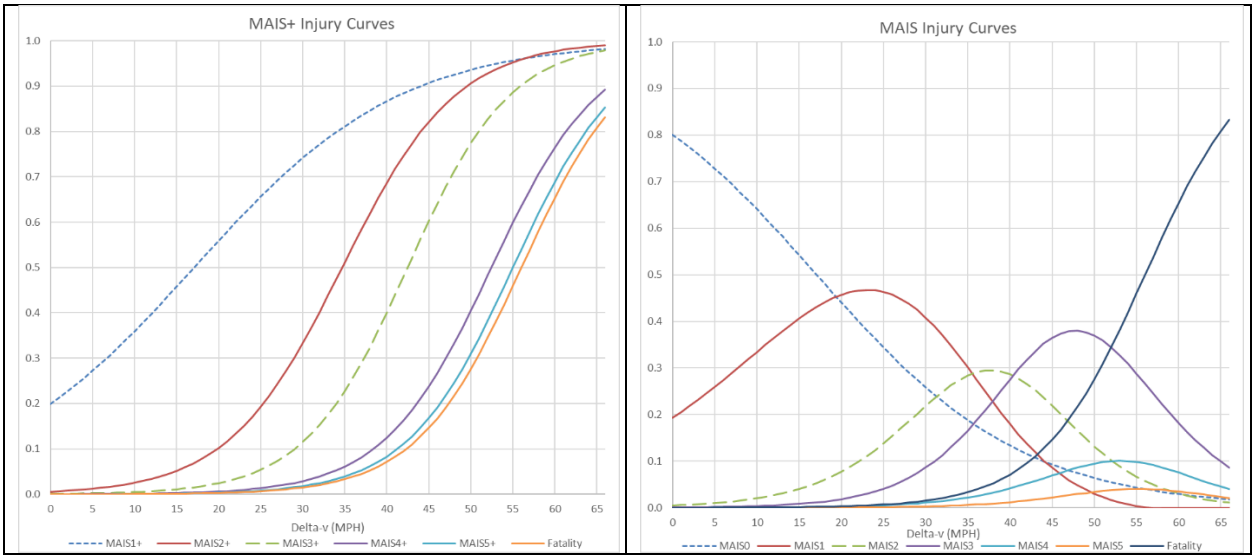
[6] Passenger vehicles (PVs) are vehicles with a gross vehicle weight rating less than or equal to 10,000 lbs. PVs include passenger cars, sport utility vehicles, and light trucks and vans.

curves for rear-end show a pattern different from that for all crashes and frontal crashes. We note rear-end crashes were relatively low severity crashes in terms of MAIS injury severity and delta V levels. These sample characteristics greatly impacted modeling outcome for high MAIS severity injury curves and generally at high-end of delta V range.

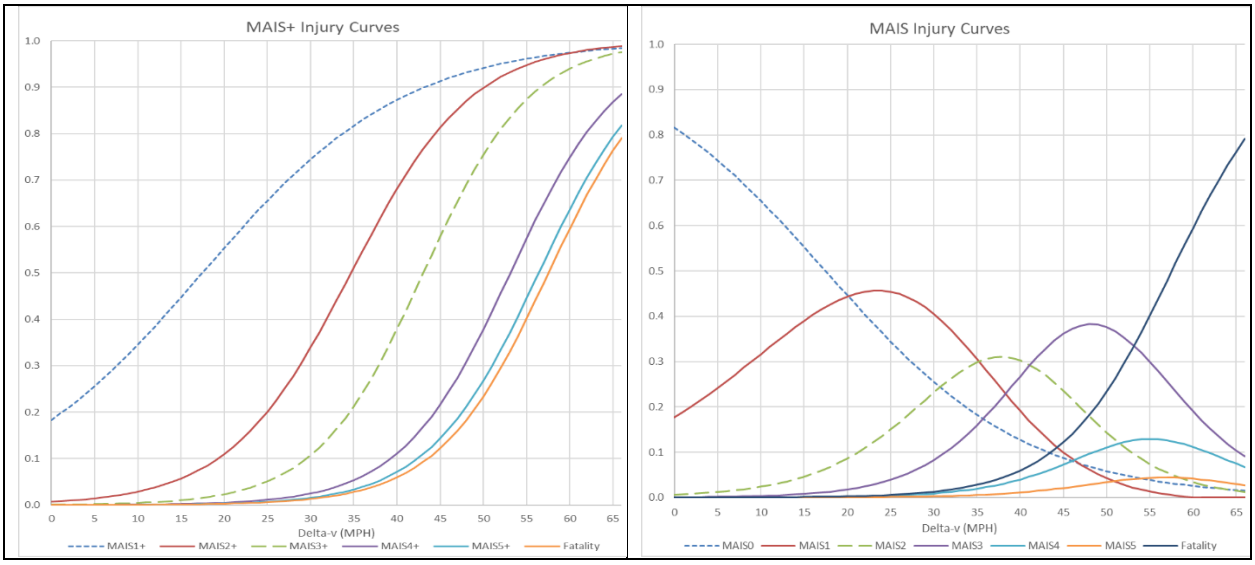
Due to the sample size limitation, modeling variations, delta V estimation errors, and the uncertainty from the extrapolation of results beyond reasonable delta V's, some anomalies occurred, i.e., negative MAISi values, a violation of probability principles. These negative MAISi probabilities were reassigned to 0. Additional adjustments were made to address the impact of this 0-reassignment step on violation of probability principles. The methodology approach section (Section 3.4) of the report discusses these adjustments in detail.

Figure 1-1 shows both MAISi+ and MAISi injury probability curves for the three crash modes. The MAISi injury probability curves show the results after the additional adjustments are made. Note that where MAISi+ probability curves intersect, implying a higher probability of injury for the less inclusive injury grouping, demonstrates the anomalies.

All Crashes



Frontal Crashes



Rear-End Crashes

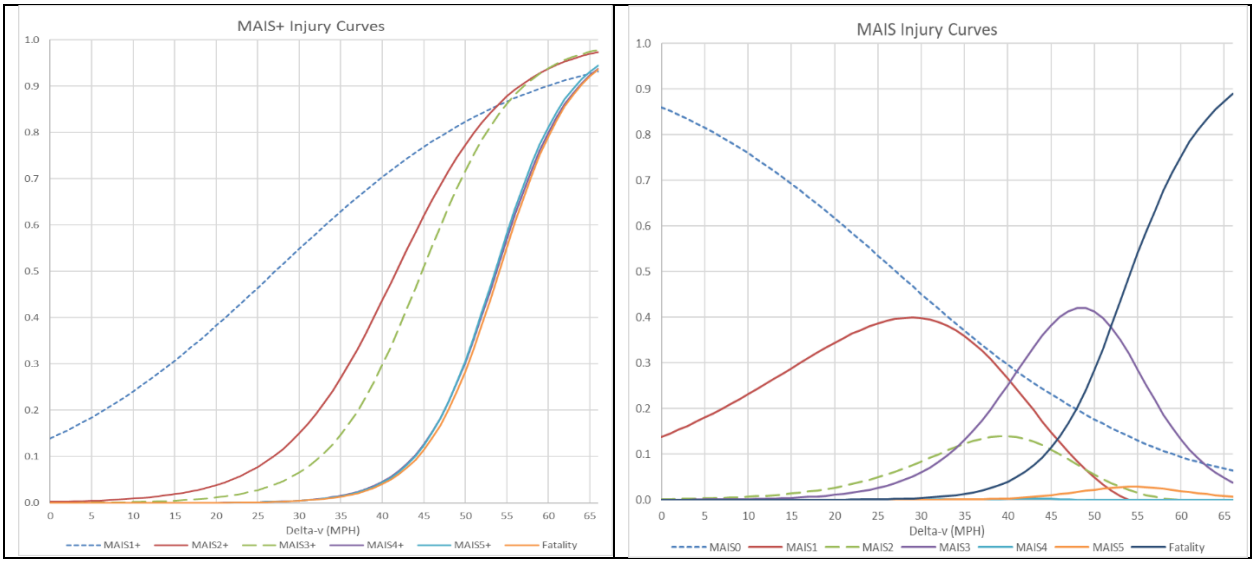


Figure 1-1. MAIS+(05/08) and MAIS(05/08) Injury Probability Curves by Crash Modes

2. Introduction

This report documents an analysis of the 2010-2015 NASS CDS for establishing injury probability predicting models as a function of crash severity. The injury severity considered in the analysis was measured in MAIS.[7] The version of MAIS used for the analysis was based on the AIS 2005 revision, 2008 update,[8] and is noted as MAIS(05/08) in this document. The crash severity considered is represented by delta V's measured in mile per hour (mph).[9] Delta V is defined simply as the total change in vehicle velocity over the duration of the crash event.[10] To simplify discussion, unless specified, MAIS and MAIS(05/08) are interchangeable, hereafter in the discussion.

Delta V has been used to predict injury risk outcome (Gabauer, 2006; Viano, 2010). In 2004 the agency had developed a set of injury probability curves when the agency promulgated the Federal Motor Vehicle Safety Standards No. 138, Tire Pressure Monitoring System (TPMS) (NHTSA, 2004). These injury probability curves were established using 1995-1999 CDS and for MAIS (93/98) that was the injury scale reported in that period of CDS. Data sample was limited to occupants in crashes where at least one passenger vehicle used brake. The model fitting was based on the approach that is described in the Validation Process (Section 3.5) of this report.

In contrast to the methodology used for the TPMS, logistic regression is used for this analysis. The analysis models the probability of occupants who had received MAISi+ injuries as a function of delta V for three crash modes" all crashes, frontal crashes, and rear-end crashes. MAISi+ represents MAIS i level and higher injuries, where i ranges from severity 1 (minor) to the highest 6 representing fatality in this analysis. The MAIS 6 scale originally defined as the maximal injuries. For this analysis, the index i=6 means fatality. All fatalities, regardless of their recorded MAIS scale, were combined into one category, represented by MAIS6 and MAIS6+.[11] Three crash modes were considered: all crashes, frontal crashes, and rear-end crashes. After MAISi+ probability curves were established, individual MAIS probability curves (noted as MAISi, i.e., MAIS0, MAIS1 and so on) were simply derived from these MAISi+ probability curves by subtracting consecutive MAISi+ values.

The SAS PROC SURVEYLOGISTIC procedure (SAS, 2016) was used to establish the injury risk models. Occupants with both known MAIS and delta V values were included in the logistic regression analysis. The logistic regression analysis/modeling for frontal- and rear-end crashes

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[7] The Abbreviated Injury Scale is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive Medicine and is used for coding single injuries, assessing multiple injuries, or for assessing cumulative effects of more than one injury. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximal. MAIS represents the maximum injury severity of an occupant at an AIS level, i.e., the highest single AIS for a person with one or more injuries. MAIS 0 means no injury.

[8] This period of CDS also recoded AIS 1993 version, updated in 1998.

[9] The measurement unit was converted from kilometer per hour that was recorded in the CDS for delta V's.

[10] Generally, delta V was estimated manually or using computer programs through crash construction techniques. Delta V used here was estimated from a Microsoft Window version of Simulating Motor Vehicle Accident Speeds on the Highway program (WinSMASH). Estimates might have relatively wider variations for certain type of crashes such as rollovers, narrow object impact, and sideswipe due to the number of variables considered.

[11] As noted previously, due to sample size concern, non-fatal MAIS 5 and MAIS 6 injuries were consolidated into MAIS 5, and the scale 6 or MAIS 6 represents fatality for this analysis.

was established by using the DOMAIN syntax in PROC SURVEYLOGISTIC to preserve the integrity of CDS sample structure. Overall, three sets of MAIS(05/08) probability curves were established, one for each crash mode where each set contains both MAISi+ and MAISi injury probability curves.

For validation of how well the MAISi models fit, the percent of each MAIS injury level by delta V was calculated. These data points were then superimposed with the corresponding MAISi curves to allow a visual examination of the model fit. The validation also can be considered as a visual comparison between the models (without a smooth curve) that were established directly from the individual MAISi levels and those that were derived from the MAISi+ logistic regression models. The Validation section of the report discusses this in detail.

The established MAISi injury probability curves can be used to quantify the impact of safety countermeasures that are designed to reduce the severity of crashes, by discerning the change in injury probability profiles.[12] These injury probability curves also can be used for estimating the crashworthiness impact for crash avoidance safety technologies that not only can avoid crashes but also mitigate crash severity for non-avoidable crashes.

[12] An early application of injury probability curves, for example, was for benefit estimates for FMVSS No. 138 Tire Pressure Monitory System rule (NHTSA, 2004). For additional information, see the set of injury curves developed using a different approach, www.regulations.gov/document/NHTSA-2004-19054-0003.

3. Methodology Approach

This chapter describes the data source, preparation of data, definition of crash modes, and logistic regression models examined for the analysis.

3.1 Data

The analysis relies on data from 2010-2015 CDS (NHTSA's NASS-CDS coding and editing manuals and analytic user's manuals, NHTSA 2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 14a, 2015a, 2015b, 2016). Crash data was limited to these 6 years because they were the only years available where injuries were recorded in AIS 2005/Updated 2008 version.[13] In 2016, CDS was transitioned into the Crash Investigation Sampling System (CISS). CISS is a modernization of CDS, but it employs a different sampling design and records injuries using the AIS 2015 version (NHTSA, 2019). Therefore, it is not feasible to combine CDS and CISS for AIS- or MAIS-specific analysis.

CDS is a nationally representative sample of passenger vehicle (PV) crashes. Passenger vehicles (PVs) are vehicles with a gross vehicle weight rating less than or equal to 10,000 lbs. PVs include passenger cars, sport utility vehicles, and light trucks and vans. The database includes crashes where at least one PV was towed due to damage. CDS is a stratified, multistage, unequal selection probability design sample (Zhang, 2013). CDS collects detailed, in-depth crash, vehicle, and occupant information in addition to those recorded in the police crash report by investigating motor vehicle crashes through interviews, medical records, vehicle inspection, and scene inspection. Since 2009 CDS recorded AIS (MAIS also) injury only for occupants in PVs 10 years and newer when crashes occurred. Therefore, all occupants for the analysis were from relatively new vehicles in each successive calendar year. The data sample for the logistic regression analysis was filtered by MAIS, occupant treatment status, and delta V's. Delta V used in this analysis is the total delta V (SAS variable: DVTOTAL) from the GV files under the SAS database structure (NHTSA, 2011a to 2016b).

DVTOTAL was estimated from a Microsoft Windows version of computer program, Simulating Motor Vehicle Accident Speeds on the Highway (WinSMASH) (Gabler et al., 2012; Sharma et al., 2007). Estimates for certain type of crashes such as rollover, narrow object impact, and sideswipe may have a relatively wider variations due to the number of variables considered. CDS has a high proportion of cases without a delta V measurement. These missing delta V cases were due to several reasons: no vehicle inspection, crash out of scope, or insufficient measurements (e.g., missing value for certain fields that are required for delta V estimation). Crashes that are out of scope, however, are not limited to cases without horizontal force such as rollovers, impact with yielding object, side swipe, severe override, overlapping damage, colliding with non-CDS vehicles (e.g., trucks), and damage/impact outside the rails. Each missing delta V case is unique, and missing values are not completely random. Given these injury curves mostly likely will be used to estimate the safety impact for safety countermeasures in new model years of vehicles for specific crash types such as frontal and real-end crashes, we decided not to impute missing values, and crashes with missing values were excluded from analysis. Note that in certain, limited cases, CDS also included EDR recorded delta V. However, to avoid introducing variation

[13] These 6 years of CDS also recorded AIS 1993/Updated 1998.

from different sources into the analysis, EDR-recorded delta V's were not used nor were replacements for missing delta V's. CDS reported DVTOTAL in kilometers per hour and was converted to mph for this analysis.

The data sample included occupants either with known MAIS except for "injured, unknown severity" or fatalities. Fatalities were identified by the SAS variable TREATMNT (TREATMNT=1) from the OA[14] file of CDS in SAS database structure. Non-fatal MAIS 6 injury cases were consolidated with non-fatal MAIS 5 for the analysis because there were insufficient observations—particularly when the data was stratified by delta V—to obtain statistically significant results for the category. Similarly, cases for delta V 60 mph and above were aggregated together as one group for the regression modeling, i.e., the delta V threshold set to 60 mph.

3.2 Crash Modes

The crash types examined for the analysis were all crashes, frontal crashes, and rear-end crashes. Frontal crashes were defined using Direction of Force (DOF1), Deformation Location (GAD1), and specific Longitudinal Location (SHL1) from the VE[15] file of CDS in a SAS database structure (NHTSA, 2011a to 2016b). This definition is identical to that which was used in the FMVSS No. 208 Advanced Airbag rules (NHTSA, 2006; NHTSA, 2000). Cases included in the frontal crashes were occupants in PVs involved in head-on crashes, single vehicle roadway departure crashes, or were the striking vehicles in rear-end crashes. For rear-end crashes, the analysis adopted the definition generally used by the agency for rear-end related research and rulemaking.

Rear-end crashes were defined using only the crash-type variable (ACCTYPE) that depicts relative vehicle position and maneuver for a specific crash scenario. Scenarios included lead vehicle stopped, lead vehicle moving, lead vehicle decelerating, and unknown movement of the lead vehicles. Occupants in both striking and struck vehicles for these scenarios were included. Table 3-1 lists the SAS codes for these crash definitions. Note that frontal- and rear-end crashes both are subsets of all crashes, and they are not mutually exclusive (e.g., the striking vehicle in a rear-end crash can also be in frontal crashes).

Table 3-1. Crash Definition

Crash Modes	Definition
Frontal Crashes	(GAD1='F') or ((GAD1 in('R','L')) and (SHL1='F') and (DOF in (1,2,10,11,12))) or ((GAD1 in('R','L')) and (SHL1^='F') and (DOF in (11,12,1)))
Rear-End Crashes	20<=ACCTYPE<=33

[14] Occupant file.
[15] Exterior Vehicle file.

3.3 Sample Size

Collectively, the 2010-2015 CDS contained a total of 15.92 million occupants. Of these occupants, 9.39 million (58.9 percent of all occupants) were occupants with known MAIS including those coded with "injured, severity unknown" and fatalities in vehicles aged 10 or newer at the time of the crash. Within these known MAIS cases, about 5.60 million occupants (35.2 percent of all occupants) had known delta V's. The final sample size for the logistic regression for all crashes was 5.49 million (base sample), i.e., weighted cases for model fitting that excluded injured occupants with unknown severity, representing 34.5 percent of all occupants. Of the base sample, 3.93 million (71.6%, not shown) were occupants in frontal crashes, and 1.48 million (27.0%) were in rear-end crashes. These two crash modes are not mutually exclusive, i.e., they overlapped. About 66.9 percent of rear-end cases were also frontal crash cases. Due to the overlap issue, the remaining other crash modes cannot be derived simply by using the total minus the sum of these two crashes modes.

