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# Frontal Crash Reconstruction Compared to Event Data Recorders in the Crash Investigation Sampling System Database and the Effect on Injury Risk Models

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## Abstract

This study compares statistical models for frontal crash injuries based on delta-v data reported by the vehicle event data recorder (EDR) with injury probability models based on delta-v reconstructed by Crash Investigation Sampling System (CISS) investigators. Injury probabilities and their follow-on use in advanced automatic crash notification (AACN) systems have traditionally been based on delta-v obtained through accident reconstruction of field crashes in the National Automotive Sampling System Crash Data System (NASS-CDS) database. Field delta-v from EDRs in the CISS database is an alternative source of information for crash injury probability modeling. In this study, frontal impact injury risk probabilities computed from EDR and reconstructed delta-v were compared. All data came from the years 2017–2021 of the CISS database, which contains EDR downloads and also reconstructed delta-v using crush measurements and NHTSA's WinSmash software. On average, CISS reconstructions overestimated delta-v below 16 kph and underestimated delta-v above 16 kph when compared to EDR delta-v. CISS also records detailed injury data using the 2015 Abbreviated Injury Scale (AIS) developed by the Association for the Advancement of Automotive Medicine (AAAM). Statistical analysis was performed using logistic regression to calculate MAIS 1+, MAIS 2+, MAIS 3+, and ISS 16+ injury probabilities. EDR-derived injury probabilities showed a lower risk for serious injury at delta-v above 48 kph when compared to probabilities based on CISS reconstructed delta-v. AACN algorithms are currently based on reconstructed delta-v but are triggered by EDR delta-v in the field. An analysis performed to determine the effect of the difference between the source of delta-v on the AACN notification threshold showed differences for AACN algorithms trained on EDR delta-v compared to reconstructed delta-v. The results of this study showed that the trigger threshold for AACN notification will differ by delta-v source, and this difference leads to variation in injury prediction.

## Keywords

AACN, CISS, EDR, Frontal collision, Injury risk, NASS

## Introduction

Frontal collisions are the most common impact mode for passenger vehicles, with over 60% of collisions having a principal direction of force (PDOF) between 11 o'clock and 1 o'clock [1]. Crash severity is commonly defined using the metric of impact-related change in velocity (delta-v). The delta-v of a crash is one of the required data elements recorded by vehicles equipped with event data recorders (EDRs) per Department of Transportation 49 CFR Part 563. Delta-v is also calculated based on post-crash evidence using accident reconstruction techniques such as those employed by investigators working for the National Highway Traffic Safety Administration's (NHTSA's) Crash Investigation Sampling System (CISS) database.

CISS is a nationally representative probability-based crash sampling system designed by the National Center for Statistics and Analysis (NCSA), overseen by NHTSA. CISS replaces the NASS-CDS database, which spanned from the 1970s to 2015.

CISS is designed as an update to NASS-CDS with improvements to the accuracy and quantity of data collected [2, 3, 4]. CISS investigates approximately 2,900 police-reported crashes per year. The crash data is collected throughout the United States and represents both urban and rural communities. A requirement for CISS investigation is that any vehicle involved in the crash is towed for any reason. The CISS database is intended to cover the full spectrum of crash severity. Currently, CISS includes five years of data from 2017 to 2021. Some of the advantages of CISS compared to NASS-CDS relate to measurements used to calculate delta-v and some upgrades relate to the coding of injury. For these reasons, injury probabilities derived from CISS may differ from those derived from NASS-CDS.

EDRs digitally preserve various parameters measured by vehicle sensors during a crash. EDR-equipped passenger vehicles manufactured on or after September 1, 2012, are subject to the Department of Transportation's 49 CFR 563—Event Data Recorders [5]. This federal regulation standardizes data elements recorded by EDRs, including delta-v. Additionally, the regulation requires an accuracy of ±10% for the delta-v data element. Previous studies have shown the accuracy of EDR-recorded delta-v compared to laboratory instrumentation to be within 6%–7% [6, 7]. Delta-v calculated in NASS-CDS frontal impact reconstructions has been compared to EDRs and shown to underestimate EDR delta-v by 2% to 27% [8, 9, 10].

The CISS database has an increased rate of EDR downloads compared to NASS-CDS. Between 2000 and 2010, NASS-CDS averaged 450 downloads per year. From 2011 to 2015 NASS-CDS averaged approximately 1,200 EDR downloads per year. CISS had a pilot year in 2016 with only 121 downloads but has averaged over 1,900 EDR downloads per year from 2017 to 2021. A majority of the EDR downloads analyzed in earlier research based on NASS-CDS were from General Motors (GM) vehicles. GM vehicles were supported by the BOSCH CDR download tools earlier than other manufacturers and are overrepresented in previous studies comparing NASS-CDS reconstructions to EDR data. CISS contains EDR downloads from a wider range of manufacturers, with GM, Toyota, Ford, Chrysler, Nissan, and Honda each having a significant percentage of downloads in the current study. Additionally, CISS vehicle model years are more recent, with the majority of CISS vehicles newer than the late 2012 compliance date of the 49 CFR 563 EDR regulation.