Examining by crash type separately, for all crashes, the base sample of 3.93 million is about 36.5 percent of initial size that included all involved occupants in PVs. For rear-end crashes, the final occupant sample size of 1.5 million is about 40.8 percent of initial one. These final sample percentages indicate that a sizable number of occupants were not included for analysis across crash modes. Table 3-2 provides the progressive deduction steps used to reach the base sample size by crash modes.

Table 3-2. Sample Size deduction by crash mode

Weighted Counts (Column %)	All Crashes	Frontal Crashes	Rear-End Crashes
Total Occupants	15,924,853 (100%)	10,782,242 (100%)	3,634,009 (100%)
Total With Known MAIS	9,386,5424 (58.9%)	6,219,811 (57.7%)	2,169,881 (59.7%)
Excluding Unknown Delta V	5,602,990 (35.2%)	4,012,144 (37.2.%)	1,519,309 (41.8%)
Base Sample, Excluding Injured With Unknown Severity	5,492,758 (34.5%)	3,934,646 (36.5%)	1,480,759 (40.8%)

Note: All crashes included frontal crashes, rear-end crashes, and other crash modes; frontal and rear-end crashes are not mutually exclusive.
Source: 2010-2015 CDS.

Given that a significant amount of the CDS observations were incomplete, it is warranted to examine the distribution of missing cases. Data in Table 3-2 also can be used to examine the distribution of these missing cases. Table 3-3 presents these cases by missing value types and distribution between crash modes. As shown, for cases missing both MAIS and delta V, 60.0 percent were frontal crashes and 16.8 percent were rear-end crashes. We reiterate that the high proportion of missing MAIS cases is the result of the injury reporting criterion imposed in the selected years of CDS, which was limited to occupants in passenger vehicles with vehicle age less than 11 years old. Missing delta V's is due to various reasons as stated previously. All cited

occupant counts here are weighted numbers. Readers can see Appendix A for detailed raw cases (and the total weights) that were used for each MAISi+ regression model. Separately, Appendix B provides tabulated MAISi probabilities by delta V's. All these statistics in these two appendixes were presented by crash modes.

Table 3-3. Distribution of Missing Cases

Missing Type	All Crashes	Frontal Crashes	Rear-End Crashes
Both Delta V and MAIS	2,577,674 (100%)	1,545,988 (60.0%)	433,404 (16.8%)
MAIS Only	3,960,635 (100%)	3,016,443 (76.2%)	1,030,724 (26.0%)
Delta V Only	3,783,552 (100%)	2,207,667 (58.4%)	650,579 (17.2%)
Total	10,321,683 (100%)	6,770,098 (65.6%)	2,114,700 (20.5%)

Note: Frontal and rear-end crashes are not mutually exclusive.
Source: 2010-2015 CDS.

3.4 Logistic Regression

The basic statistical technique utilized in the analysis was logistic regression (or a logit model). The logit function models the log odds of a dichotomous outcome variable (or dependent variables in binary format) as a linear function of predictors. The outcome variable here is MAISi+ injury and delta V is the predictor. MAISi+ represents injuries from the ith scale to fatality where i ranges from 1 to 6 (fatality). In the modelling, MAISi+ has two values for each occupant, "1" if the occupant had MAISi+ injuries, "0" if the occupant's MAIS level was less than i. For example, MAIS2+ is "1" if an occupant had a MAIS 2 or higher severity injury and "0" if this occupant was either not injured or had a MAIS 1 injury. MAIS6+ and MAIS6, both represent fatalities. Similarly, MAIS6+ has a value of 1 if an occupant was fatally injured and "0" if not. The delta V is measured in miles per hour (mph) in the analysis. All cases for delta V's higher than 60 mph were consolidated into 60 mph, the delta V threshold setting for the regression analysis.

For each MAISi+, the logistic regression modeled log odds of the probability of MAISi+ being "1" and can be expressed mathematically as following:

$$\text{Logit}\left(p_i^+\right) = \log\left(\frac{p_i^+}{1-p_i^+}\right) = a_{i0} + a_{i1} * D \text{ , } i = 1 \text{ to } 6 \qquad \text{-------- (1)}$$

Where, p_i^+ = the probability of MAISi+ = 1

a_{i0} = estimated intercept for MAISi+

a_{i1} = estimated coefficient for D for MAISi+

D = delta V measured in mph.

The SAS SURVEYLOGISTIC procedure (PROC SURVEYLOGISTIC) was used for modeling and estimating a_{i0} and a_{i1} (SAS, 2016) of Equation 1. PROC SURVEYLOGISTIC is used to

account for the multistage sampling design of CDS and thus reduce the likelihood of false significancy. The DOMAIN syntax in PROC SURVEYLOGSTIC was used for sub-crash population analysis, i.e., frontal and rear-end crashes. The use of DOMAIN is to preserve the integrity of the CDS sampling structure and not to underestimate the standard errors of the estimated coefficients.

From Equation 1, exponentiating both sides of the equation, the logit function can be transformed into the probability p_i^+ which becomes a function of delta V as shown below:

$$e^{\log\left(\frac{p_i^+}{1-p_i^+}\right)} = e^{(a_{i0}+ a_{i1}*D)}$$

$$\frac{p_i^+}{1-p_i^+} = e^{(a_{i0}+ a_{i1}*D)}$$

$$p_i^+ = \frac{e^{(a_{i0}+ a_{i1}*D)}}{1+e^{(a_{i0}+ a_{i1}*D)}}$$

or expressed more formally,

$$p_i^+(D) = \frac{e^{(a_{i0}+ a_{i1}*D)}}{1+e^{(a_{i0}+ a_{i1}*D)}} \text{ ---------- (2)}$$

The probabilities for individual MAIS (p_i) or formally $p_i(D)$, then can be derived from the established $p_i^+(D)$. Recall that $p_0^+(D)$ represents all potential crash outcomes ranging from no injury to fatal injury. Logically, the probability of having any injury outcome must be 100 percent, hence $p_0^+(D) = 1$, for every D. Therefore, p_i, i from 0 to 6, can be noted as:

p_0 (i.e., MAIS 0 probability) = $p_0^+ - p_1^+ = 1 - p_1^+$,

$p_i = p_i^+ - p_{i+1}^+$, i from 1 to 5, and

p_6 (i.e., fatality) = p_6^+

Logically, p_i^+ should be greater than p_{i+1}^+ since the change of an occupant sustaining a MAIS i and higher injury is greater than that of receiving MAIS (i+i) and higher injuries. Thus, every p_i should not be less than 0. However, due to the modeling variations, sample size limitations, and other factors imbedded in the crash database, certain delta V's produced negative p_is. The analysis reassigned these negative p_is to 0 after considering that this generally occurred at the tail of delta V distributions and this would have minimal impact on the predictive risks for relatively populated data V's. As we know that for each delta V, the initial sum of p_is (p-total) before reassigning negative value to 0 is 1 (with some rounding errors). The reassignment artificially inflated p-total to greater than 1 by the absolute value of the total reassigned negatives. For example, if the value of p_1 is -0.06 for a delta V, after reassigning it to 0 the p-total for that delta V would then become 1.06, a 6 percent increase. When the impact of the reassignment is outside of reasonable rounding errors (i.e., more than 1%), the analysis rebalanced p_is for affected delta V's to ensure that each p-total is 1. Rebalancing discounts each p_i by the percentage of inflated p-total that is over 1. With the sample example that p-total became 1.06, a 6 percent increase over the initial p-total 1. This increase cannot be addressed merely by rounding errors. Therefore, for this incidence, each MAIS severity probability p_i, i from 0 to 6, for that delta V would be

discounted by 6 percent (i.e., dividing individual p_i by 1.06), to ensure p-total to be adjusted down to 1. If rebalancing is needed, the analysis would start from the lowest affected delta V. Sections for individual crash mode will discuss the reassignment and rebalancing processes and its impact in detail.

3.5 Validation Process

For validating the model fit, the analysis calculated imputed weighted percentage for individual MAIS injury level for each of the delta V from 1 to 66 mph. These data points are superimposed with the corresponding MAIS injury probability curves, $p_i(D)$. The intent is to examine logistic model fit and its variations from calculated, imputed percentages. This process also can be considered as a visual comparison between the a MAISi model (without a smooth curve or mathematical expression) that was established by fitting the 66 data points and that derived from the consecutive MAISi+ logistic regression models.

The imputed percentages, noted as $p_{i,j}$, where i represents the MAIS i severity level (6 as fatality) and j represents delta V of j mph can be mathematically expressed as:

$$p_{i,j}=\frac{I_{i,j}}{T_j}\text{ , i = 0 to 6, j = 0 to 66 ---------- (3)}$$

Where,

$p_{i,j}$ = percent of MAISi injuries at j mph delta V

$I_{i,j}$ = the number of MAISi injuries (i.e., MAIS0, MAIS1, MAIS2, …, fatal) at j mph delta V

T_j = total number of involved occupants at i mph delta V with known MAIS.

Each injury counts, $I_{i,j}$, was the imputed result that includes its initial injuries and those were distributed from occupants who were injured with unknown severity. The distribution among known MAIS 1-5 injuries and fatalities was based on their relative proportions at each delta V level. The total occupant counts, T_j, included injured occupants with unknown severity. For missing cases, their $p_{i,j}$s were given the value 0. This was to ensure consistency that each MAIS level has a total of 66 data points to compared with. Extending delta V to 66 mph, beyond the 60-mph threshold setup for the logistic regression primarily was intended to illustrate the logistic model fit trend. Note that the inclusion of injured but severity unknown occupants increase the sample size for logistic regression by 2 percent for all crashes and frontal crashes and 3 percent for rear-end crashes. In other words, the total number of occupant counts is about 2-3 percent higher than the base sample.

4. MAIS+ Injury Probability Curves

This chapter presents the logistic regression modeling results, i.e., MAISi+ probability curves (p_i^+ , i ranges from 1 to 6) and the derived MAISi injury probabilities (p_is). These results are presented in three sections, one section for each crash type considered (all crashes, frontal, and rear-end). Each section contains two pairs of tables and figures combinations. The first pair is for MAISi+ probability curves in which the table provides the mathematical formula for the curves and the figure depicts these curves. The second pair is for MAISi probability curves. The difference from the first pair is that the table here presents the value of p_is by delta V's instead of their mathematical formulas since each p_i simply is the difference of two consecutive p_i^+ s. Negative p_is are indicated by shaded cells. The paired figure depicts the MAISi curves.

The SAS PROC SURVEYLOGISTIC (Statistical Analysis System software from the SAS institute) procedure was used to estimate the values of parameters a_{i0} and a_{i1} in Equation 1 for each of these p_i^+ curves. Appendix A summarizes these a_{i0} and a_{i1} and their significance statistics for each of the crash modes. In addition, Appendix A also provides raw and weighted sample sizes (Response Profiles) for establishing p_i^+ s. For individual MAISi, please see Appendix B that provides the weighted sample by delta V's.

Note that cases with missing values were not included in the model fitting. As shown in Table 3-2, 64.8 percent of all occupants, 62.8 percent of occupants in frontal crashes, and 58.2 percent of occupants in rear-end crashes were dropped from the data due to missing MAIS or missing delta V values. Non-response adjustments were not made to account for these missing values. Hence, there could be non-response bias in the estimates.

4.1 All Crashes

Figure 4-1 lists the mathematical formulas of p_i^+ for all crashes. For a complete reference, the table also includes a MAIS0 probability curve. Table 4-2 tabulates p_i by delta V's. Figure 4-1 and Figure 4-2 are graphic depictions of those probability curves presented in Tables 4-1 and Table 4-2, respectively.

The only negative results occurred in p_1 at delta V 57 mph and higher where sample size was generally insufficient. The negative p_1s can also be observed in Figure 4-1 at the top right corner where two curves cross each other. The negative p_1s on p-total (under the "Total" column) is smaller than 1 percent. The discrepancy was within rounding errors. Given this insignificant impact and the intent to preserve the integrity of modeling results to the maximum extent possible, the analysis did not rebalance MAIS probabilities for these delta V's.

As described earlier, one application of these injury probability curves is for quantifying the safety impact of countermeasures that are designed to reduce delta V or impact speed. Benefits are derived from the injury risk change between two delta V levels. For example, if a countermeasure can reduce the overall crash severity from 40 mph to 25 mph delta V's, based on Table 4-2, at 40 mph delta V, occupants would have a 28.6 percent chance of receiving MAIS 2 injuries and a 7.0 percent chance of being fatally injured. In contrast, at 25 mph delta V, the chance of an occupant receiving MAIS 2 injuries would reduce to 13.8 percent while being fatally injured would be less than 1.0 percent. Applying these probabilities to its corresponding

baseline injuries determines the number of occupants whose injury severity would be lower and to which level and thus derives the safety benefits of this countermeasure.

Table 4-1. Mathematical Formula for MAIS+(05/08) Probability Curves, All Crashes

MAIS Level	Formula for Probability Curves
MAIS 0	$p(D)=1-\frac{e^{-1.3925+0.0815*D}}{1+e^{-1.3925+0.0815*D}}$
MAIS 1+	$p(D)=\frac{e^{-1.3925+0.0815*D}}{1+e^{-1.3925+0.0815*D}}$
MAIS 2+	$p(D)=\frac{e^{-5.1331+0.1479*D}}{1+e^{-5.1331+0.1479*D}}$
MAIS 3+	$p(D)=\frac{e^{-6.9540+0.1637*D}}{1+e^{-6.9540+0.1637*D}}$
MAIS 4+	$p(D)=\frac{e^{-8.2070+0.1564*D}}{1+e^{-8.2070+0.1564*D}}$
MAIS 5+	$p(D)=\frac{e^{-8.7927+0.1598*D}}{1+e^{-8.7927+0.1598*D}}$
Fatality	$p(D)=\frac{e^{-8.9819+0.1603*D}}{1+e^{-8.9819+0.1603*D}}$

D: delta V in mph.
Data source: 2010-2015 CDS.