Injuries in CISS are coded using the AIS published by the Association for the Advancement of Automotive Medicine (AAAM). The CISS database uses the most recent version of the AIS dictionary revised in 2015. This is a change from NASS-CDS, which used different AIS scales over the decades, with AIS 2005 revision 2008 used in the most recent years. The AIS scale classifies injuries based on severity. AIS is a six-point scale, with AIS 1, 2, 3, 4, 5, and 6 corresponding to minor, moderate, serious, severe, critical, and maximal, respectively. The most severe injury in a patient with multiple injuries is called the Maximum AIS (MAIS). CISS also records the Injury Severity Score (ISS), which is the sum of the squares of the highest AIS scores in three different body regions.

The paired crash severity and injury outcome data in NASS-CDS and CISS provide a dose-response relationship that previous authors have used to derive injury risk curves [10, 11, 12]. These studies define human injury tolerance in real-world automotive collisions and are used in aspects of vehicle safety including research, design, and policymaking. The majority of prior studies used NASS-CDS reconstructed delta-v in the calculation of injury risk, though some have used EDR data [13, 14]. A 2008 study by Funk investigated the effect of error in reconstructed delta-v on injury risk curves by comparison to EDR data [9]. The study concluded that risk curves calculated using uncorrected NASS-CDS data were accurate at low delta-vs and conservative at higher delta-vs.

AACN systems transmit data over a cellular signal when an AACN-equipped vehicle is involved in a collision with the potential for serious injury. The information transmitted by AACN is used in EMS response and triage decisions. The indication of crash severity for AACN systems comes from onboard sensors tied to the EDR. The algorithms used by current AACN systems are based on risk models developed from the NASS-CDS database. A panel of experts in conjunction with the Centers for Disease Control and Prevention (CDC) and NHTSA has provided recommendations for AACN systems. The expert panel recommendations include definitions of serious injury and guidelines on the magnitude of the predictive utility of various triage criteria for use by the AACN. The 2021 recommendations include an ISS greater than or equal to 16 as one of the definitions of serious injury [15]. ISS is a NASS-CDS and CISS variable and has been used in AACN algorithms [16]. MAIS 3+ and other injury metrics have also been used in AACN algorithms [17, 18].

AACN algorithms predict injury based on crash parameters. The performance of a predictive algorithm is described by four terms: True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN). In terms of injury prediction, a TP is the result of correctly predicting an injury severe enough to warrant transport to a Level I trauma center. A TN correctly identifies a level of injury that does not require a Level I trauma center. A FP is a case where a serious injury was predicted for a person who did not sustain an injury serious enough to warrant Level I trauma center care. A FN is when serious injury is not predicted but is present.

The True Positive Rate (TPR), also known as Sensitivity, has the following definition:

$$\text{TPR} = \frac{\text{TP}}{\text{TP} + \text{FN}} = \text{Sensitivity}$$

The True Negative Rate (TNR), also known as Specificity, is defined as follows:

$$\text{TNR} = \frac{\text{TN}}{\text{TN} + \text{FP}} = \text{Specificity}$$

These terms are directly related to the triage function of AACN systems. The American College of Surgeons (ACS) has defined acceptable rates for overtriage and undertriage [19]. Overtriage occurs when minimally injured patients are transported to higher-level trauma centers. This is an example of a FP. Overtriage occurs more frequently with lower Specificity. Undertriage occurs when seriously injured patients are transported to lower-level trauma centers, which is an example of a FN. Undertriage occurs more frequently with lower Sensitivity. The ACS gives higher priority to the reduction of undertriage as it may result in preventable mortality or morbidity from delays in definitive care. The ACS recommendation is for a 5% undertriage rate. The false negative rate (FNR) is equal to 1 – TPR, indicating that an AACN system operating to this standard would have a TPR (sensitivity) of 95%. The ACS recommends an overtriage rate of 25% to 35%. The false positive rate (FPR) is equal to 1 – TNR (specificity), therefore the ACS overtriage recommendation indicates a specificity of 65% to 75%.

Predictive algorithms such as AACN use a cutoff point ranging from 0 to 1 to make the notification determination. The cutoff point is the predetermined point on the injury probability continuum of an event occurring given a certain set of inputs. Below the cutoff point, serious injury is not predicted, and a crash notification may not be sent. At or above the cutoff, serious injury is predicted, and crash notification is sent. Sensitivity and Specificity are functions of the cutoff, with Sensitivity highest at low values of cutoff and decreasing as the cutoff increases. Specificity is low at low cutoff values and increases as the cutoff increases. At low cutoff values true injury is predicted, but at the cost of a high number of false positives. At high cutoff values, false positives are reduced at the cost of a high number of false negatives and a reduction of true positives. The choice of the cutoff point is therefore a compromise that maximizes both Sensitivity and Specificity.

In 2008 an expert panel convened by the CDC recommended a cutoff at 20% risk of serious injury [20]. Since 2011 researchers have published studies indicating that a cutoff of 20% is associated with a sensitivity much lower than the desired 95% and have recommended cutoff values in the range of 2% to 10% in order to converge with the ACS-recommended 5% undertriage rate [21].

In 2021 the National Expert Panel on Field Triage gave recommendations for individual triage criteria [15]. They determined that triage criteria should be evaluated based on Positive Likelihood Ratios (+LR) and area under the receiver operating characteristic curve (AUROC). Positive Likelihood ratios are defined as TPR/FPR or Sensitivity/(1 − Specificity) [22]. The AUROC is the area under the curve of Sensitivity plotted against (1 − Specificity) for the full range of cutoff points [23]. The expert panel classified the magnitude of predictive utility as Large Effect: +LR ≥ 10, AUROC ≥ 0.8, Moderate Effect: +LR ≥ 5–9, AUROC 0.7–0.79, Small Effect: +LR ≥ 2–4, AUROC 0.6–0.69.

Previous studies have shown differences between reconstructed delta-v in NASS-CDS cases and the delta-v measured by EDRs. Existing AACN algorithms have been built on NASS-CDS reconstructed delta-v but use EDR delta-v as input [16, 17, 18]. In this study, we compare the effect of delta-v source in injury prediction models and its secondary effect on the use of those models in AACN algorithms.

# Methods

In the present study, injury risk curves were generated by performing logistic regression on weighted CISS data consisting of delta-v exposure and injury outcome. The survey design of CISS incorporates weighting factors for raw data to arrive at a nationally representative sample. The weighting system used by CISS is complex and nonlinear [24]. The PROC Survey Logistic function within the SAS statistical software accounts for the survey design and was used to perform the logistic regressions (SAS Institute Inc, Carey, NC). The predictive abilities of the injury risk curves were tested using raw CISS data. This situation is analogous to real-world AACN systems in which the AACN-predictive algorithms are based on weighted data but utilized on a singular basis when an AACN-equipped vehicle experiences a crash.

At the time of this study, five years of CISS data files were available (2017–2021). Within this data 29,143 occupants were present, with a CISS-weighted count of 24,124,289. There were 9,521 vehicles with EDR downloads, with a CISS-weighted count of 7,831,194. These data were queried and sorted using Microsoft Access and Microsoft Excel. Frontal impacts were defined by the CISS-reported PDOF between 300 and 60 degrees and the CISS variable CDCPLANE of F and PDOF between 330 and 30 degrees with CDCPLANE of L or R [10]. Multiple impacts and rollovers were excluded. Occupants aged 12 and up were included. Only occupants with known treatment status were included. Fatally injured occupants do not always have complete injury data in CISS and, as a consequence, some fatally injured occupants had no or low MAIS codes. A MAIS of 3 and ISS of 16 were assigned in these few cases. The CISS variable BELTUSE was used to determine whether an occupant was belted or not.

Within CISS, all vehicles do not have an EDR download. Conversely, some have an EDR download, but no CISS reconstruction. Some vehicles have both an EDR download and a CISS reconstructed delta-v. This characteristic resulted in three datasets. A dataset with all of the vehicles that met the above criteria and had both an EDR download and a CISS reconstructed delta-v ($n$ = 1,739). This dataset is referred to as the paired dataset. A second dataset consisted of all vehicles that met the criteria and had a CISS reconstructed delta-v only ($n$ = 2,040). A third dataset consisted of all vehicles with an EDR download and no CISS reconstructed delta-v ($n$ = 618). This resulted in a total of 2,357 vehicles with EDR downloads and 3,779 vehicles with a CISS reconstructed delta-v.

Using the paired dataset, the delta-v calculated by CISS reconstruction was compared to the delta-v measured by the EDR for each case. This comparison was performed within delta-v bins as well as using linear regression. A regression of intercept of zero was used in this analysis enabling comparison to previous studies [8, 9, 25, 26].

The paired dataset was also used to calculate injury probability models for MAIS 1+, MAIS 2+, MAIS 3+, and ISS 16+ based on EDR delta-v as well as CISS reconstructed delta-v. The models were calculated using binary logistic regression [23, 27]. Variables in the models included delta-v, belt status, and age above or below 55 years. The paired dataset was also used to compare the distribution of CISS delta-v to EDR delta-v for MAIS 3+ and ISS 16+ injury.

Predictive models for MAIS3+ and ISS 16+ injury were created to test the effects of using EDR delta-v as the input to AACN models developed with CISS reconstructed delta-v in frontal collisions. AACNs make notification calls based on a preset threshold, previously described as a delta-v of 24 kph or airbag deployment [16, 21]. A dataset consisting of all cases with a CISS reconstructed delta-v of 24 kph or higher or airbag deployment was used to train the algorithms ($n$ = 3,294). Cutoff points for the CISS-derived MAIS3+ and ISS16+ models were iterated to show the effect of cutoff on the metrics of Overtriage, Undertriage, AUROC, and positive likelihood ratios. Variables in the models were delta-v, belt use, age above or below 55 years, and gender. Although AACNs cannot currently tell the age or gender of an occupant, this information can be conveyed by voice upon contact. The models were then tested on a dataset containing all notification-level EDR cases ($n$ = 2,068) in order to characterize the performance of the CISS reconstruction-derived predictive models with EDR delta-v as the input. The cutoff ranged from 0.01 to 0.1 in this test.