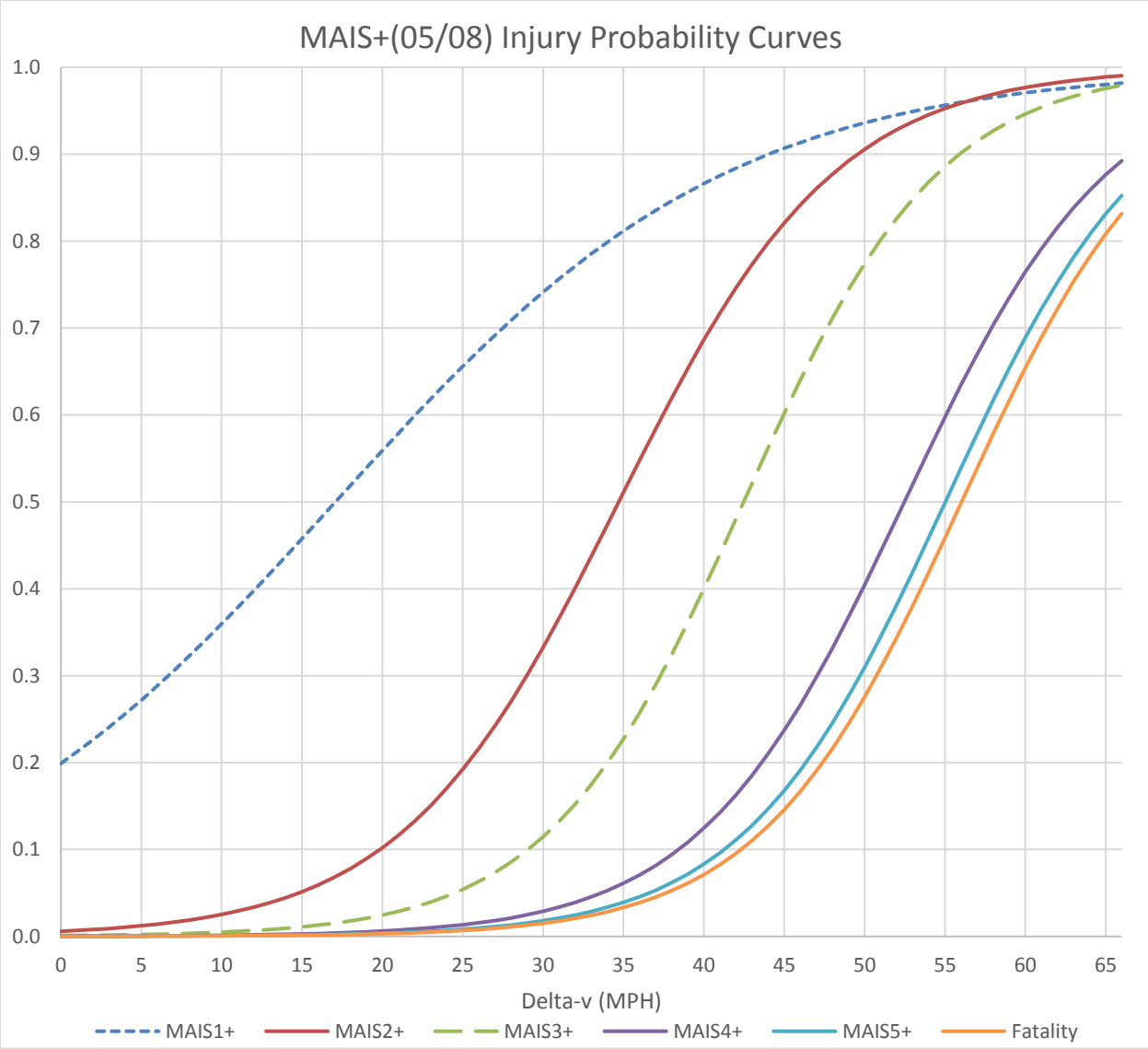

Figure 4-1. MAIS+(05/08) Injury Probability Curves, All Crashes

Table 4-2. MAIS(05/08) Injury Probability by Delta V, All Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
0	0.8010	0.1931	0.0049	0.0007	0.0001	0.0000	0.0001	1.0000
1	0.7877	0.2055	0.0057	0.0008	0.0001	0.0000	0.0001	1.0000
2	0.7737	0.2184	0.0065	0.0010	0.0002	0.0000	0.0002	1.0000
3	0.7591	0.2317	0.0076	0.0011	0.0002	0.0000	0.0002	1.0000
4	0.7439	0.2455	0.0087	0.0013	0.0002	0.0000	0.0002	1.0000
5	0.7281	0.2597	0.0100	0.0016	0.0003	0.0001	0.0003	1.0000
6	0.7117	0.2742	0.0116	0.0018	0.0003	0.0001	0.0003	1.0000
7	0.6947	0.2890	0.0133	0.0022	0.0003	0.0001	0.0004	1.0000
8	0.6771	0.3040	0.0154	0.0026	0.0004	0.0001	0.0005	1.0000
9	0.6590	0.3191	0.0177	0.0030	0.0005	0.0001	0.0005	1.0000
10	0.6405	0.3343	0.0203	0.0036	0.0006	0.0001	0.0006	1.0000
11	0.6215	0.3493	0.0234	0.0042	0.0006	0.0001	0.0007	1.0000
12	0.6022	0.3642	0.0269	0.0050	0.0007	0.0002	0.0009	1.0000
13	0.5825	0.3787	0.0308	0.0059	0.0009	0.0002	0.0010	1.0000
14	0.5625	0.3928	0.0353	0.0069	0.0010	0.0002	0.0012	1.0000
15	0.5424	0.4062	0.0404	0.0082	0.0012	0.0003	0.0014	1.0000
16	0.5221	0.4187	0.0462	0.0096	0.0014	0.0003	0.0016	1.0000
17	0.5017	0.4303	0.0527	0.0113	0.0016	0.0004	0.0019	1.0000
18	0.4814	0.4407	0.0601	0.0133	0.0018	0.0004	0.0022	1.0000
19	0.4611	0.4497	0.0683	0.0157	0.0021	0.0005	0.0026	1.0000
20	0.4409	0.4571	0.0774	0.0184	0.0025	0.0006	0.0031	1.0000
21	0.4209	0.4627	0.0875	0.0216	0.0029	0.0007	0.0036	1.0000
22	0.4012	0.4663	0.0987	0.0254	0.0034	0.0008	0.0043	1.0000
23	0.3818	0.4678	0.1108	0.0297	0.0039	0.0010	0.0050	1.0000
24	0.3627	0.4670	0.1240	0.0348	0.0045	0.0011	0.0059	1.0000
25	0.3441	0.4637	0.1381	0.0407	0.0052	0.0013	0.0069	1.0000
26	0.3260	0.4578	0.1531	0.0474	0.0061	0.0015	0.0080	1.0000
27	0.3083	0.4493	0.1689	0.0552	0.0070	0.0018	0.0094	1.0000
28	0.2912	0.4383	0.1851	0.0642	0.0081	0.0021	0.0111	1.0000
29	0.2747	0.4246	0.2015	0.0743	0.0094	0.0024	0.0130	1.0000
30	0.2587	0.4086	0.2179	0.0859	0.0109	0.0028	0.0152	1.0000
31	0.2434	0.3903	0.2338	0.0989	0.0126	0.0033	0.0178	1.0000
32	0.2287	0.3700	0.2488	0.1134	0.0145	0.0038	0.0208	1.0000
33	0.2147	0.3481	0.2624	0.1294	0.0166	0.0045	0.0243	1.0000
34	0.2013	0.3249	0.2742	0.1470	0.0191	0.0052	0.0284	1.0000
35	0.1885	0.3007	0.2837	0.1661	0.0219	0.0060	0.0332	1.0000
36	0.1763	0.2760	0.2905	0.1865	0.0250	0.0069	0.0388	1.0000
37	0.1648	0.2512	0.2943	0.2080	0.0285	0.0080	0.0452	1.0000
38	0.1539	0.2267	0.2950	0.2303	0.0324	0.0092	0.0526	1.0000
39	0.1436	0.2028	0.2923	0.2529	0.0367	0.0105	0.0612	1.0000
40	0.1338	0.1799	0.2864	0.2754	0.0413	0.0120	0.0711	1.0000

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
41	0.1247	0.1581	0.2775	0.2972	0.0464	0.0137	0.0824	1.0000
42	0.1160	0.1377	0.2659	0.3176	0.0518	0.0155	0.0954	1.0000
43	0.1079	0.1188	0.2520	0.3361	0.0574	0.0175	0.1102	1.0000
44	0.1003	0.1016	0.2362	0.3520	0.0633	0.0197	0.1269	1.0000
45	0.0932	0.0859	0.2192	0.3647	0.0693	0.0220	0.1457	1.0000
46	0.0866	0.0718	0.2014	0.3737	0.0752	0.0244	0.1669	1.0000
47	0.0803	0.0593	0.1834	0.3788	0.0809	0.0269	0.1903	1.0000
48	0.0745	0.0483	0.1655	0.3798	0.0863	0.0293	0.2163	1.0000
49	0.0691	0.0387	0.1482	0.3767	0.0910	0.0317	0.2447	1.0000
50	0.0640	0.0303	0.1317	0.3696	0.0950	0.0339	0.2755	1.0000
51	0.0593	0.0231	0.1162	0.3587	0.0980	0.0360	0.3086	1.0000
52	0.0549	0.0170	0.1020	0.3447	0.0999	0.0377	0.3438	1.0000
53	0.0508	0.0118	0.0890	0.3279	0.1007	0.0390	0.3808	1.0000
54	0.0470	0.0075	0.0772	0.3089	0.1002	0.0399	0.4193	1.0000
55	0.0435	0.0038	0.0667	0.2884	0.0984	0.0403	0.4587	1.0000
56	0.0403	0.0009	0.0575	0.2670	0.0955	0.0402	0.4987	1.0000
57	0.0372	0.0000	0.0493	0.2451	0.0916	0.0396	0.5387	1.0016
58	0.0344	0.0000	0.0421	0.2234	0.0868	0.0385	0.5782	1.0035
59	0.0318	0.0000	0.0359	0.2022	0.0814	0.0370	0.6168	1.0050
60	0.0294	0.0000	0.0306	0.1818	0.0754	0.0351	0.6539	1.0062
61	0.0271	0.0000	0.0260	0.1626	0.0693	0.0329	0.6892	1.0071
62	0.0251	0.0000	0.0220	0.1446	0.0630	0.0306	0.7225	1.0077
63	0.0232	0.0000	0.0186	0.1280	0.0568	0.0281	0.7534	1.0082
64	0.0214	0.0000	0.0157	0.1129	0.0509	0.0256	0.7820	1.0084
65	0.0197	0.0000	0.0132	0.0991	0.0452	0.0231	0.8081	1.0085
66	0.0182	0.0000	0.0112	0.0868	0.0399	0.0207	0.8317	1.0085

Data source: 2010-2015 CDS.

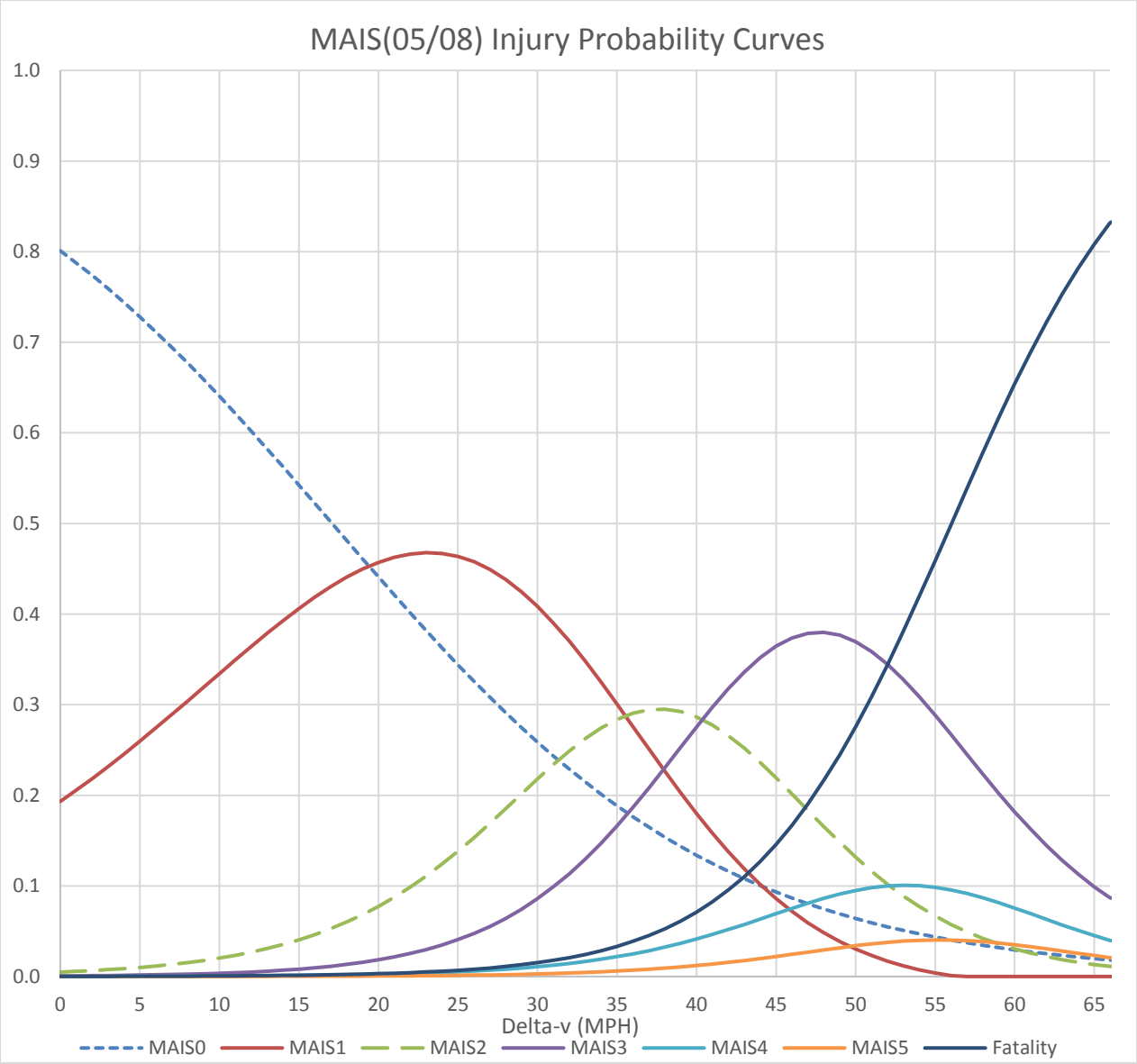

Figure 4-2. MAIS(05/08) Injury Probability Curves, All Crashes

4.2 Frontal Crashes

Parallel to the structure presented for the all-crash mode, Table 4-3 presents the mathematical expression of p_i^+ for frontal crashes. Figure 4-3 depicts these curves. Similarly, Table 4-4 tabulates p_is by delta V's, and Figure 4-4 is the graphic presentation of these curves.

Judging visually from the shape, peak, and the rise of these MAISi curves as well as the gaps and intersections among them, these curves are very similar to those for all crashes. This is probably due to the fact that frontal crashes comprise about 71.6 percent of the all-crash sample. The discernable differences between these two sets of curves are the peaks for MAIS2 and MAIS4 curves, although the peaks occur at slightly different delta V's. The peak magnitude of these two curves are slightly higher for frontal crashes compared with those for all crashes.

As indicated in the shaded cells in Table 4-4, negative p_is occurred also only in MAIS1 at delta V's higher than 60 mph, a range outside of delta V threshold setup (i.e., all cases above 60 mph were combined into 60 mph group) for the logistic regression. The impact of reassigning negatives was insignificant and primarily in area beyond 60 mph delta V. Therefore, the analysis did not perform rebalancing for frontal crashes, either. Again, the occurrence of negative p_is also was indicated by the two crossed curves on the right top corner in Figure 4-3.

Using the same example in all crashes, based on Table 4-4, occupants in frontal crashes that experienced a delta V of 40 mph would have a 30.3 percent probability of receiving MAIS2 injuries and 6.0 percent chance of being fatally injured. When delta V decreases to 40 mph, the chance of having MAIS2 injuries decreases to 15.1 percent while the chance of having fatal injuries also decreases to less than 1.0 percent.

Table 4-3. Mathematical Formula for MAIS+(05/08) Injury Probability Curves, Frontal Crashes

MAIS Level	Formula for Probability Curves
MAIS 0	$p(D)=1-\frac{e^{-1.4930+0.0854*D}}{1+e^{-1.4930+0.0854*D}}$
MAIS 1+	$p(D)=\frac{e^{-1.4930+0.0854*D}}{1+e^{-1.4930+0.0854*D}}$
MAIS 2+	$p(D)=\frac{e^{-4.9429+0.1425*D}}{1+e^{-4.9429+0.1425*D}}$
MAIS 3+	$p(D)=\frac{e^{-6.9774+0.1620*D}}{1+e^{-6.9774+0.1620*D}}$
MAIS 4+	$p(D)=\frac{e^{-8.4254+0.1586*D}}{1+e^{-8.4254+0.1586*D}}$
MAIS 5+	$p(D)=\frac{e^{-8.8355+0.1566*D}}{1+e^{-8.8355+0.1566*D}}$
Fatality	$p(D)=\frac{e^{-9.0422+0.1571*D}}{1+e^{-9.0422+0.1571*D}}$

D: delta V in mph.
Data source: 2010-2015 CDS.

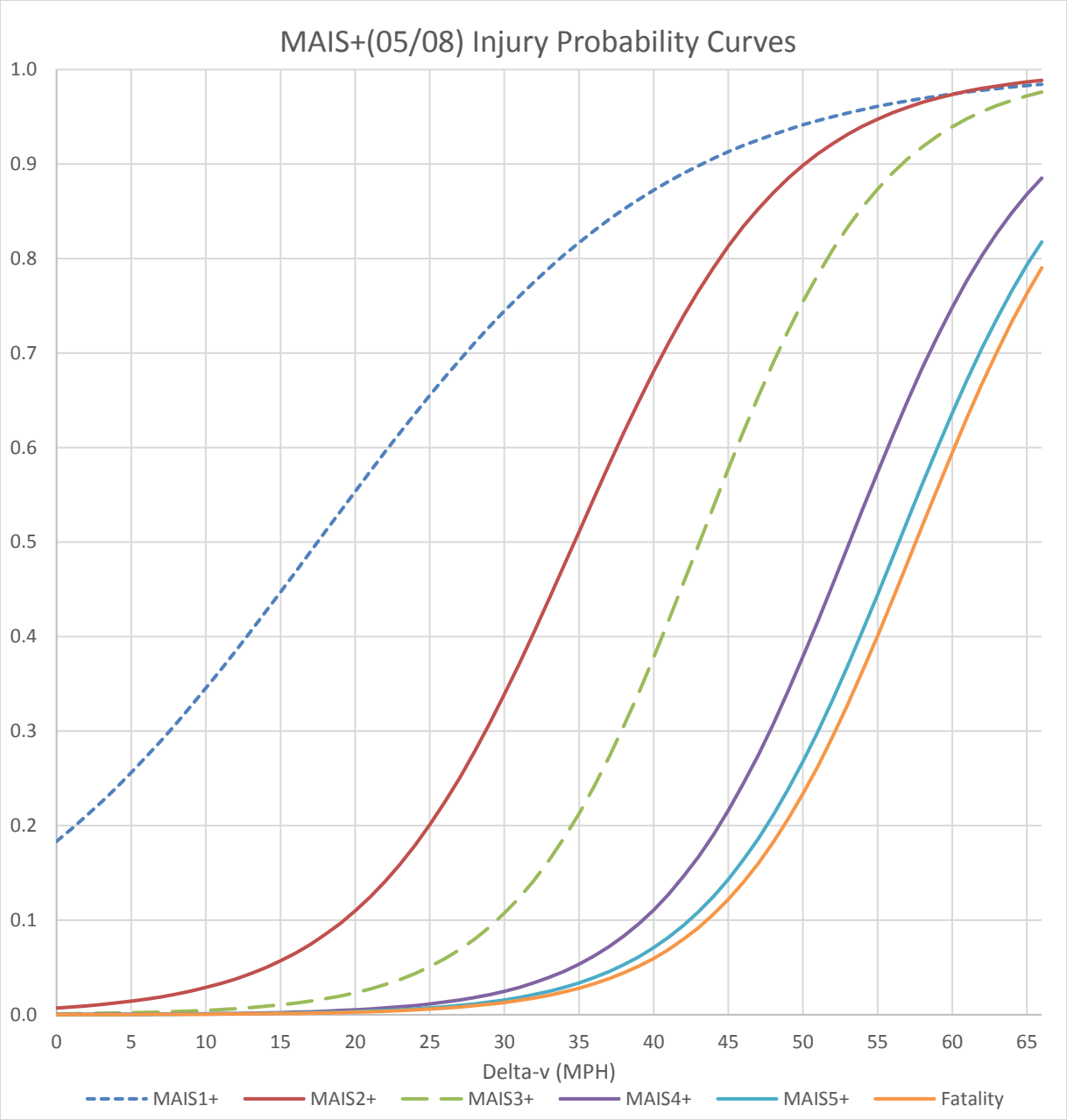

Figure 4-3. MAIS+(05/08) Injury Probability Curves, Frontal Crashes

Table 4-4. MAIS(05/08) Injury Probability Curves, Frontal Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
0	0.8165	0.1764	0.0062	0.0007	0.0001	0.0000	0.0001	1.0000
1	0.8034	0.1885	0.0071	0.0008	0.0001	0.0000	0.0001	1.0000
2	0.7895	0.2011	0.0081	0.0010	0.0001	0.0000	0.0002	1.0000
3	0.7750	0.2142	0.0093	0.0012	0.0001	0.0000	0.0002	1.0000
4	0.7598	0.2278	0.0107	0.0014	0.0001	0.0001	0.0002	1.0000
5	0.7438	0.2418	0.0122	0.0016	0.0002	0.0001	0.0003	1.0000
6	0.7272	0.2563	0.0140	0.0019	0.0002	0.0001	0.0003	1.0000
7	0.7100	0.2711	0.0161	0.0022	0.0002	0.0001	0.0004	1.0000
8	0.6921	0.2861	0.0184	0.0026	0.0003	0.0001	0.0004	1.0000
9	0.6736	0.3013	0.0211	0.0031	0.0003	0.0001	0.0005	1.0000
10	0.6545	0.3167	0.0241	0.0036	0.0004	0.0001	0.0006	1.0000
11	0.6350	0.3320	0.0276	0.0043	0.0004	0.0001	0.0007	1.0000
12	0.6150	0.3471	0.0315	0.0050	0.0005	0.0002	0.0008	1.0000
13	0.5945	0.3619	0.0359	0.0059	0.0006	0.0002	0.0009	1.0000
14	0.5738	0.3764	0.0409	0.0069	0.0007	0.0002	0.0011	1.0000
15	0.5528	0.3902	0.0465	0.0081	0.0008	0.0003	0.0012	1.0000
16	0.5316	0.4032	0.0529	0.0095	0.0010	0.0003	0.0015	1.0000
17	0.5103	0.4153	0.0600	0.0112	0.0012	0.0004	0.0017	1.0000
18	0.4890	0.4262	0.0679	0.0131	0.0014	0.0004	0.0020	1.0000
19	0.4676	0.4357	0.0768	0.0154	0.0016	0.0005	0.0023	1.0000
20	0.4465	0.4438	0.0865	0.0181	0.0019	0.0006	0.0027	1.0000
21	0.4255	0.4500	0.0973	0.0212	0.0022	0.0007	0.0032	1.0000
22	0.4047	0.4544	0.1090	0.0247	0.0026	0.0008	0.0037	1.0000
23	0.3843	0.4566	0.1218	0.0289	0.0030	0.0009	0.0044	1.0000
24	0.3643	0.4566	0.1355	0.0338	0.0036	0.0011	0.0051	1.0000
25	0.3448	0.4543	0.1501	0.0394	0.0042	0.0013	0.0060	1.0000
26	0.3258	0.4494	0.1656	0.0459	0.0049	0.0015	0.0070	1.0000
27	0.3073	0.4421	0.1817	0.0533	0.0057	0.0017	0.0082	1.0000
28	0.2894	0.4323	0.1982	0.0618	0.0067	0.0020	0.0095	1.0000
29	0.2722	0.4200	0.2150	0.0715	0.0079	0.0023	0.0111	1.0000
30	0.2556	0.4054	0.2316	0.0825	0.0092	0.0027	0.0130	1.0000
31	0.2397	0.3887	0.2476	0.0949	0.0107	0.0031	0.0152	1.0000
32	0.2245	0.3701	0.2628	0.1088	0.0125	0.0036	0.0177	1.0000
33	0.2100	0.3499	0.2765	0.1242	0.0146	0.0042	0.0207	1.0000
34	0.1961	0.3283	0.2885	0.1411	0.0170	0.0049	0.0241	1.0000
35	0.1830	0.3058	0.2982	0.1595	0.0197	0.0057	0.0281	1.0000
36	0.1706	0.2828	0.3053	0.1793	0.0228	0.0065	0.0327	1.0000
37	0.1589	0.2595	0.3094	0.2003	0.0263	0.0075	0.0381	1.0000
38	0.1478	0.2363	0.3104	0.2222	0.0304	0.0087	0.0443	1.0000
39	0.1373	0.2137	0.3081	0.2447	0.0349	0.0099	0.0514	1.0000
40	0.1275	0.1917	0.3026	0.2672	0.0399	0.0114	0.0596	1.0000