The coefficients for the logistic regressions are given in Tables 4 and 5. The equation for plotting the regressions is shown below:

$$\frac{1}{1+e^{\left(-\left(\alpha+\beta 1*DV+\beta 2*Belt+\beta 3*Older\right)\right)}}$$

where alpha is the intercept value, beta1 is the delta-v coefficient, beta2 is the belt coefficient, and beta3 is the age 55 or older coefficient.

## Results

The resulting final datasets contained 4,397 vehicles with 5,525 occupants, with weighted estimates of 4,240,150 vehicles and 5,235,041 occupants [24]. The average model year was 2011 for vehicles without EDR downloads and 2014 for vehicles with downloads. Table 1 shows a list of the different vehicle makes and Table 2 shows the model year counts. The occupants were 52% female and 48% male. Weighted injury counts are shown in Table 3. Injury probabilities were calculated for MAIS1+, MAIS2+, MAIS3+, and ISS 16+. Preliminary analysis showed that vehicle type, PDOF within 60 degrees of straight ahead, gender, and seating row were not statistically significant at $p \leq 0.05$ and were not included in the final models. Belted status was significant for MAIS 2+ and higher injury risk. Age of 55 or older was significant at all injury levels. Belt usage was 79.7% overall. Women had a higher belt usage rate of 82.4%, compared to 76.4% for men.

The average EDR delta-v was 25.3 kph. The average CISS delta-v was 21.8 kph. The difference between CISS reconstructed delta-v and EDR delta-v was dependent on crash severity. At a delta-v up to 16 kph, CISS reconstructions overestimated the EDR-derived data. Between 16 and 24 kph the CISS reconstructions underestimated the EDR by 10%. Between 24 and 32 kph, the CISS underestimate was 19%. At 32 kph and above, the CISS underestimate was 25% (Figure 1). For the full range of delta-v, CISS reconstructions underestimated the EDR by 20% with $R^2$ 0.882 and root mean square error (RMSE) of 8.7 kph (Figure 2).

**TABLE 1** Manufacturer counts.

| Manufacturer | Total vehicles | With EDR |
|---|---|---|
| Stellantis | 518 | 274 |
| GM | 978 | 664 |
| Ford | 641 | 373 |
| Tesla | 3 | 3 |
| VW | 98 | 36 |
| BMW | 45 | 11 |
| Nissan | 423 | 244 |
| Honda | 461 | 208 |
| Isuzu | 1 | - |
| Tata | 6 | - |
| Mazda | 69 | 42 |
| Mercedes-Benz | 38 | 10 |
| Subaru | 115 | 37 |
| Toyota | 602 | 438 |
| Volvo | 19 | 4 |
| Mitsubishi | 44 | 10 |
| Suzuki | 3 | - |
| Hyundai | 331 | 3 |
| McLaren | 1 | - |
| Daimler truck | 1 | - |



The distribution of higher-severity injuries varied based on the delta-v source. Within the paired dataset CISS reconstructions had an average delta-v of 44.7 kph for MAIS 3+. The average delta-v for MAIS 3+ using EDR data was 57.1 kph. For ISS 16+ injury, the average CISS delta-v was 51 kph and the average EDR delta-v was 62.8 kph. These differences were statistically significant ($p < 0.0001$). The distributions for MAIS 3+ and ISS 16+ are shown in Figures 3 and 4. The data were normally distributed on the basis of a $t$-test.

Table 4 shows the regression results for the risk models. At the minor (MAIS 1+) injury level, the difference between the EDR and CISS reconstruction risk models was small, with the EDR model predicting a 2.8% lower risk of MAIS 1+ at a 19.3 kph delta-v (Figure 5). Belt use reduced risk for MAIS 1+, but this was not statistically significant.

For MAIS 2+ injury, the EDR-driven risk prediction was 16.2% lower than the CISS reconstructed model at a delta-v of 67.6 kph (Figure 6). The difference in risk did not exceed 5% until a delta-v of 41.8 kph. Belt use and age equal to or greater than 55 were significant variables for MAIS 2+.

The EDR-driven prediction of MAIS 3+ risk was 17.3% lower than the CISS reconstruction model at a delta-v of 77.2 kph. The difference in risk exceeded 5% at a delta-v of 53.1 kph (Figure 7). Belt use and age equal to or greater than 55 were significant variables for MAIS 3+.

The models for ISS 16+ showed the largest difference in risk, with the EDR model reporting 29.1% lower risk at a delta-v of 88.5 kph (Figure 8). The difference in risk did not exceed 5% until a delta-v of 61.2 kph. Belt use and age of 55 or greater were significant for ISS 16+ injury.