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
41	0.1183	0.1708	0.2939	0.2894	0.0455	0.0130	0.0691	1.0000
42	0.1097	0.1510	0.2825	0.3105	0.0516	0.0148	0.0799	1.0000
43	0.1016	0.1326	0.2686	0.3299	0.0583	0.0167	0.0922	1.0000
44	0.0941	0.1155	0.2528	0.3471	0.0654	0.0189	0.1062	1.0000
45	0.0871	0.0999	0.2355	0.3614	0.0729	0.0212	0.1221	1.0000
46	0.0805	0.0858	0.2172	0.3723	0.0806	0.0236	0.1400	1.0000
47	0.0744	0.0731	0.1985	0.3793	0.0885	0.0262	0.1600	1.0000
48	0.0687	0.0617	0.1799	0.3823	0.0963	0.0288	0.1822	1.0000
49	0.0635	0.0516	0.1617	0.3812	0.1038	0.0315	0.2068	1.0000
50	0.0586	0.0428	0.1442	0.3758	0.1108	0.0341	0.2338	1.0000
51	0.0540	0.0351	0.1277	0.3666	0.1169	0.0366	0.2631	1.0000
52	0.0498	0.0284	0.1123	0.3539	0.1220	0.0389	0.2946	1.0000
53	0.0459	0.0226	0.0983	0.3381	0.1259	0.0409	0.3283	1.0000
54	0.0423	0.0176	0.0855	0.3198	0.1284	0.0425	0.3638	1.0000
55	0.0390	0.0134	0.0740	0.2997	0.1293	0.0437	0.4009	1.0000
56	0.0359	0.0098	0.0638	0.2783	0.1286	0.0444	0.4392	1.0000
57	0.0331	0.0068	0.0548	0.2562	0.1264	0.0445	0.4781	1.0000
58	0.0305	0.0044	0.0469	0.2340	0.1227	0.0441	0.5174	1.0000
59	0.0280	0.0023	0.0401	0.2121	0.1179	0.0432	0.5564	1.0000
60	0.0258	0.0006	0.0341	0.1910	0.1119	0.0418	0.5948	1.0000
61	0.0237	0.0000	0.0289	0.1709	0.1052	0.0399	0.6320	1.0008
62	0.0218	0.0000	0.0245	0.1521	0.0979	0.0378	0.6677	1.0018
63	0.0201	0.0000	0.0207	0.1346	0.0903	0.0353	0.7016	1.0027
64	0.0185	0.0000	0.0175	0.1186	0.0826	0.0327	0.7335	1.0034
65	0.0170	0.0000	0.0147	0.1041	0.0750	0.0300	0.7630	1.0039
66	0.0156	0.0000	0.0124	0.0911	0.0676	0.0273	0.7902	1.0042

Data source: 2010-2015 CDS.

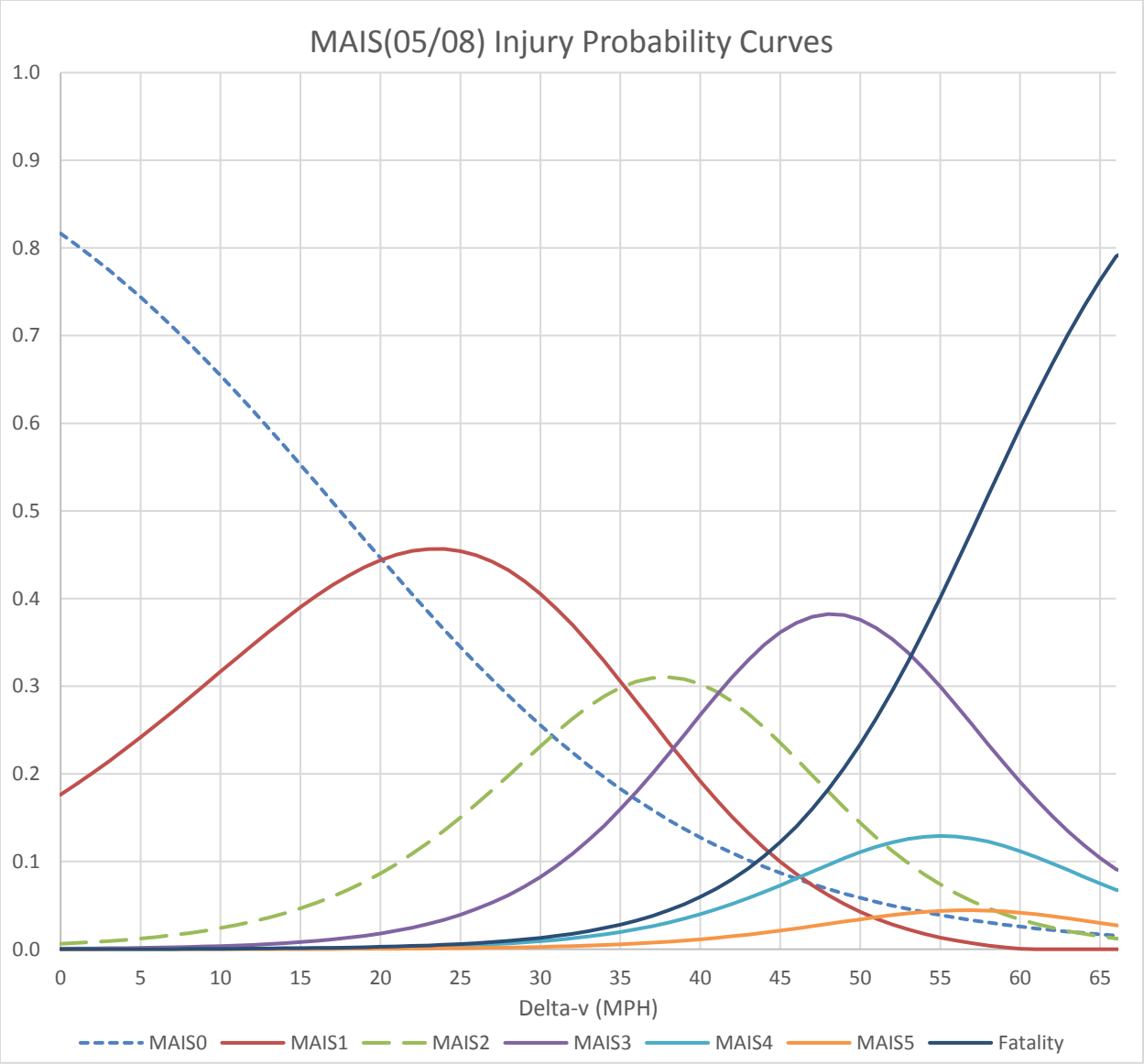

Figure 4-4. MAIS(05/08) Injury Probability Curves, Frontal Crashes

4.3 Rear-End Crashes

The probability curves for rear-end crashes showed a different pattern than all crashes and frontal crashes. The paired Table 4-5 and Figure 4-5 is for MAISi+ curves, and the Table 4-6 and Figure 4-6 pair is for MAIS curves. In the first figure, note that several MAISi+ curves intersect with each other and at lower delta V's than those shown for all and frontal crashes. These indicate more negative p_is occurred in more MAIS curves (shaded cells in Table 4-6). Furthermore, the gap between MAIS4+ and MAIS5+ curves is almost invisible implying that the probability of receiving an MAIS4+ injury is similar to that of receiving an MAIS5+ injury and that the number of MAIS 4 injuries is insufficient to make difference between MAIS4+ and MAIS5+ probability models. As a result, the probability of an MAIS 4 injury (p_4) in rear-end crashes is near 0 and is reflected by the flat MAIS4 curve shown in Figure 4-6 that hovers around the x-axis.

Rear-end crashes generally are of low injury severity and occurred in relatively lower delta V's compared with frontal crashes. This greatly affected the modeling outcome for high delta V's and for high injury severity curves. The curve interference and the closeness of several high MAIS level curves also demonstrated the inherent uncertainty for rear-end injury curves. Therefore, we caution users not to extrapolate the results for delta V's higher than 40 mph.

Note that p_is in Table 4-6 and corresponding graphics represent the outcome after the reassignment and rebalancing process. The rebalancing was implemented because the impact of reassigning negative p_is to 0 was larger than the rounding errors for certain delta V levels. An additional pair of table and figure was provided to illustrate the process of reassigning values and show its impact. Table 4-7, presents the probabilities before rebalancing and the paired Figure 4-7 depicts the corresponding curves. As shown in the shaded cells, simply setting negative probabilities to 0 would increase the p-total (i.e., the value under "Total" column) for certain delta V's by up to 5.6 percentage points (at 63 mph). The magnitude of the impact cannot be addressed by rounding errors. As stated earlier, rebalancing would start with the lowest delta V where at least one negative p_i occurred. For rear-end crashes, that is 48 mph.

Table 4-5. Mathematical Formula for MAIS+(05/08) Probability Curves, Rear-End Crashes

MAIS Level	Formula for Probability Curves
MAIS 0	$p(D)=1-\frac{e^{-1.8199+0.0671*D}}{1+e^{-1.8199+0.0671*D}}$
MAIS 1+	$p(D)=\frac{e^{-1.8199+0.0671*D}}{1+e^{-1.8199+0.0671*D}}$
MAIS 2+	$p(D)=\frac{e^{-6.1818+0.1482*D}}{1+e^{-6.1818+0.1482*D}}$
MAIS 3+	$p(D)=\frac{e^{-8.0329+0.1793*D}}{1+e^{-8.0329+0.1793*D}}$
MAIS 4+	$p(D)=\frac{e^{-11.8787+0.2210*D}}{1+e^{-11.8787+0.2210*D}}$
MAIS 5+	$p(D)=\frac{e^{-12.1944+0.2276*D}}{1+e^{-12.1944+0.2276*D}}$
Fatality	$p(D)=\frac{e^{-12.1982+0.2255*D}}{1+e^{-12.1982+0.2255*D}}$

D: delta V.
Data source: 2010-2015 CDS.

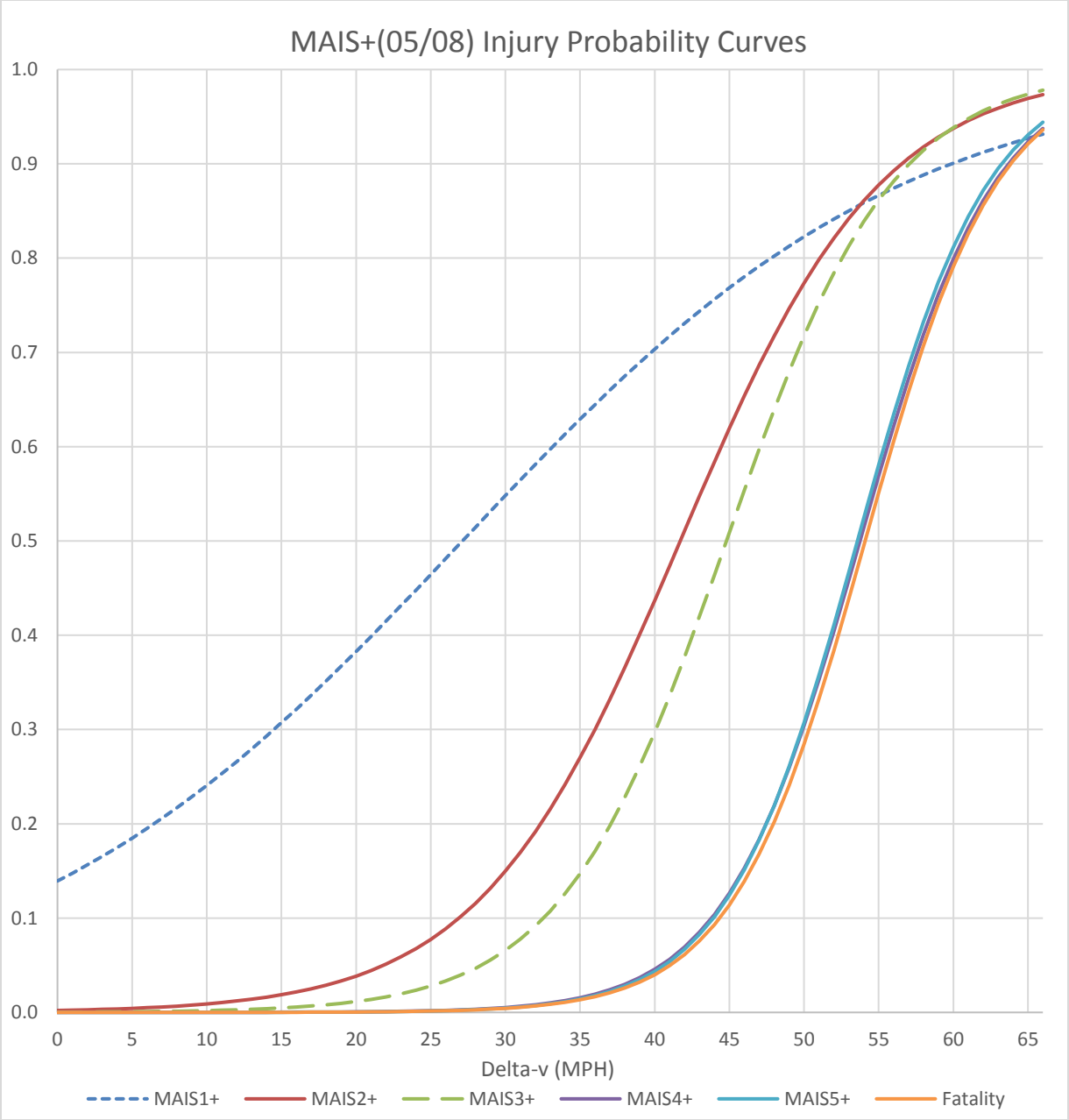

Figure 4-5. MAIS+(05/08) Injury Probability Curves, Rear-End Crashes

Table 4-6. MAIS(05/08) Injury Probability Curves, Rear-End Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
0	0.8606	0.1374	0.0017	0.0003	0.0000	0.0000	0.0000	1.0000
1	0.8523	0.1453	0.0020	0.0004	0.0000	0.0000	0.0000	1.0000
2	0.8437	0.1536	0.0023	0.0005	0.0000	0.0000	0.0000	1.0000
3	0.8346	0.1622	0.0027	0.0005	0.0000	0.0000	0.0000	1.0000
4	0.8251	0.1711	0.0031	0.0006	0.0000	0.0000	0.0000	1.0000
5	0.8152	0.1804	0.0035	0.0008	0.0000	0.0000	0.0000	1.0000
6	0.8049	0.1901	0.0041	0.0009	0.0000	0.0000	0.0000	1.0000
7	0.7942	0.2000	0.0047	0.0011	0.0000	0.0000	0.0000	1.0000
8	0.7830	0.2103	0.0054	0.0013	0.0000	0.0000	0.0000	1.0000
9	0.7714	0.2209	0.0062	0.0016	0.0000	0.0000	0.0000	1.0000
10	0.7593	0.2317	0.0071	0.0019	0.0000	0.0000	0.0000	1.0000
11	0.7468	0.2427	0.0081	0.0022	0.0000	0.0000	0.0001	1.0000
12	0.7339	0.2540	0.0093	0.0027	0.0000	0.0000	0.0001	1.0000
13	0.7206	0.2654	0.0107	0.0032	0.0000	0.0000	0.0001	1.0000
14	0.7069	0.2769	0.0122	0.0038	0.0000	0.0000	0.0001	1.0000
15	0.6928	0.2884	0.0140	0.0046	0.0000	0.0000	0.0001	1.0000
16	0.6784	0.3000	0.0160	0.0054	0.0000	0.0000	0.0002	1.0000
17	0.6636	0.3114	0.0182	0.0065	0.0001	0.0000	0.0002	1.0000
18	0.6484	0.3227	0.0208	0.0077	0.0001	0.0000	0.0003	1.0000
19	0.6330	0.3337	0.0237	0.0092	0.0001	0.0000	0.0004	1.0000
20	0.6173	0.3442	0.0269	0.0110	0.0001	0.0000	0.0005	1.0000
21	0.6013	0.3543	0.0306	0.0131	0.0001	0.0000	0.0006	1.0000
22	0.5851	0.3638	0.0346	0.0156	0.0001	0.0000	0.0007	1.0000
23	0.5687	0.3725	0.0391	0.0185	0.0002	0.0000	0.0009	1.0000
24	0.5522	0.3803	0.0441	0.0220	0.0002	0.0001	0.0011	1.0000
25	0.5355	0.3870	0.0496	0.0262	0.0002	0.0001	0.0014	1.0000
26	0.5188	0.3924	0.0556	0.0310	0.0003	0.0001	0.0018	1.0000
27	0.5020	0.3964	0.0620	0.0368	0.0003	0.0001	0.0022	1.0000
28	0.4853	0.3989	0.0690	0.0435	0.0004	0.0002	0.0028	1.0000
29	0.4685	0.3995	0.0764	0.0514	0.0005	0.0002	0.0035	1.0000
30	0.4519	0.3983	0.0841	0.0605	0.0006	0.0003	0.0044	1.0000
31	0.4353	0.3950	0.0921	0.0711	0.0007	0.0004	0.0054	1.0000
32	0.4189	0.3895	0.1001	0.0834	0.0008	0.0005	0.0068	1.0000
33	0.4027	0.3817	0.1081	0.0975	0.0009	0.0006	0.0085	1.0000
34	0.3866	0.3716	0.1158	0.1135	0.0011	0.0008	0.0107	1.0000
35	0.3708	0.3592	0.1228	0.1315	0.0013	0.0011	0.0133	1.0000
36	0.3553	0.3445	0.1291	0.1517	0.0014	0.0013	0.0166	1.0000
37	0.3401	0.3277	0.1342	0.1739	0.0016	0.0017	0.0207	1.0000
38	0.3252	0.3090	0.1378	0.1982	0.0018	0.0022	0.0259	1.0000
39	0.3107	0.2885	0.1397	0.2241	0.0020	0.0028	0.0322	1.0000
40	0.2965	0.2666	0.1397	0.2514	0.0022	0.0035	0.0400	1.0000