The AACN regression models are shown in Table 5. The range of undertriage and overtriage obtained with the MAIS 3+ model is shown in Figure 9. This model could not produce undertriage ≤5% with overtriage ≤35% on the CISS

**TABLE 2** Model year counts.

| Model year | Without EDR | With EDR |
|---|---|---|
| 1970s | 2 | - |
| 1980s | 13 | - |
| 1990 | 4 | - |
| 1991 | 8 | - |
| 1992 | 7 | - |
| 1993 | 9 | - |
| 1994 | 20 | - |
| 1995 | 11 | - |
| 1996 | 18 | - |
| 1997 | 29 | 2 |
| 1998 | 33 | 3 |
| 1999 | 36 | 2 |
| 2000 | 56 | 3 |
| 2001 | 85 | 20 |
| 2002 | 104 | 31 |
| 2003 | 124 | 29 |
| 2004 | 103 | 34 |
| 2005 | 145 | 51 |
| 2006 | 128 | 35 |
| 2007 | 140 | 23 |
| 2008 | 172 | 30 |
| 2009 | 130 | 22 |
| 2010 | 187 | 71 |
| 2011 | 207 | 100 |
| 2012 | 282 | 145 |
| 2013 | 330 | 239 |
| 2014 | 359 | 271 |
| 2015 | 390 | 293 |
| 2016 | 351 | 273 |
| 2017 | 365 | 275 |
| 2018 | 247 | 189 |
| 2019 | 172 | 120 |
| 2020 | 92 | 71 |
| 2021 | 38 | 25 |



**TABLE 3** Weighted injury counts.

| Injury | Weighted count |
|---|---|
| Uninjured | 3,737,938 |
| MAIS 1 | 1,224,477 |
| MAIS 2 | 200,570 |
| MAIS 3 | 58,700 |
| MAIS 4 | 8,467 |
| MAIS 5 | 5,016 |
| MAIS 6 | 1,824 |
| ISS 16+ | 29,429 |
| Fatal | 9,520 |



**FIGURE 1** EDR delta-v compared to CISS delta-v.

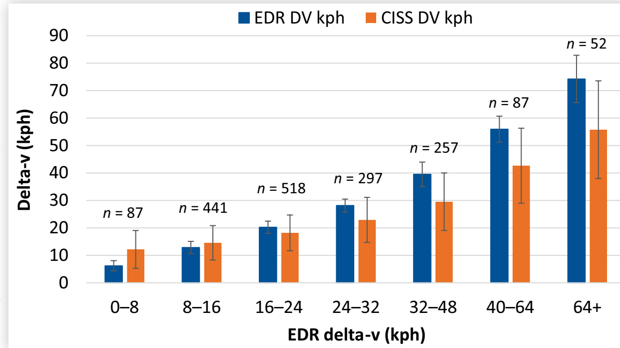





**FIGURE 2** EDR delta-v vs CISS delta-v. Points above the 1:1 diagonal are overestimates, points below are underestimates. Orange dotted line is the regression line.

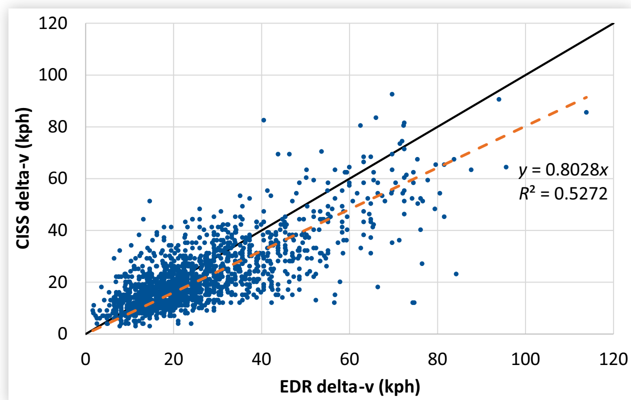
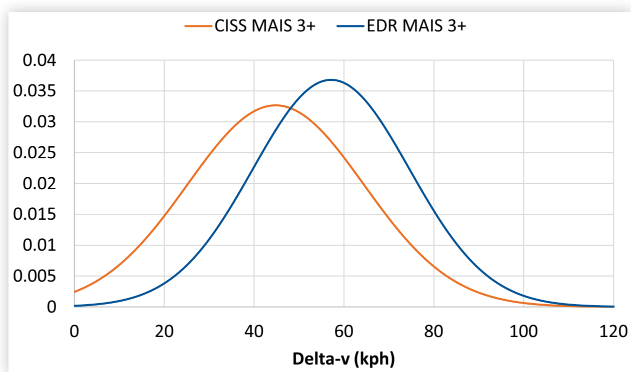





**FIGURE 3** MAIS 3+ delta-v distribution.






reconstructed delta-v dataset. The best compromise on the CISS reconstructed delta-v dataset was with a cutoff of 0.29. At this cutoff, the model had an undertriage of 19%, an overtriage of 35%, a positive likelihood ratio of 2.3, and an AUROC of 0.806 when tested on the CISS reconstructed delta-v dataset. When tested on the EDR dataset, the recommended undertriage and overtriage targets were achievable. When tested on the EDR dataset with a cutoff of 0.029 this model had undertriage of 4%, overtriage of 27%, positive likelihood ratio of 3.6, and AUROC of 0.789.