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
41	0.2827	0.2437	0.1377	0.2795	0.0024	0.0044	0.0496	1.0000
42	0.2693	0.2201	0.1336	0.3076	0.0024	0.0055	0.0614	1.0000
43	0.2563	0.1962	0.1276	0.3349	0.0024	0.0069	0.0757	1.0000
44	0.2437	0.1724	0.1198	0.3602	0.0023	0.0084	0.0931	1.0000
45	0.2315	0.1490	0.1105	0.3826	0.0020	0.0103	0.1140	1.0000
46	0.2198	0.1265	0.1002	0.4007	0.0016	0.0124	0.1388	1.0000
47	0.2085	0.1050	0.0892	0.4136	0.0008	0.0148	0.1680	1.0000
48	0.1976	0.0849	0.0779	0.4204	0.0000	0.0174	0.2019	1.0000
49	0.1870	0.0662	0.0666	0.4199	0.0000	0.0200	0.2404	1.0000
50	0.1767	0.0491	0.0558	0.4123	0.0000	0.0226	0.2834	1.0000
51	0.1669	0.0338	0.0458	0.3979	0.0000	0.0249	0.3307	1.0000
52	0.1575	0.0201	0.0367	0.3772	0.0000	0.0269	0.3816	1.0000
53	0.1485	0.0082	0.0286	0.3514	0.0000	0.0283	0.4349	1.0000
54	0.1397	0.0000	0.0216	0.3210	0.0000	0.0289	0.4887	1.0000
55	0.1305	0.0000	0.0156	0.2865	0.0000	0.0287	0.5387	1.0000
56	0.1221	0.0000	0.0106	0.2520	0.0000	0.0277	0.5876	1.0000
57	0.1144	0.0000	0.0066	0.2186	0.0000	0.0262	0.6342	1.0000
58	0.1072	0.0000	0.0035	0.1872	0.0000	0.0243	0.6778	1.0000
59	0.1006	0.0000	0.0010	0.1585	0.0000	0.0220	0.7178	1.0000
60	0.0945	0.0000	0.0000	0.1326	0.0000	0.0197	0.7533	1.0000
61	0.0886	0.0000	0.0000	0.1099	0.0000	0.0172	0.7842	1.0000
62	0.0833	0.0000	0.0000	0.0903	0.0000	0.0149	0.8115	1.0000
63	0.0783	0.0000	0.0000	0.0737	0.0000	0.0128	0.8353	1.0000
64	0.0736	0.0000	0.0000	0.0597	0.0000	0.0108	0.8559	1.0000
65	0.0692	0.0000	0.0000	0.0482	0.0000	0.0091	0.8735	1.0000
66	0.0651	0.0000	0.0000	0.0386	0.0000	0.0076	0.8887	1.0000

Data source: 2010-2015 CDS.

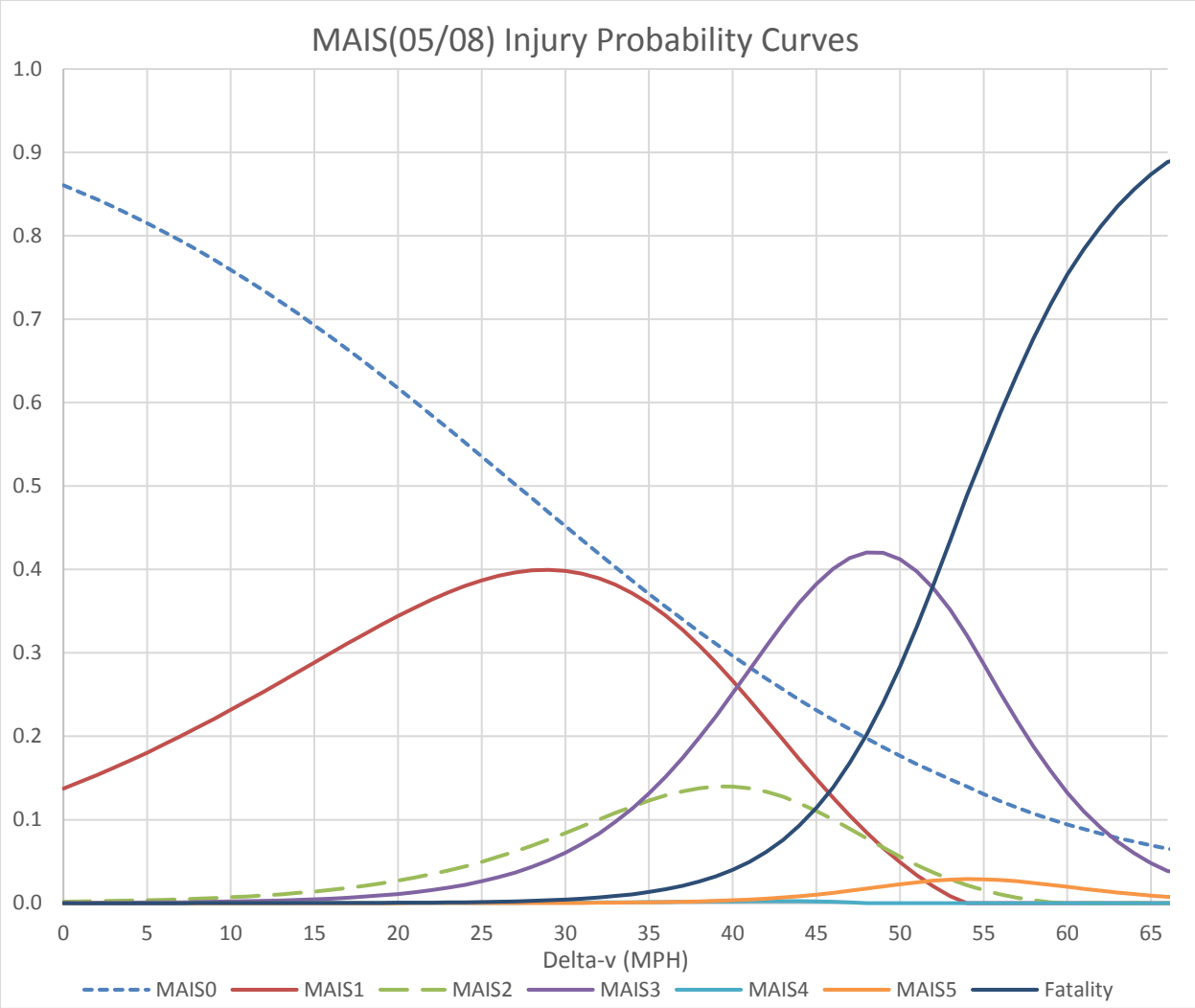

Figure 4-6. MAIS(05/08) Injury Probability Curves, Rear-End Crashes

Table 4-7. MAIS(05/08) Injury Probabilities Without Rebalancing, Rear-End Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
0	0.8606	0.1374	0.0017	0.0003	0.0000	0.0000	0.0000	1.0000
1	0.8523	0.1453	0.0020	0.0004	0.0000	0.0000	0.0000	1.0000
2	0.8437	0.1536	0.0023	0.0005	0.0000	0.0000	0.0000	1.0000
3	0.8346	0.1622	0.0027	0.0005	0.0000	0.0000	0.0000	1.0000
4	0.8251	0.1711	0.0031	0.0006	0.0000	0.0000	0.0000	1.0000
5	0.8152	0.1804	0.0035	0.0008	0.0000	0.0000	0.0000	1.0000
6	0.8049	0.1901	0.0041	0.0009	0.0000	0.0000	0.0000	1.0000
7	0.7942	0.2000	0.0047	0.0011	0.0000	0.0000	0.0000	1.0000
8	0.7830	0.2103	0.0054	0.0013	0.0000	0.0000	0.0000	1.0000
9	0.7714	0.2209	0.0062	0.0016	0.0000	0.0000	0.0000	1.0000
10	0.7593	0.2317	0.0071	0.0019	0.0000	0.0000	0.0000	1.0000

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
11	0.7468	0.2427	0.0081	0.0022	0.0000	0.0000	0.0001	1.0000
12	0.7339	0.2540	0.0093	0.0027	0.0000	0.0000	0.0001	1.0000
13	0.7206	0.2654	0.0107	0.0032	0.0000	0.0000	0.0001	1.0000
14	0.7069	0.2769	0.0122	0.0038	0.0000	0.0000	0.0001	1.0000
15	0.6928	0.2884	0.0140	0.0046	0.0000	0.0000	0.0001	1.0000
16	0.6784	0.3000	0.0160	0.0054	0.0000	0.0000	0.0002	1.0000
17	0.6636	0.3114	0.0182	0.0065	0.0001	0.0000	0.0002	1.0000
18	0.6484	0.3227	0.0208	0.0077	0.0001	0.0000	0.0003	1.0000
19	0.6330	0.3337	0.0237	0.0092	0.0001	0.0000	0.0004	1.0000
20	0.6173	0.3442	0.0269	0.0110	0.0001	0.0000	0.0005	1.0000
21	0.6013	0.3543	0.0306	0.0131	0.0001	0.0000	0.0006	1.0000
22	0.5851	0.3638	0.0346	0.0156	0.0001	0.0000	0.0007	1.0000
23	0.5687	0.3725	0.0391	0.0185	0.0002	0.0000	0.0009	1.0000
24	0.5522	0.3803	0.0441	0.0220	0.0002	0.0001	0.0011	1.0000
25	0.5355	0.3870	0.0496	0.0262	0.0002	0.0001	0.0014	1.0000
26	0.5188	0.3924	0.0556	0.0310	0.0003	0.0001	0.0018	1.0000
27	0.5020	0.3964	0.0620	0.0368	0.0003	0.0001	0.0022	1.0000
28	0.4853	0.3989	0.0690	0.0435	0.0004	0.0002	0.0028	1.0000
29	0.4685	0.3995	0.0764	0.0514	0.0005	0.0002	0.0035	1.0000
30	0.4519	0.3983	0.0841	0.0605	0.0006	0.0003	0.0044	1.0000
31	0.4353	0.3950	0.0921	0.0711	0.0007	0.0004	0.0054	1.0000
32	0.4189	0.3895	0.1001	0.0834	0.0008	0.0005	0.0068	1.0000
33	0.4027	0.3817	0.1081	0.0975	0.0009	0.0006	0.0085	1.0000
34	0.3866	0.3716	0.1158	0.1135	0.0011	0.0008	0.0107	1.0000
35	0.3708	0.3592	0.1228	0.1315	0.0013	0.0011	0.0133	1.0000
36	0.3553	0.3445	0.1291	0.1517	0.0014	0.0013	0.0166	1.0000
37	0.3401	0.3277	0.1342	0.1739	0.0016	0.0017	0.0207	1.0000
38	0.3252	0.3090	0.1378	0.1982	0.0018	0.0022	0.0259	1.0000
39	0.3107	0.2885	0.1397	0.2241	0.0020	0.0028	0.0322	1.0000
40	0.2965	0.2666	0.1397	0.2514	0.0022	0.0035	0.0400	1.0000
41	0.2827	0.2437	0.1377	0.2795	0.0024	0.0044	0.0496	1.0000
42	0.2693	0.2201	0.1336	0.3076	0.0024	0.0055	0.0614	1.0000
43	0.2563	0.1962	0.1276	0.3349	0.0024	0.0069	0.0757	1.0000
44	0.2437	0.1724	0.1198	0.3602	0.0023	0.0084	0.0931	1.0000
45	0.2315	0.1490	0.1105	0.3826	0.0020	0.0103	0.1140	1.0000
46	0.2198	0.1265	0.1002	0.4007	0.0016	0.0124	0.1388	1.0000
47	0.2085	0.1050	0.0892	0.4136	0.0008	0.0148	0.1680	1.0000
48	0.1977	0.0849	0.0779	0.4204	0.0000	0.0174	0.2019	1.0002
49	0.1872	0.0663	0.0667	0.4205	0.0000	0.0200	0.2407	1.0015
50	0.1772	0.0492	0.0560	0.4136	0.0000	0.0226	0.2843	1.0030
51	0.1677	0.0339	0.0460	0.3998	0.0000	0.0250	0.3323	1.0048
52	0.1585	0.0203	0.0369	0.3798	0.0000	0.0271	0.3841	1.0066

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality	Total
53	0.1498	0.0083	0.0289	0.3544	0.0000	0.0285	0.4386	1.0085
54	0.1414	0.0000	0.0219	0.3250	0.0000	0.0293	0.4947	1.0123
55	0.1335	0.0000	0.0159	0.2930	0.0000	0.0293	0.5509	1.0226
56	0.1259	0.0000	0.0110	0.2598	0.0000	0.0286	0.6058	1.0311
57	0.1187	0.0000	0.0069	0.2269	0.0000	0.0272	0.6582	1.0379
58	0.1119	0.0000	0.0036	0.1953	0.0000	0.0253	0.7070	1.0431
59	0.1054	0.0000	0.0011	0.1659	0.0000	0.0231	0.7514	1.0469
60	0.0992	0.0000	0.0000	0.1393	0.0000	0.0206	0.7911	1.0503
61	0.0934	0.0000	0.0000	0.1157	0.0000	0.0182	0.8260	1.0532
62	0.0878	0.0000	0.0000	0.0953	0.0000	0.0157	0.8560	1.0549
63	0.0826	0.0000	0.0000	0.0778	0.0000	0.0135	0.8817	1.0555
64	0.0777	0.0000	0.0000	0.0630	0.0000	0.0114	0.9032	1.0554
65	0.0730	0.0000	0.0000	0.0508	0.0000	0.0096	0.9212	1.0546
66	0.0686	0.0000	0.0000	0.0407	0.0000	0.0080	0.9361	1.0534

Data source: 2010-2015 CDS.

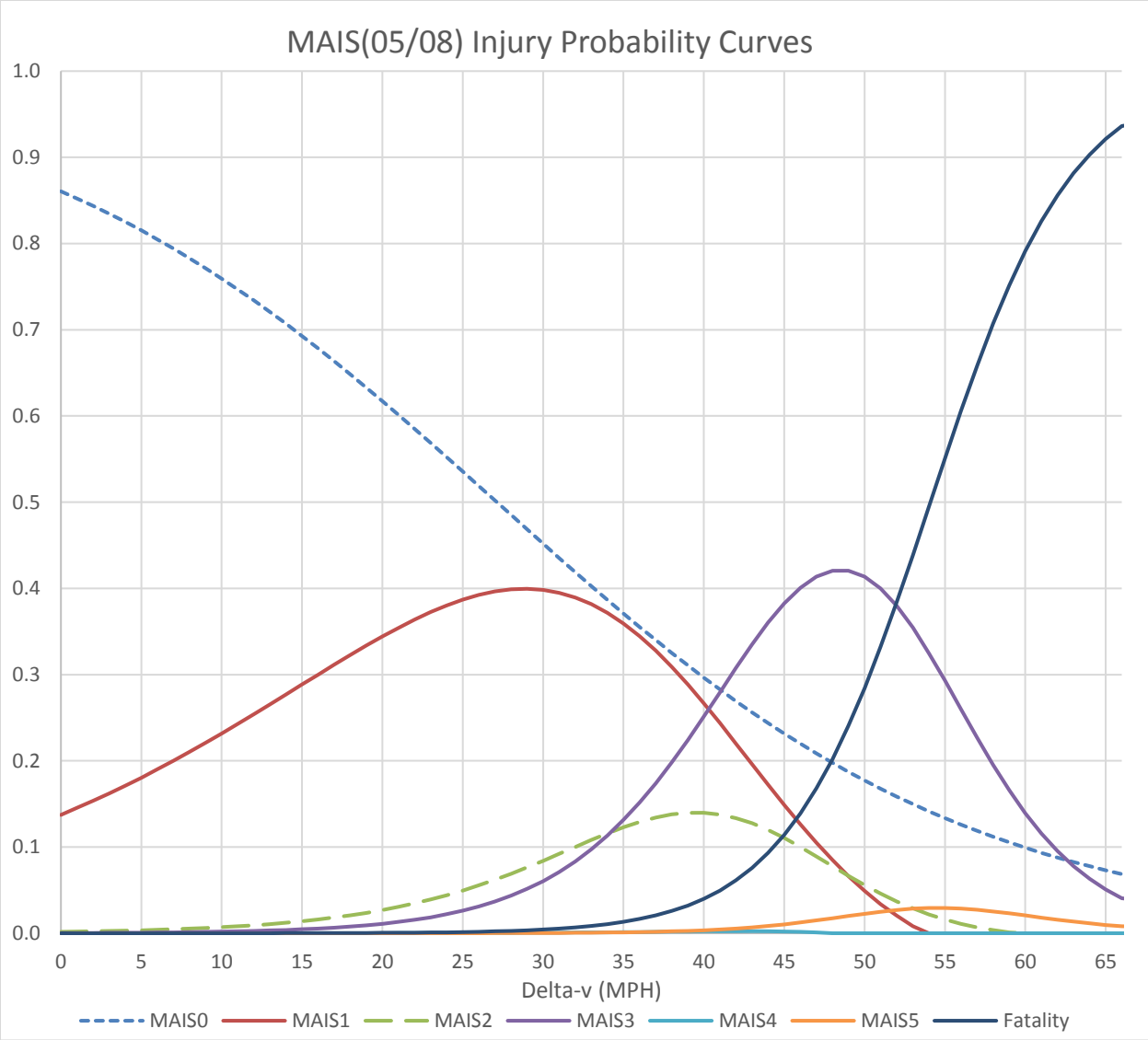

Figure 4-7. MAIS(05/08) Injury Probability Curves Without Rebalancing, Rear-End Crashes

4.4 Validation

This section visually compares the predicted probabilities from the logistic regression to a set of calculated MAIS percentages as described in Section 3.5, Validation Process. Figure 4-8 superimposes a MAIS probability curve from the logistic regression (in red) with a curved format of $p_{i,j}$s (blue jagged curves) for all crashes. Figure 4-9 is the same visual presentation for frontal crashes and Figure 4-10 is for rear-end crashes. The jagged blue lines fluctuate up and down greatly between delta V's and not as smooth as we expected. Logically, probabilities should increase with delta V's until a peak is reached then decrease gradually. This jagged pattern likely is due to small sample sizes and delta V estimation variations. It also highlights the limitations and uncertainty for any approach intending to fit MAISi curves directly from the 66 data points.

From these figures, one can observe that overall MAIS4 and MAIS5 have fewer cases for all three crash modes. Examining separately by crash modes, we can conclude that for all crashes and frontal crashes, the predicted injury curves generally follow the trend line of the 66 calculated percentages. For rear-end crashes, the fitting of MAIS3 and higher level curves combined with the pattern of corresponding $p_{i,j}$ further validate the concerns that were discussed earlier about the low severity of rear-end crashes and their occurrence on relatively low delta V's.

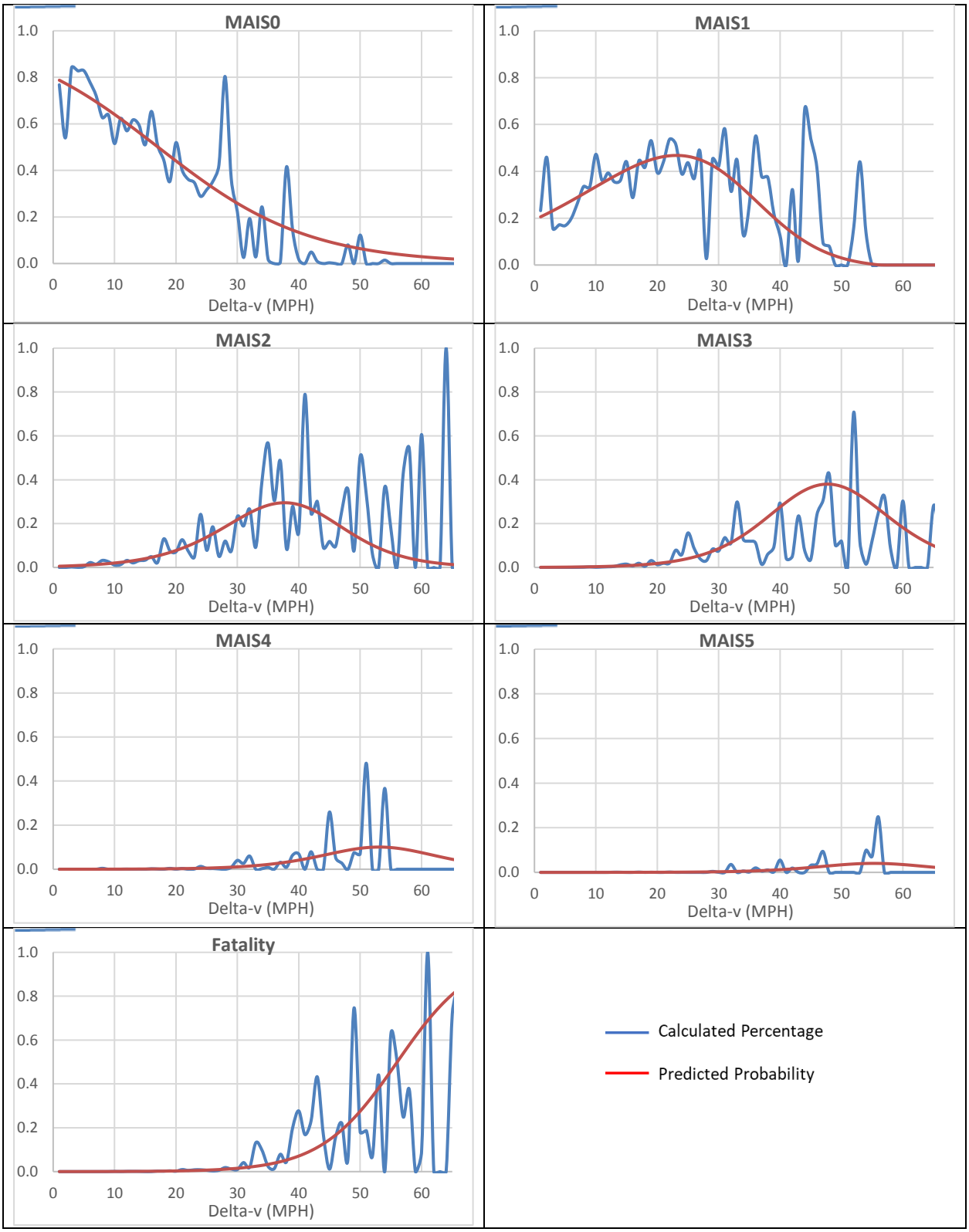

Figure 4-8. MAIS(05/08) Probabilities Versus Calculated Percentages, All Crashes

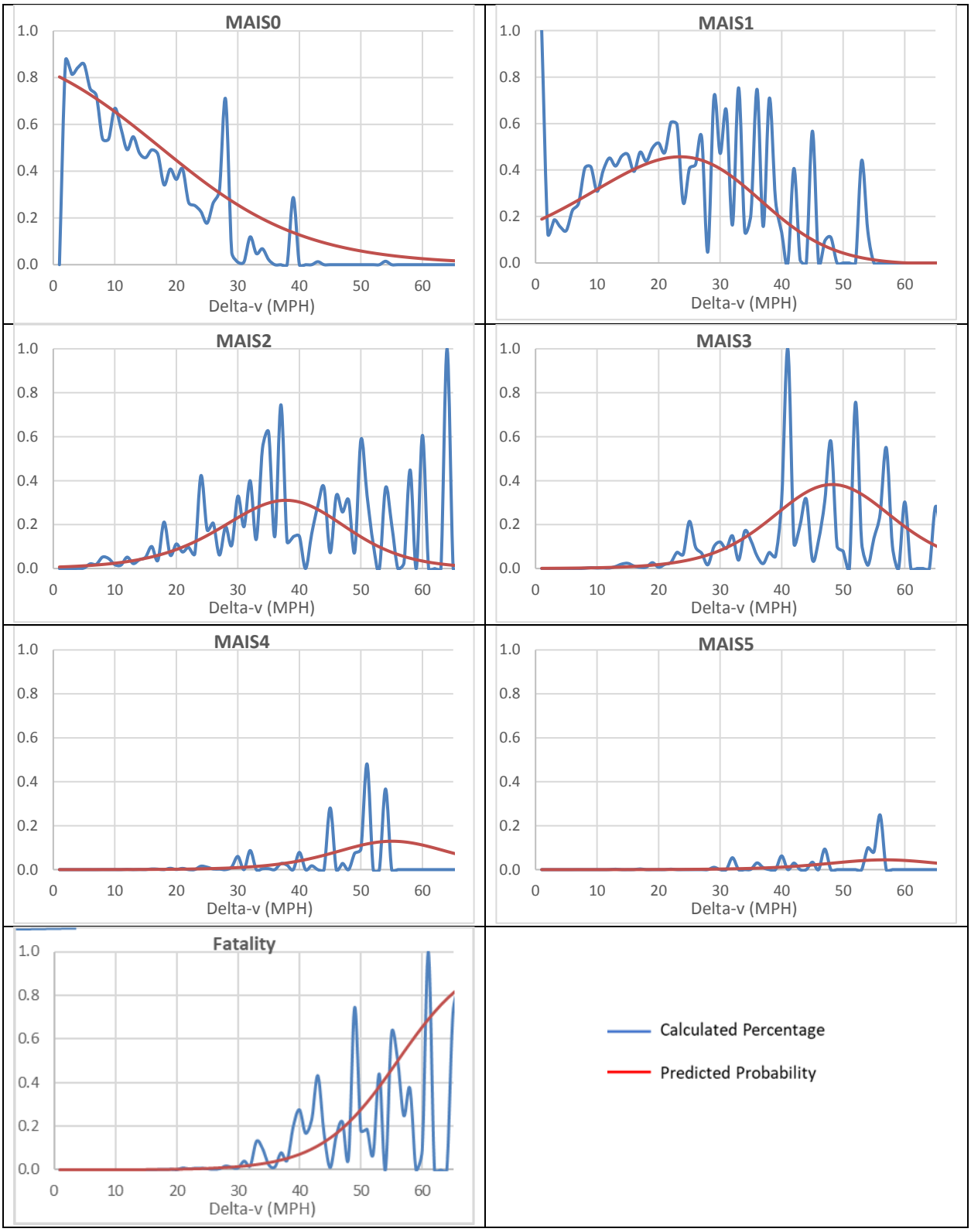

Figure 4-9. MAIS(05/08) Probabilities Versus Calculated Percentages, Frontal Crashes

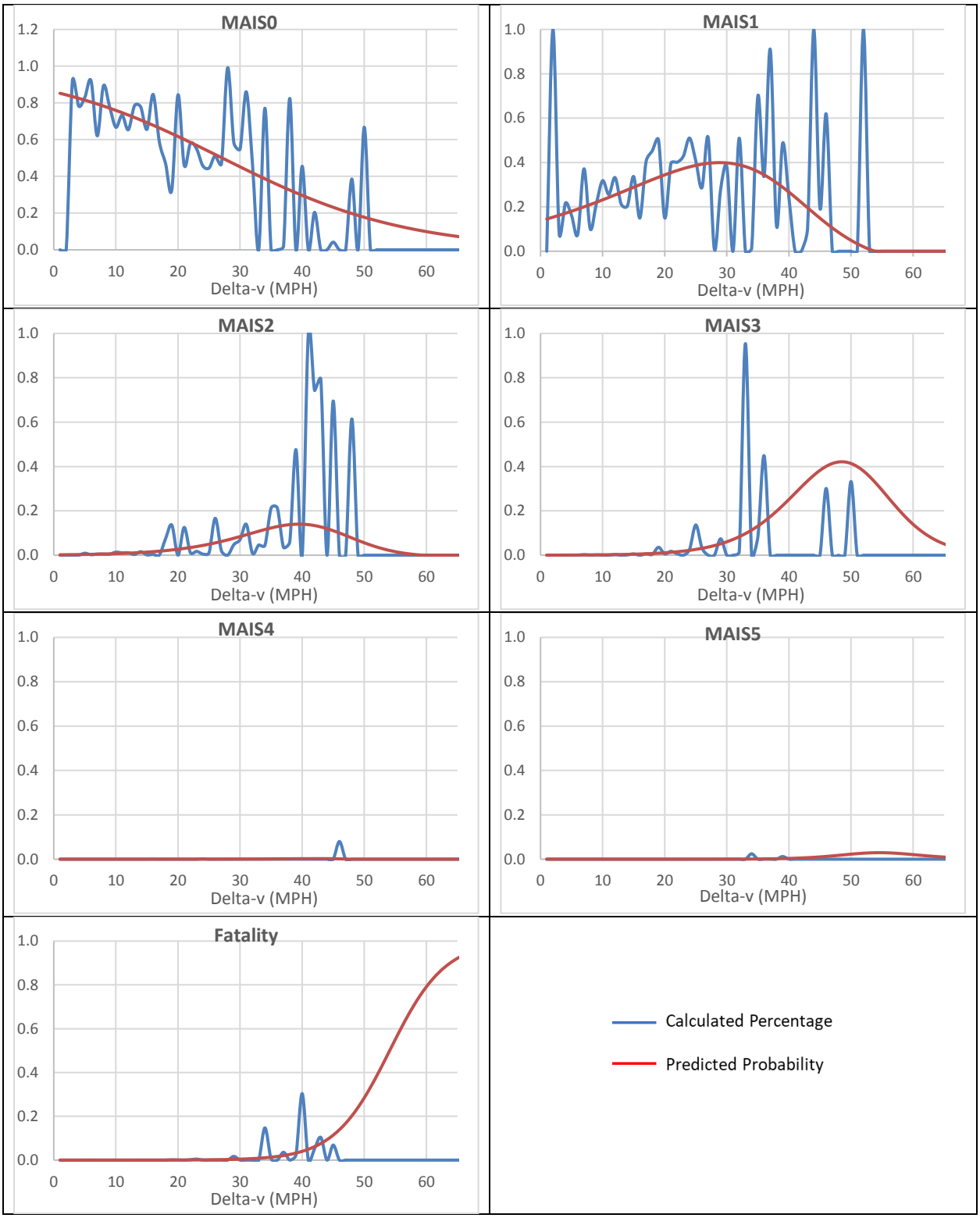

Figure 4-10. MAIS(05/08) Probabilities Versus Calculated Percentages, Rear-End Crashes

4.5 Summary

Based on the estimated parameters for MAISi+ probability curves, these curves are similar between all and frontal crashes, consequently, the derived MAISi curves also are similar between these two crash modes. Specifically, the similarity of these two sets of MAISi curves also can be observed from the figures portraying them through the shape, peak, and rise of these curves and the interaction among them. The discernable difference observed for MAISi curves from the presented figures is from the peaks for MAIS2-MAIS4 curves. These peaks are slightly higher for frontal crashes than those for all crashes, although they occur at slightly different delta V's. The similarity of these two sets of probability curves might be due to the fact that frontal crashes comprised the majority of all crashes.

In contrast, MAISi+ and MAISi probability curves for rear-end crashes showed a different pattern. Rear-end crashes generally result in low injury severity and occur at relatively lower delta V's compared to all and frontal crash types. Given the relative infrequency of high injury severity rear-end crashes, the predicted injury risks are subject to high levels of variation for high delta V's and for high injury severity curves (MAIS 3 to Fatality). The interference and the closeness of several high MAIS level curves also demonstrates the inherently uncertainty for rear-end injury curves. Therefore, we caution users not to extrapolate the results for delta V's higher than 40 mph for rear-end crashes.

We observed some anomalies especially for rear-end crashes. The anomalies were most likely due to modeling coefficient estimation errors, sample size limitations, delta V estimation errors, and the extrapolation of model results too far beyond the reasonable delta V range. The last is a special concern for rear-end crashes.

The superimposed plots in the Validation section showed that the predicted MAIS probability curves generally fit well with the calculated weighted percentages for all- and frontal crashes. Similar plots for rear-end crashes show that only lower MAIS level curves, i.e., MAIS0 to MAIS2, fit relatively well with calculated percentages. Other higher MAIS level curves deviated greatly from calculated percentages. These visual presentations further validated that the application of MAIS probability curves for rear-end crashes should be limited to lower MAIS severities and not be extended delta V's above 40 mph.

Finally, the occupant sample for the logistic regression analysis has several inherit limitations that affect the use of the established probability curves. First, by design CDS collects severe crashes. Second, also by design, 2010-2015 CDS record injury information only for occupants in vehicles 10 years old and newer when crash occurred. Third, many CDS cases are missing either MAIS or delta V values. Missing MAIS values are primarily the result of the injury reporting limitation imposed in this period of CDS. Missing delta V values are due to no vehicle inspection, crash out of scope, or insufficient data as discussed previously in the Sample Size section. Thus, the established injury curves might not properly reflect injury risks for a sample containing a sizeable number of older vehicles nor for a sample having a crash profile that is vastly different from the base sample. That the larger number of cases with missing values were not included in the model fitting might also bias the estimated risks.

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Appendix A: Estimated Coefficients

The SAS PROC SURVEYLOGISTIC procedure was used to establish the probability predicting models (SAS, 2015). It incorporates complex survey sample designs. This ensures the variance estimation accounts for the sample design of CDS and reduces the likelihood of false significance. This appendix summarizes the PROC SURVEYLOGISTIC generated Response Profile tables (i.e., the number of raw and weighted observations in each MIAS i+ model), model fit statistics (Model Fit Statistics and Test for Global Null Hypothesis tables), and the estimated coefficients with their standard errors, t Value statistics, and associated p Values for the determination of significance. The variance estimation method is the JACKKNIFF option that is provided by the SAS program. Note that the SAS fits linear logistic regression models for discrete response data by the method of maximum likelihood through Fisher scoring algorithm. All models are with 1 degree of freedom. However, the degrees of freedom for model error estimates is 12 (e.g., t-test). All of these Statistics are organized by crash modes. For each crash mode, model response profile (Table A-1, Table A-4, and Table A-7) is presented first then followed by the model fit statistics (Table A-2, Table A-5, and Table A-8) and coefficient estimates (Table A-3, Table A-6, and Table A-9).

In the model response profile tables, the "Total Frequency" column represents the number of occupants (i.e., raw cases) and "Total Weights" represents the corresponding weighted cases. Value of 1 represents an occupant having that level of injuries. For the model fit tables, Akaike Information Criterion (AIC), Schwarz Criterion (SC), and the negative two times the Log-Likelihood (-2 Log L) were used to assess the model fit based on the likelihood for fitting a model with intercepts only and for fitting a model with both intercepts and delta V. AIC and SC are deviants of -2 Log L. The bottom half of these tables "Test for Global Null Hypothesis" provide the outcome from the Likelihood Ratio, Score, and Wald tests that tested if at least one of the predictors' regression coefficient is not equal to zero in the model. From the estimated coefficient tables, the estimated value for Intercept and Delta V under the "Coefficient" column represent a_{i0} and a_{i1} in Equation 1, respectively.