**FIGURE 4** ISS 16+ delta-v distribution.

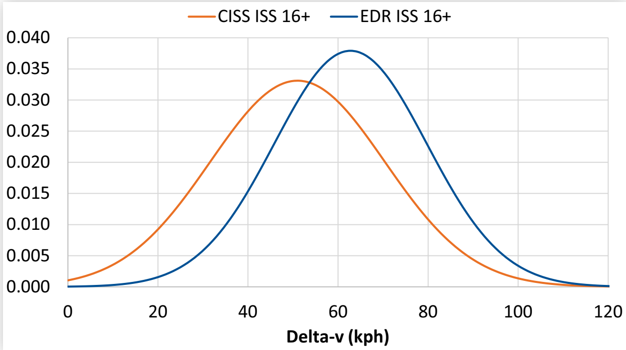





**TABLE 4** Injury risk regression models.

| | EDR MAIS 1+ | *P* value | CISS MAIS 1+ | *P* value |
|---|---|---|---|---|
| Intercept | −2.0367 | <0.0001 | −1.7973 | <0.0001 |
| DV | 0.1120 | 0.0015 | 0.1064 | <0.0001 |
| Belt | 0.2314 | 0.0809 | 0.2709 | 0.0938 |
| Older | −0.3290 | 0.0350 | −0.3265 | 0.0271 |
| | **EDR MAIS 2+** | ***P* value** | **CISS MAIS 2+** | ***P* value** |
| Intercept | −4.4628 | <0.0001 | −4.3665 | <0.0001 |
| DV | 0.1180 | 0.0003 | 0.1311 | <0.0001 |
| Belt | 0.6297 | 0.0006 | 0.6213 | 0.0040 |
| Older | −0.4465 | 0.0036 | −0.3716 | 0.0030 |
| | **EDR MAIS 3+** | ***P* value** | **CISS MAIS 3+** | ***P* value** |
| Intercept | −7.8367 | <0.0001 | −6.9336 | <0.0001 |
| DV | 0.1698 | <0.0001 | 0.1638 | <0.0001 |
| Belt | 0.7515 | 0.0003 | 0.6645 | 0.0029 |
| Older | −1.5174 | <0.0001 | −1.1251 | <0.0001 |
| | **EDR ISS 16+** | ***P* value** | **CISS ISS 16+** | ***P* value** |
| Intercept | −8.6939 | <0.0001 | −8.2329 | <0.0001 |
| DV | 0.1660 | <0.0001 | 0.1797 | <0.0001 |
| Belt | 0.8474 | 0.0090 | 0.8519 | 0.0038 |
| Older | −1.0224 | 0.0009 | −0.7617 | 0.0032 |