A.1 All Crashes

Table A-1. MAIS+(05/08) Model Response Profile, All Crashes

Model	Value	Total Frequency	Total Weights
MAIS1+	1	6913	2216310.0
	0	4659	3276448.9
MAIS2+	1	1916	272824.9
	0	9656	5219934.0
MAIS3+	1	823	73857.5
	0	10749	5418901.3
MAIS4+	1	366	21973.1
	0	11206	5470785.8
MAIS5+	1	264	14293.8
	0	11308	5478465.0
Fatality	1	228	12313.8
	0	11344	5480445.1

Table A-2. Model Fit Statistics, All Crashes

Model		AIC	SC	-2LogL
MAIS1+	Intercept Model	7408679.1	7408692.6	7408677.1
	Full Model (Intercept + Delta V)	7145347.5	7145374.5	7145343.5
MAIS2+	Intercept Model	2170105.3	2170118.8	2170103.3
	Full Model	1861651.7	1861678.7	1861647.7
MAIS3+	Intercept Model	783230.90	783244.42	783228.90
	Full Model	617860.80	617887.83	617856.80
MAIS4+	Intercept Model	286502.83	286516.34	286500.83
	Full Model	217401.45	217428.49	217397.45
MAIS5+	Intercept Model	198687.79	198701.31	198685.79
	Full Model	144507.04	144534.08	144503.04
Fatality	Intercept Model	174841.44	174854.96	174839.44
	Full Model	125676.24	125703.28	125672.24

Test for Global Null Hypothesis

Model	Likelihood Ratio		Score		Wald	
	F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F
MAIS1+	911.49	<.0001	82.37	<.0001	117.65	<.0001
MAIS2+	384.84	<.0001	68.01	<.0001	139.85	<.0001
MAIS3+	255.61	<.0001	59.84	<.0001	231.81	<.0001
MAIS4+	57.19	<.0001	22.94	.0004	70.97	<.0001
MAIS5+	39.22	<.0001	24.51	.0003	81.09	<.0001
Fatality	36.17	<.0001	22.68	.0005	81.07	<.0001

Note: The degree of freedom for the F tests is 12

Table A-3. Estimates Coefficients for MAIS+(05/08) Probability Curves, All Crashes

Model	Variable	Coefficient	Standard Error	t-Value	Pr > |t|
MAIS1+	Intercept	-1.3925	0.1614	-8.63	<.0001
	Delta V	0.0815	0.0075	10.85	<.0001
MAIS2+	Intercept	-5.1331	0.2262	-22.69	<.0001
	Delta V	0.1479	0.0125	11.83	<.0001
MAIS3+	Intercept	-6.9540	0.1892	-36.75	<.0001
	Delta V	0.1637	0.0107	15.26	<.0001
MAIS4+	Intercept	-8.2070	0.4249	-19.32	<.0001
	Delta V	0.1564	0.0186	8.42	<.0001
MAIS5+	Intercept	-8.7927	0.4113	-21.38	<.0001
	Delta V	0.1598	0.0177	9.00	<.0001
Fatality	Intercept	-8.9819	0.4140	-21.69	<.0001
	Delta V	0.1603	0.0178	9.00	<.0001

Note: The degree of freedom for the t tests is 12.

A.2 Frontal Crashes

Table A-4. MAIS+(05/08) Model Response Profile, Frontal Crashes

Model	Value	Total Frequency	Total Weights
MAIS1+	1	5150	1561323.3
	0	3318	2373323.3
MAIS2+	1	1470	221884.9
	0	6998	3712761.6
MAIS3+	1	600	53998.5
	0	7868	3880648.1
MAIS4+	1	243	15075.9
	0	8225	3919570.6
MAIS5+	1	172	10235.8
	0	8296	3924410.8
Fatality	1	148	8697.9
	0	8320	3925948.7

Table A-5. Model Fit Statistics, Frontal Crashes

Model		AIC	SC	-2LogL
MAIS1+	Intercept Model	5285796.3	5285809.4	5285794.3
	Full Model (Intercept + Delta V)	5072627.1	5072653.5	5072623.1
MAIS2+	Intercept Model	1707040.8	1707054.0	1707038.8
	Full Model	1473696.2	1473722.6	1473692.2
MAIS3+	Intercept Model	570412.47	570425.65	570410.47
	Full Model	443464.60	443490.97	443460.60
MAIS4+	Intercept Model	197875.54	197888.72	197873.54
	Full Model	142808.29	142834.67	142804.29
MAIS5+	Intercept Model	142287.56	142300.74	142285.56
	Full Model	101303.21	101329.58	101299.21
Fatality	Intercept Model	123744.66	123757.84	123742.66
	Full Model	87022.446	87048.817	87018.446

Test for Global Null Hypothesis

Model	Likelihood Ratio		Score		Wald	
	F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F
MAIS1+	720.47	<.0001	74.01	<.0001	104.17	<.0001
MAIS2+	685.11	<.0001	80.46	<.0001	226.16	<.0001
MAIS3+	273.73	<.0001	69.67	<.0001	232.06	<.0001
MAIS4+	46.72	<.0001	22.05	.0005	69.90	<.0001
MAIS5+	31.29	.0001	24.75	.0003	65.00	<.0001
Fatality	29.21	.0002	21.23	.0006	66.63	<.0001

Note: The degree of freedom for the F tests is 12.

Table A-6. Estimates Coefficients for MAIS+(05/08) Probability Curves, Frontal Crashes

Model	Variable	Coefficient	Standard Error	t-Value	Pr > |t|
MAIS1+	Intercept	-1.4930	0.1000	-14.93	<.0001
	Delta V	0.0854	0.0084	10.21	<.0001
MAIS2+	Intercept	-4.9429	0.2074	-23.84	<.0001
	Delta V	0.1425	0.0095	15.04	<.0001
MAIS3+	Intercept	-6.9774	0.1851	-37.69	<.0001
	Delta V	0.1620	0.0106	15.23	<.0001
MAIS4+	Intercept	-8.4254	0.4241	-19.87	<.0001
	Delta V	0.1586	0.0190	8.36	<.0001
MAIS5+	Intercept	-8.8355	0.4873	-18.13	<.0001
	Delta V	0.1566	0.0194	8.06	<.0001
Fatality	Intercept	-9.0422	0.5011	-18.05	<.0001
	Delta V	0.1571	0.0193	8.16	<.0001

Note: The degree of freedom for the t tests is 12.

A.3 Rear-End Crashes

Table A-7. MAIS+(05/08) Model Response Profile, Rear-End Crashes

Model	Value	Total Frequency	Total Weights
MAIS1+	1	1069	425653.5
	0	1127	1055103.7
MAIS2+	1	199	31907.2
	0	1997	1448850.1
MAIS3+	1	76	10362.2
	0	2120	1470395.1
MAIS4+	1	26	768.5
	0	2170	1479988.7
MAIS5+	1	23	687.0
	0	2173	1480070.3
Fatality	1	21	645.2
	0	2175	1480112.1

Table A-8. Model Fit Statistics, Rear-End Crashes

Model		AIC	SC	-2LogL
MAIS1+	Intercept Model	1776492.2	1776504.4	1776490.2
	Full Model (Intercept + Delta V)	1733354.4	1733378.8	1733350.4
MAIS2+	Intercept Model	308010.44	308022.65	308008.44
	Full Model	272204.66	272229.08	272200.66
MAIS3+	Intercept Model	123491.19	123503.40	123489.19
	Full Model	101712.93	101737.35	101708.93

Model		AIC	SC	-2LogL
MAIS4+	Intercept Model	13164.586	13176.794	13162.586
	Full Model	9493.343	9517.759	9489.343
MAIS5+	Intercept Model	11921.704	11933.912	11919.704
	Full Model	8360.013	8384.429	8356.013
Fatality	Intercept Model	11277.559	11289.767	11275.559
	Full Model	7995.655	8020.071	7991.655

Test for Global Null Hypothesis

Model	Likelihood Ratio		Score		Wald	
	F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F
MAIS1+	140.04	<.0001	16.29	.0017	30.32	.0001
MAIS2+	18.93	.0009	17.30	.0013	30.92	.0001
MAIS3+	29.63	.0001	8.65	.0124	87.39	<.0001
MAIS4+	1.71	.2150	3.65	.0803	66.12	<.0001
MAIS5+	2.72	.1248	3.16	.1006	128.07	<.0001
Fatality	2.67	.1284	3.39	.0903	131.13	<.0001

Note: The degree of freedom for the F tests is 12.

Table A-9. Estimates Coefficients for MAIS+(05/08) Probability Curves, Rear-End Crashes

Model	Variable	Coefficient	Standard Error	t-Value	Pr > |t|
MAIS1+	Intercept	-1.8199	0.1840	-9.89	<.0001
	Delta V	0.0671	0.0122	5.51	.0001
MAIS2+	Intercept	-6.1818	0.5220	-11.84	<.0001
	Delta V	0.1482	0.0266	5.56	.0001
MAIS3+	Intercept	-8.0329	0.5053	-15.90	<.0001
	Delta V	0.1793	0.0192	9.35	<.0001
MAIS4+	Intercept	-11.8787	0.4150	-28.62	<.0001
	Delta V	0.2210	0.0272	8.13	<.0001
MAIS5+	Intercept	-12.1944	0.2767	-44.07	<.0001
	Delta V	0.2276	0.0201	11.32	<.0001
Fatality	Intercept	-12.1982	0.2750	-44.36	<.0001
	Delta V	0.2255	0.0197	11.45	<.0001

Note: The degree of freedom for the t tests is 12.

Appendix B: Weighted Sample Size by MAIS and delta V

This Appendix presents the weighted occupant counts for calculating MAIS percentages for delta V's from 1 to 66 mph. These are 2010 to 2015 CDS aggregated totals of those occupants with known delta V and MAIS. These totals also include occupants who were injured with unknown severity and those with unknown MAIS but with "fatal" as the treatment status (i.e., fatalities). Table B-1 and Table B-2 tabulate these occupants by delta V's and MAIS, for all crashes and frontal crashes, respectively. Table B-3 is for rear-end crashes. Due to the imputation process (i.e., the distribution of injured occupants whose severity were unknown), the total injury sample size (i.e., MAIS 1-5 and fatalities) is about 5 percent higher than those presented in the Response Profiles (Appendix A) and 2-3 percent higher if based on the total occupants (i.e., MAIS 0-5 and fatalities). The number 0 in these tables means missing data.

As shown in the following tables, MAIS counts fluctuated between delta V's. For injury occurrence, it is not surprising that MAIS 1-2 injuries were more likely to occur in lower delta V's and higher MAIS injuries would less likely to occur in delta V's lower than 15 mph. Overall, the sample sizes for delta V 45 mph and higher were sparse so were for MAIS 4, MAIS 5, and fatalities. Thus, the corresponding modeled results would come with increased uncertainty.

Table B-1. Total Weighted Occupant Counts by MAIS and delta V, All Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	350.09	105.68	0.00	0.00	0.00	0.00	0.00
2	1,568.75	1,335.72	0.00	0.00	0.00	0.00	0.00
3	17,093.66	3,853.43	57.29	0.00	0.00	0.00	0.00
4	95,462.20	20,300.16	60.75	0.00	0.00	0.00	0.00
5	94,557.10	20,995.82	427.80	0.00	0.00	0.00	0.00
6	245,835.00	66,022.17	7,415.85	83.87	0.00	0.00	4.97
7	375,201.60	154,042.71	8,603.60	362.58	96.24	28.22	12.61
8	193,928.30	106,964.80	10,270.46	350.84	1,371.40	0.00	5.13
9	385,450.00	212,096.07	16,703.89	1,561.30	85.01	0.00	90.14
10	237,644.00	221,841.21	5,007.86	382.33	26.56	0.00	399.45
11	383,295.00	227,343.30	8,235.93	1,270.28	193.98	0.00	147.19
12	262,123.90	190,913.77	15,613.38	1,492.57	319.05	69.52	510.42
13	122,173.90	72,910.23	4,283.24	968.97	13.21	198.89	229.59
14	154,172.30	104,091.10	8,866.85	3,438.38	131.41	241.20	253.96
15	83,077.70	73,267.76	5,531.25	2,520.48	21.37	0.00	0.00
16	212,016.30	100,274.17	17,168.55	2,492.79	752.43	45.40	80.68
17	123,681.90	113,058.24	5,665.33	4,878.45	256.27	349.61	605.04
18	44,235.60	43,824.76	13,674.84	549.24	23.53	4.09	201.62
19	47,450.42	73,266.83	10,574.79	4,348.83	566.64	108.12	492.05
20	35,921.90	28,726.74	5,165.40	921.95	39.21	0.00	118.03
21	43,069.47	48,201.80	13,887.60	2,095.10	397.65	0.00	1,029.38
22	32,013.61	49,982.69	6,943.92	1,881.50	0.00	142.85	525.92
23	5,649.84	8,785.06	809.01	1,340.55	18.95	0.00	142.43
24	13,315.64	19,085.31	11,890.51	2,866.67	632.76	11.77	424.43
25	12,639.51	17,822.39	3,191.14	6,424.56	163.14	0.00	253.12
26	4,575.45	5,747.71	2,892.10	1,362.14	53.87	0.00	45.55
27	22,624.54	26,134.57	2,751.13	2,130.73	83.34	0.00	332.56

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
28	13,602.54	532.71	2,361.22	604.55	0.00	0.00	361.19
29	7,111.83	8,850.41	1,454.11	1,643.98	176.26	87.55	231.35
30	1,999.37	3,804.12	2,102.20	680.10	364.32	4.06	84.61
31	128.80	2,894.17	940.65	677.10	131.65	0.00	205.09
32	1,329.70	2,495.91	2,102.84	874.27	474.06	282.11	156.10
33	77.92	1,240.78	255.67	826.68	0.00	0.00	364.63
34	1,432.19	768.90	2,332.63	765.82	16.03	37.29	583.62
35	145.89	2,009.40	4,390.41	928.38	66.83	10.64	183.84
36	0.00	1,327.09	734.94	270.63	0.00	48.54	32.07
37	22.04	1,401.54	1,800.96	53.20	118.18	21.29	293.36
38	841.91	763.23	172.78	123.66	18.38	22.12	90.90
39	355.39	545.16	696.03	235.86	159.92	4.98	498.70
40	27.16	198.81	256.13	465.47	109.70	87.40	438.83
41	0.00	0.00	147.79	7.83	0.00	0.00	31.57
42	81.31	541.68	416.65	84.97	133.65	32.44	388.30
43	19.42	41.47	604.48	471.60	0.00	0.00	867.07
44	0.00	356.60	48.97	41.83	0.00	0.00	91.20
45	6.31	1,095.12	241.30	74.26	527.47	63.50	22.83
46	0.00	100.90	23.53	58.24	13.03	9.16	38.22
47	0.00	73.00	199.14	236.40	21.91	72.55	171.02
48	37.08	37.35	165.17	197.33	0.00	0.00	25.72
49	0.00	0.00	16.29	22.01	16.29	0.00	160.82
50	92.97	0.00	424.54	100.77	58.92	0.00	151.21
51	0.00	0.00	73.74	0.00	106.83	0.00	41.59
52	0.00	24.36	9.15	107.39	0.00	0.00	10.74
53	0.00	58.78	0.00	15.69	0.00	0.00	58.78
54	9.69	91.01	243.06	9.69	243.06	65.55	0.00
55	0.00	0.00	56.25	39.03	0.00	22.99	198.70
56	0.00	0.00	0.00	21.99	0.00	22.03	44.49
57	0.00	0.00	203.01	154.38	0.00	0.00	118.89
58	0.00	0.00	28.65	4.52	0.00	0.00	19.82
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	1,061.44	530.72	0.00	0.00	158.91
61	0.00	0.00	0.00	0.00	0.00	0.00	26.66
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	18.68	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	86.52	0.00	0.00	220.52
66	0.00	0.00	0.00	74.75	0.00	0.00	431.19
Total	**3,276,449.19**	**2,040,246.66**	**209,274.86**	**54,213.72**	**8,002.48**	**2,093.87**	**12,706.80**

Source: 2010-2015 CDS.

Table B-2. Total Weighted Occupant Counts by MAIS and delta V, Frontal Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	0.00	105.68	0.00	0.00	0.00	0.00	0.00
2	918.57	197.52	0.00	0.00	0.00	0.00	0.00
3	12,865.60	3,508.25	0.00	0.00	0.00	0.00	0.00
4	67,035.40	11,841.00	59.21	0.00	0.00	0.00	0.00
5	56,541.00	9,696.70	158.18	0.00	0.00	0.00	0.00
6	147,601.00	42,890.44	3,829.97	0.00	0.00	0.00	4.86
7	277,534.00	109,234.56	7,396.68	258.79	0.00	27.88	12.46
8	151,337.00	81,880.19	10,131.94	307.51	58.40	0.00	5.11
9	279,675.00	158,168.86	16,045.98	1,552.87	63.33	0.00	0.00
10	135,942.00	67,458.30	3,688.61	376.51	26.15	0.00	393.37
11	302,611.00	182,282.65	7,302.72	1,144.17	54.37	0.00	0.00
12	181,071.00	132,581.40	12,843.57	538.29	257.06	69.85	260.17
13	77,223.10	53,340.51	2,402.83	968.32	13.21	198.75	198.78
14	114,856.00	85,897.28	7,637.77	3,256.19	133.74	0.00	195.93
15	70,311.60	53,555.36	4,092.71	2,245.36	21.26	0.00	0.00
16	193,802.00	67,725.72	15,799.75	1,746.16	452.74	45.05	7.31
17	94,827.90	78,771.50	4,401.42	1,288.21	259.62	354.18	294.42
18	25,070.70	29,585.76	12,991.61	361.78	0.00	0.00	157.60
19	41,622.20	49,787.90	9,589.59	2,381.45	521.53	0.00	208.92
20	25,202.20	23,974.75	4,687.75	361.22	26.47	0.00	61.47
21	34,744.30	37,387.52	8,201.55	1,692.57	360.14	0.00	999.63
22	22,981.20	42,267.81	5,979.33	1,880.37	0.00	125.84	143.85
23	5,201.95	7,240.12	800.72	770.63	4.48	0.00	116.27
24	12,869.10	12,117.92	11,938.27	2,236.35	441.81	0.00	300.77
25	7,332.05	9,404.84	2,798.99	6,264.77	161.66	0.00	212.94
26	3,988.77	5,507.27	2,072.08	981.65	28.70	0.00	47.17
27	16,922.60	24,687.68	2,036.05	2,088.09	75.06	0.00	280.84
28	5,865.54	542.24	1,906.52	170.77	0.00	0.00	378.67
29	1,514.17	7,067.28	890.90	934.63	103.05	87.74	205.07
30	1,513.00	3,575.43	1,931.93	655.57	325.43	0.00	43.16
31	48.43	2,706.35	798.69	375.79	0.00	0.00	205.09
32	1,172.98	1,025.18	2,051.03	759.40	443.85	276.35	141.71
33	77.92	1,242.01	219.19	827.50	0.00	0.00	44.96
34	1,432.19	528.37	2,113.72	659.23	16.08	0.00	292.41
35	145.89	1,961.63	4,176.59	923.36	29.13	10.64	106.83
36	0.00	1,226.53	231.82	90.85	0.00	48.65	32.14
37	22.04	1,393.18	1,751.20	52.88	64.92	21.16	130.68
38	841.91	646.17	141.18	66.88	18.40	0.00	68.86
39	355.39	335.57	178.92	69.24	0.00	0.00	297.26
40	0.00	189.91	195.71	417.93	104.78	83.49	359.48
41	0.00	0.00	147.79	7.83	0.00	0.00	0.00
42	81.31	305.21	118.43	86.42	13.07	22.22	226.09
43	19.42	20.42	597.96	304.58	0.00	0.00	744.64
44	0.00	356.60	48.97	41.83	0.00	0.00	41.83
45	6.31	1,095.23	241.32	74.27	527.52	63.50	12.30
46	0.00	0.00	24.83	9.67	0.00	0.00	40.33

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
47	0.00	73.00	199.14	236.40	21.91	72.55	171.02
48	37.08	37.35	143.14	197.33	0.00	0.00	0.00
49	0.00	0.00	16.29	22.01	16.29	0.00	160.82
50	92.97	0.00	343.62	94.00	54.96	0.00	141.05
51	0.00	0.00	73.74	0.00	106.83	0.00	41.59
52	0.00	0.00	8.47	57.20	0.00	0.00	9.94
53	0.00	58.78	0.00	15.69	0.00	0.00	58.78
54	9.69	91.01	243.06	9.69	243.06	65.55	0.00
55	0.00	0.00	56.25	39.03	0.00	22.99	164.01
56	0.00	0.00	0.00	21.99	0.00	22.03	44.49
57	0.00	0.00	7.41	154.38	0.00	0.00	118.89
58	0.00	0.00	19.82	4.52	0.00	0.00	19.82
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	1,061.44	530.72	0.00	0.00	158.91
61	0.00	0.00	0.00	0.00	0.00	0.00	26.66
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	18.68	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	86.52	0.00	0.00	220.52
66	0.00	0.00	0.00	48.21	0.00	0.00	362.19
Total	**2,373,323.47**	**1,405,574.96**	**176,844.99**	**40,747.57**	**5,049.01**	**1,618.42**	**8,972.06**

Source: 2010-2015 CDS.