**FIGURE 5** Belted occupant MAIS1+ injury risk curves for EDR and CISS delta-v.

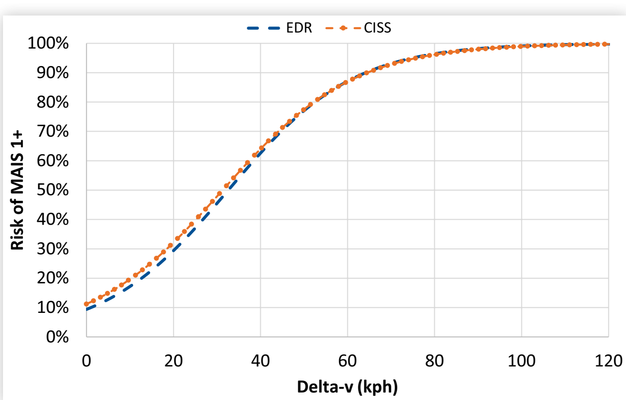





**FIGURE 6** Belted occupant MAIS 2+ injury risk curves for EDR and CISS delta-v.

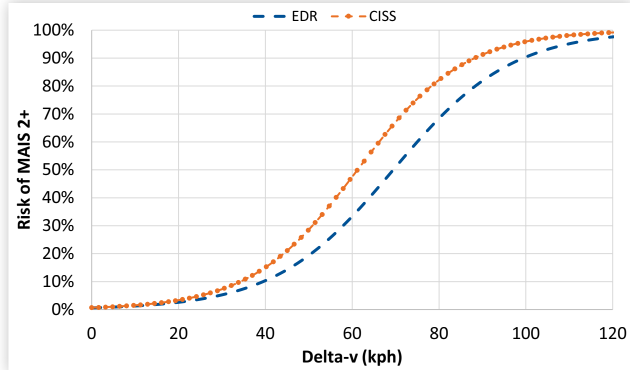





**FIGURE 7** Belted occupant MAIS 3+ injury risk curves for EDR and CISS delta-v.

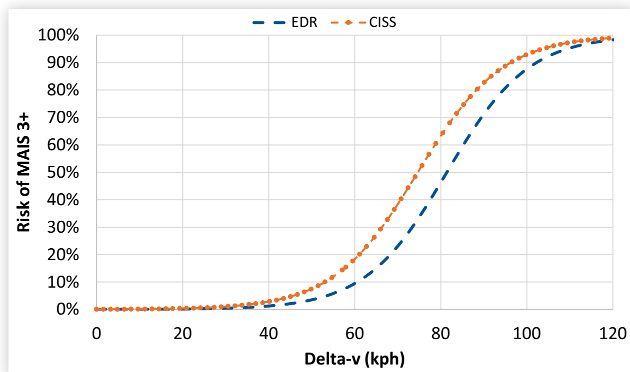





**FIGURE 8** Belted occupant ISS 16+ injury risk curves for EDR and CISS delta-v.

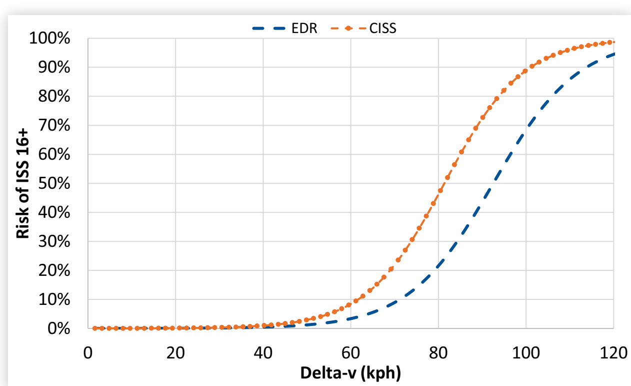


**TABLE 5** Regression models for AACN analysis.

| | ISS 16+ | *P* value | MAIS 3+ | *P* value |
|---|---|---|---|---|
| Intercept | −7.4615 | <0.0001 | −5.6798 | <0.0001 |
| DV | 0.1685 | <0.0001 | 0.1408 | <0.0001 |
| Belt | 0.8111 | 0.0004 | 0.8157 | <0.0001 |
| Older | −1.0055 | <0.0001 | −1.2763 | <0.0001 |
| Gender | 0.386 | 0.0569 | 0.3490 | 0.0415 |



**FIGURE 9** Triage rates for MAIS 3+ AACN model using EDR delta-v and CISS reconstructed delta-v data.

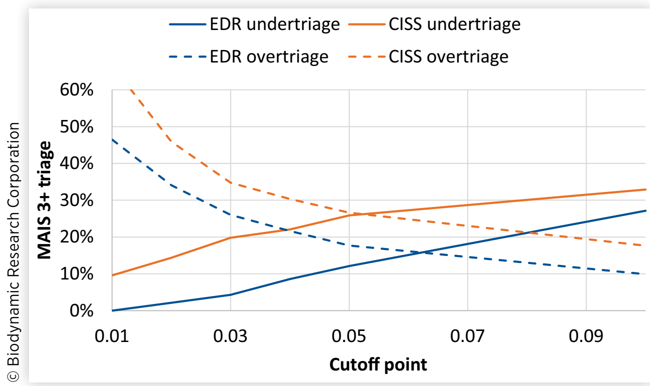
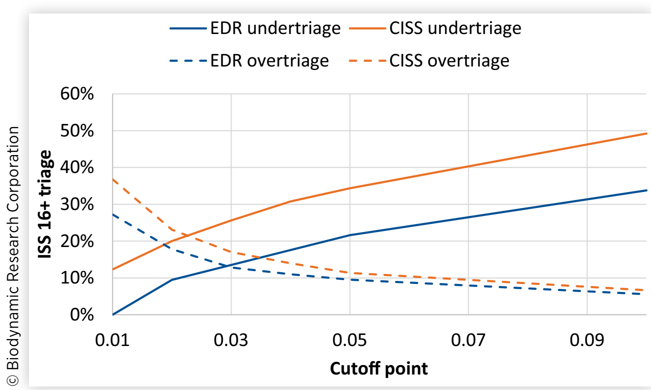



**FIGURE 10** Triage rates for ISS 16+ AACN model using EDR delta-v and CISS reconstructed delta-v data.




The range of undertriage and overtriage obtained with the ISS 16+ model is shown in Figure 10. When tested on CISS reconstructed delta-v data, undertriage ≤5% with overtriage ≤35% was not possible. At a cutoff of 0.0125, the model produced 14% undertriage and 32% overtriage on CISS data. When tested on EDR delta-v data the triage targets were attainable. On EDR data with a cutoff of 0.0125, the ISS 16+ model gave undertriage of 4% and overtriage of 23% with a positive likelihood ratio of 4.2 and AUROC of 0.776.