Table B-3. Total Weighted Occupant Counts by MAIS and delta V, Rear-End Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	511.78	0.00	0.00	0.00	0.00	0.00
3	624.48	55.43	0.00	0.00	0.00	0.00	0.00
4	8,485.13	2,348.27	0.00	0.00	0.00	0.00	0.00
5	14,864.30	4,024.02	222.73	0.00	0.00	0.00	0.00
6	77,688.60	7,905.94	243.04	11.81	0.00	0.00	5.76
7	43,525.00	32,593.68	454.13	221.89	0.00	0.00	0.00
8	68,458.20	8,404.09	438.70	61.48	0.00	0.00	0.00
9	134,825.00	40,769.93	861.60	262.06	0.00	0.00	0.00
10	49,232.80	25,700.15	1,115.90	47.62	0.00	0.00	0.00
11	103,629.00	37,983.45	1,602.27	0.00	0.00	0.00	0.00
12	99,415.10	52,105.80	1,727.32	469.30	0.00	0.00	0.00
13	36,971.10	10,641.67	158.69	0.00	0.00	0.00	0.00
14	71,872.60	25,902.46	1,995.40	199.45	0.00	0.00	0.00
15	46,362.40	24,090.15	115.94	424.59	0.00	0.00	0.00
16	129,471.00	26,192.15	641.72	22.18	55.33	0.00	0.00
17	54,946.90	39,786.16	101.39	609.36	0.00	0.00	0.00
18	8,931.94	10,149.16	1,662.62	83.25	0.00	0.00	0.00
19	9,924.82	15,288.50	4,153.32	1,087.54	0.00	0.00	38.35
20	17,947.10	4,553.79	0.00	171.48	0.00	0.00	15.64
21	13,364.80	11,481.63	3,640.04	506.62	0.00	0.00	0.00

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
22	16,436.80	11,748.91	327.67	197.24	0.00	0.00	50.72
23	3,083.12	2,500.58	101.93	0.00	0.00	0.00	26.21
24	7,388.21	8,999.77	94.55	456.56	22.30	0.00	0.00
25	10,019.70	9,173.15	244.35	3,074.82	0.00	0.00	0.00
26	1,976.26	1,111.02	645.23	128.26	0.00	0.00	0.00
27	7,985.27	8,924.59	342.81	0.00	0.00	0.00	0.00
28	7,426.55	65.53	0.00	0.00	0.00	0.00	0.00
29	5,794.67	2,773.95	477.48	739.70	0.00	0.00	168.10
30	1,455.01	1,030.11	190.48	0.00	0.00	0.00	0.00
31	80.37	0.00	13.04	0.00	0.00	0.00	0.00
32	634.90	991.34	16.63	28.99	0.00	0.00	0.00
33	0.00	0.00	37.28	775.71	0.00	0.00	0.00
34	1,173.50	20.26	67.26	0.00	0.00	36.82	224.06
35	0.00	545.84	165.84	63.80	0.00	0.00	4.52
36	0.00	138.85	87.26	184.08	0.00	0.00	0.00
37	22.04	1,024.50	39.02	0.00	0.00	0.00	40.19
38	841.91	117.27	62.07	0.00	0.00	0.00	0.00
39	0.00	205.33	200.30	0.00	0.00	5.03	10.06
40	27.16	45.26	0.00	0.00	0.00	0.00	56.96
41	0.00	0.00	147.79	0.00	0.00	0.00	0.00
42	81.31	0.00	295.57	0.00	0.00	0.00	20.95
43	0.00	21.06	161.32	0.00	0.00	0.00	21.06
44	0.00	356.60	0.00	0.00	0.00	0.00	0.00
45	6.31	29.31	104.92	0.00	0.00	0.00	10.37
46	0.00	98.60	0.00	47.96	12.73	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	37.08	0.00	59.11	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	92.97	0.00	0.00	46.27	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	33.83	0.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**1,055,103.41**	**430,443.85**	**23,016.73**	**9,922.02**	**90.36**	**41.85**	**692.94**

Source: 2010-2015 CDS.

Appendix C: The Weighted Imputed MAIS Injury Percentages by delta V

Appendix C presents the weighted, imputed MAIS percentages that were derived from the occupant counts provided in Appendix B. These weighted percentages, a total of 66 data points for each MAIS level, were used to test the logistic regression model fit as shown in the Figures in the Validation section.

Table C-1 provides these data points for all crashes. Table C-2 and Table C-3 are for frontal- and rear-end crashes, respectively. The 0 percent means the value is either negligible or missing.

Table C-1. MAIS Percentage by delta V, All Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	76.81	23.19	0.00	0.00	0.00	0.00	0.00
2	54.01	45.99	0.00	0.00	0.00	0.00	0.00
3	81.38	18.35	0.27	0.00	0.00	0.00	0.00
4	82.42	17.53	0.05	0.00	0.00	0.00	0.00
5	81.53	18.10	0.37	0.00	0.00	0.00	0.00
6	76.98	20.67	2.32	0.03	0.00	0.00	0.00
7	69.70	28.61	1.60	0.07	0.02	0.01	0.00
8	61.98	34.19	3.28	0.11	0.44	0.00	0.00
9	62.57	34.43	2.71	0.25	0.01	0.00	0.01
10	51.07	47.68	1.08	0.08	0.01	0.00	0.09
11	61.77	36.64	1.33	0.20	0.03	0.00	0.02
12	55.65	40.53	3.31	0.32	0.07	0.01	0.11
13	60.85	36.31	2.13	0.48	0.01	0.10	0.11
14	56.85	38.38	3.27	1.27	0.05	0.09	0.09
15	50.53	44.56	3.36	1.53	0.01	0.00	0.00
16	63.70	30.13	5.16	0.75	0.23	0.01	0.02
17	49.77	45.50	2.28	1.96	0.10	0.14	0.24
18	43.15	42.75	13.34	0.54	0.02	0.00	0.20
19	34.68	53.55	7.73	3.18	0.41	0.08	0.36
20	50.67	40.52	7.29	1.30	0.06	0.00	0.17
21	39.63	44.35	12.78	1.93	0.37	0.00	0.95
22	34.99	54.63	7.59	2.06	0.00	0.16	0.57
23	33.74	52.46	4.83	8.01	0.11	0.00	0.85
24	27.61	39.57	24.66	5.94	1.31	0.02	0.88
25	31.21	44.01	7.88	15.87	0.40	0.00	0.63
26	31.17	39.16	19.71	9.28	0.37	0.00	0.31
27	41.85	48.35	5.09	3.94	0.15	0.00	0.62
28	77.90	3.05	13.52	3.46	0.00	0.00	2.07
29	36.37	45.26	7.44	8.41	0.90	0.45	1.18
30	22.12	42.09	23.26	7.52	4.03	0.04	0.94
31	2.59	58.15	18.90	13.60	2.64	0.00	4.12
32	17.24	32.35	27.26	11.33	6.14	3.66	2.02
33	2.82	44.86	9.24	29.89	0.00	0.00	13.18
34	24.13	12.95	39.29	12.90	0.27	0.63	9.83

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
35	1.89	25.98	56.76	12.00	0.86	0.14	2.38
36	0.00	54.99	30.45	11.21	0.00	2.01	1.33
37	0.59	37.77	48.54	1.43	3.19	0.57	7.91
38	41.41	37.54	8.50	6.08	0.90	1.09	4.47
39	14.24	21.84	27.89	9.45	6.41	0.20	19.98
40	1.71	12.56	16.18	29.40	6.93	5.52	27.71
41	0.00	0.00	78.95	4.18	0.00	0.00	16.87
42	4.84	32.26	24.82	5.06	7.96	1.93	23.13
43	0.97	2.07	30.16	23.53	0.00	0.00	43.27
44	0.00	66.21	9.09	7.77	0.00	0.00	16.93
45	0.31	53.93	11.88	3.66	25.97	3.13	1.12
46	0.00	41.51	9.68	23.96	5.36	3.77	15.72
47	0.00	9.43	25.73	30.54	2.83	9.37	22.10
48	8.01	8.07	35.70	42.65	0.00	0.00	5.56
49	0.00	0.00	7.56	10.22	7.56	0.00	74.66
50	11.22	0.00	51.25	12.16	7.11	0.00	18.25
51	0.00	0.00	33.19	0.00	48.09	0.00	18.72
52	0.00	16.06	6.04	70.82	0.00	0.00	7.08
53	0.00	44.11	0.00	11.78	0.00	0.00	44.11
54	1.46	13.75	36.71	1.46	36.71	9.90	0.00
55	0.00	0.00	17.75	12.31	0.00	7.25	62.69
56	0.00	0.00	0.00	24.84	0.00	24.89	50.27
57	0.00	0.00	42.62	32.41	0.00	0.00	24.96
58	0.00	0.00	54.07	8.53	0.00	0.00	37.40
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	60.62	30.31	0.00	0.00	9.07
61	0.00	0.00	0.00	0.00	0.00	0.00	100.00
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	100.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	28.18	0.00	0.00	71.82
66	0.00	0.00	0.00	14.78	0.00	0.00	85.23

Source: 2010-2015 CDS.

Table C-2. MAIS Percentage by delta V, Frontal Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	0.00	100.00	0.00	0.00	0.00	0.00	0.00
2	82.30	17.70	0.00	0.00	0.00	0.00	0.00
3	78.57	21.43	0.00	0.00	0.00	0.00	0.00
4	84.92	15.00	0.08	0.00	0.00	0.00	0.00
5	85.16	14.60	0.24	0.00	0.00	0.00	0.00
6	75.96	22.07	1.97	0.00	0.00	0.00	0.00
7	70.36	27.69	1.88	0.07	0.00	0.01	0.00
8	62.09	33.60	4.16	0.13	0.02	0.00	0.00
9	61.40	34.72	3.52	0.34	0.01	0.00	0.00

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
10	65.39	32.45	1.77	0.18	0.01	0.00	0.19
11	61.33	36.94	1.48	0.23	0.01	0.00	0.00
12	55.27	40.47	3.92	0.16	0.08	0.02	0.08
13	57.48	39.70	1.79	0.72	0.01	0.15	0.15
14	54.18	40.52	3.60	1.54	0.06	0.00	0.09
15	53.99	41.12	3.14	1.72	0.02	0.00	0.00
16	69.32	24.22	5.65	0.62	0.16	0.02	0.00
17	52.62	43.71	2.44	0.71	0.14	0.20	0.16
18	36.78	43.40	19.06	0.53	0.00	0.00	0.23
19	39.98	47.82	9.21	2.29	0.50	0.00	0.20
20	46.40	44.14	8.63	0.67	0.05	0.00	0.11
21	41.67	44.84	9.84	2.03	0.43	0.00	1.20
22	31.32	57.60	8.15	2.56	0.00	0.17	0.20
23	36.80	51.22	5.67	5.45	0.03	0.00	0.82
24	32.25	30.37	29.92	5.60	1.11	0.00	0.75
25	28.01	35.93	10.69	23.93	0.62	0.00	0.81
26	31.59	43.62	16.41	7.78	0.23	0.00	0.37
27	36.72	53.56	4.42	4.53	0.16	0.00	0.61
28	66.17	6.12	21.51	1.93	0.00	0.00	4.27
29	14.02	65.42	8.25	8.65	0.95	0.81	1.90
30	18.81	44.45	24.02	8.15	4.05	0.00	0.54
31	1.17	65.46	19.32	9.09	0.00	0.00	4.96
32	19.98	17.46	34.94	12.94	7.56	4.71	2.41
33	3.23	51.50	9.09	34.31	0.00	0.00	1.86
34	28.41	10.48	41.92	13.07	0.32	0.00	5.80
35	1.98	26.67	56.79	12.56	0.40	0.14	1.45
36	0.00	75.25	14.22	5.57	0.00	2.98	1.97
37	0.64	40.55	50.97	1.54	1.89	0.62	3.80
38	47.21	36.23	7.92	3.75	1.03	0.00	3.86
39	28.75	27.14	14.47	5.60	0.00	0.00	24.04
40	0.00	14.05	14.48	30.93	7.75	6.18	26.60
41	0.00	0.00	94.97	5.03	0.00	0.00	0.00
42	9.53	35.79	13.89	10.13	1.53	2.61	26.51
43	1.15	1.21	35.44	18.05	0.00	0.00	44.14
44	0.00	72.89	10.01	8.55	0.00	0.00	8.55
45	0.31	54.21	11.94	3.68	26.11	3.14	0.61
46	0.00	0.00	33.18	12.92	0.00	0.00	53.90
47	0.00	9.43	25.73	30.54	2.83	9.37	22.10
48	8.94	9.00	34.50	47.56	0.00	0.00	0.00
49	0.00	0.00	7.56	10.22	7.56	0.00	74.66
50	12.79	0.00	47.29	12.94	7.56	0.00	19.41
51	0.00	0.00	33.19	0.00	48.09	0.00	18.72
52	0.00	0.00	11.20	75.65	0.00	0.00	13.15
53	0.00	44.11	0.00	11.78	0.00	0.00	44.11
54	1.46	13.75	36.71	1.46	36.71	9.90	0.00
55	0.00	0.00	19.93	13.83	0.00	8.14	58.10
56	0.00	0.00	0.00	24.84	0.00	24.89	50.27

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
57	0.00	0.00	2.64	55.00	0.00	0.00	42.36
58	0.00	0.00	44.88	10.24	0.00	0.00	44.88
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	60.62	30.31	0.00	0.00	9.07
61	0.00	0.00	0.00	0.00	0.00	0.00	100.00
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	100.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	28.18	0.00	0.00	71.82
66	0.00	0.00	0.00	11.75	0.00	0.00	88.25

Source: 2010-2015 CDS.

Table C-3. MAIS Percentage by delta V, Rear-End Crashes

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	100.00	0.00	0.00	0.00	0.00	0.00
3	91.85	8.15	0.00	0.00	0.00	0.00	0.00
4	78.32	21.68	0.00	0.00	0.00	0.00	0.00
5	77.78	21.06	1.17	0.00	0.00	0.00	0.00
6	90.49	9.21	0.28	0.01	0.00	0.00	0.01
7	56.68	42.44	0.59	0.29	0.00	0.00	0.00
8	88.49	10.86	0.57	0.08	0.00	0.00	0.00
9	76.29	23.07	0.49	0.15	0.00	0.00	0.00
10	64.70	33.77	1.47	0.06	0.00	0.00	0.00
11	72.36	26.52	1.12	0.00	0.00	0.00	0.00
12	64.67	33.90	1.12	0.31	0.00	0.00	0.00
13	77.39	22.28	0.33	0.00	0.00	0.00	0.00
14	71.89	25.91	2.00	0.20	0.00	0.00	0.00
15	65.31	33.93	0.16	0.60	0.00	0.00	0.00
16	82.79	16.75	0.41	0.01	0.04	0.00	0.00
17	57.57	41.69	0.11	0.64	0.00	0.00	0.00
18	42.89	48.73	7.98	0.40	0.00	0.00	0.00
19	32.55	50.14	13.62	3.57	0.00	0.00	0.13
20	79.10	20.07	0.00	0.76	0.00	0.00	0.07
21	46.10	39.60	12.55	1.75	0.00	0.00	0.00
22	57.15	40.85	1.14	0.69	0.00	0.00	0.18
23	53.98	43.78	1.78	0.00	0.00	0.00	0.46
24	43.56	53.06	0.56	2.69	0.13	0.00	0.00
25	44.51	40.75	1.09	13.66	0.00	0.00	0.00
26	51.19	28.78	16.71	3.32	0.00	0.00	0.00
27	46.28	51.73	1.99	0.00	0.00	0.00	0.00
28	99.13	0.87	0.00	0.00	0.00	0.00	0.00
29	58.22	27.87	4.80	7.43	0.00	0.00	1.69
30	54.38	38.50	7.12	0.00	0.00	0.00	0.00
31	86.04	0.00	13.96	0.00	0.00	0.00	0.00

Delta-V (mph)	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatality
32	37.98	59.30	0.99	1.73	0.00	0.00	0.00
33	0.00	0.00	4.59	95.41	0.00	0.00	0.00
34	77.11	1.33	4.42	0.00	0.00	2.42	14.72
35	0.00	69.98	21.26	8.18	0.00	0.00	0.58
36	0.00	33.85	21.27	44.88	0.00	0.00	0.00
37	1.96	91.01	3.47	0.00	0.00	0.00	3.57
38	82.44	11.48	6.08	0.00	0.00	0.00	0.00
39	0.00	48.80	47.61	0.00	0.00	1.20	2.39
40	20.99	34.98	0.00	0.00	0.00	0.00	44.03
41	0.00	0.00	100.00	0.00	0.00	0.00	0.00
42	20.44	0.00	74.30	0.00	0.00	0.00	5.27
43	0.00	10.35	79.30	0.00	0.00	0.00	10.35
44	0.00	100.00	0.00	0.00	0.00	0.00	0.00
45	4.18	19.42	69.53	0.00	0.00	0.00	6.87
46	0.00	61.90	0.00	30.11	7.99	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	38.55	0.00	61.45	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	66.77	0.00	0.00	33.23	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	100.00	0.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: 2010-2015 CDS.

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