## Discussion

Risk for MAIS 1+, MAIS 2+, MAIS 3+, and ISS 16+ was calculated using paired CISS cases that had CISS reconstructed delta-v as well as EDR delta-v. The risk models were calculated using logistic regression and CISS weighting factors. Regression variables included delta-v, belt status, and age above or below 55 years. With the inclusion of crash severity and injury outcomes, the CISS database is designed to allow the calculation of relative risk across the spectrum of crash severity and weighted to provide nationally representative probabilities [2]. Other injury and fatality databases lack the combination of crash severity and injury outcomes needed to perform risk analysis. Like its predecessor, NASS-CDS, CISS uses NHTSA's WinSmash software along with crush measurements to calculate crash severity in the form of delta-v.

Previous comparisons of WinSmash reconstructions in frontal collisions compared to EDR data have shown reconstruction underestimates of delta-v ranging from 2% to 27% [10]. This study found that CISS reconstructed delta-v underestimated EDR-reported delta-v by 20% on average. The error was a function of delta-v with CISS reconstructions overestimating the EDR at lower delta-v and underestimating at higher delta-v. The higher delta-v underestimation had an effect on risk models calculated using CISS reconstructed delta-v when compared to risk models calculated using EDR delta-v. When tied to injury data, underestimation of delta-v moves the distribution of injuries lower on the delta-v scale. For example, the average ISS 16+ injury occurred at a delta-v of 51 kph when using CISS reconstructed data and a delta-v of 62.8 kph when using EDR data. The magnitude of this difference is highest for the most severe injuries and decreases with injury severity down to MAIS 0 (uninjured) where the average delta-v for CISS reconstructions is 18.2 kph and the average for EDR data is 19.5 kph. The effect of this is an overestimate of injury risk, moving the risk curve to the left when using risk models built on CISS reconstructed delta-v. The effect is most apparent for higher-severity injuries at higher delta-v. For MAIS 3+ injury to belted occupants, the risk when using EDR data is 7.1% at 56.3 kph. At the same delta-v, the risk is 14.4% when using CISS reconstructed delta-v. The difference is most pronounced at very high delta-v. The ISS 16+ EDR risk curve showed a 40% risk for belted occupants at an 88.5 kph delta-v while the CISS reconstructed curve showed a 69% risk at the same delta-v.

AACN systems are intended to aid triage decisions by providing early notification of crashes with the potential for serious injury. Existing AACN systems use NASS-CDS data in their injury prediction models [16, 17]. At least one AACN algorithm uses correction factors to account for the underestimate in delta-v [18]. AACN system notifications are used to indicate the potential for serious injury and therefore operate in the range of delta-v and injury risk most affected by the underestimation in CISS delta-v. To quantify this effect AACN-type algorithms for MAIS3+ and ISS16+ injuries were developed in this study using CISS reconstructed delta-v. The effect of using EDR delta-v as an input to these models resulted in improved performance of the AACN algorithms. For both MAIS 3+ and ISS 16+ injury, undertriage and overtriage were lower when driven by EDR data across a spectrum of cutoff points ranging from 0.01 to 0.1 (Figures 9 and 10). With either source of delta-v, both models met statistical criteria for moderate to large effect outlined by the National Expert Panel on Field Triage across the range of cutoffs (+LR ≥5 or AUROC

≥0.7). In 2008 the CDC expert panel recommended a cutoff point of 20%. Research since then has shown that a 20% cutoff point leads to sensitivity values less than 50%, and as a result, undertriage rates over 50%, which is much higher than the ACS goal of 5% undertriage. A 2019 NHTSA study based on NASS-CDS data reported the best results with a cutoff of 2% [21]. The models created for the present study performed best with a cutoff in the range of 1% to 2% for ISS 16+ and 2% to 3% for MAIS 3+.

The characteristics of the error in CISS reconstructed delta-v have an effect on predictive injury models. The underestimation of EDR delta-v by CISS reconstructions has an effect similar to using a lower cutoff point in an AACN model when the CISS-trained model is run on EDR delta-v input. Because the model trained on CISS reconstructed delta-v overpredicts risk, it marks more people as potentially injured when driven by EDR delta-v. This reduces the undertriage rate, which is a desirable goal, but also increases the overtriage rate, which is not desirable. A second effect of using EDR input data is reducing or eliminating scatter error in delta-v. Unlike the underestimation of delta-v, scatter error has an effect in both directions; some cases are overestimated, and some are underestimated. The reduction of random overestimates and underestimates improves undertriage as well as overtriage. The development of future AACN algorithms may benefit from an approach incorporating injury outcomes linked to EDR delta-v.

This study was limited to examining statistical models for frontal crash injuries using data derived from years 2017 to 2021. Injury rates could vary for side, rear, or rollover collisions. The result of the analysis may change with the addition of new data as vehicle sensing continues to improve. An additional limitation of this study is the assumption that occupant age can be verbally reported along with an AACN notification. Age is an important factor in the triage decision and relying on verbal occupant notification may not always be feasible.

## Conclusions

The CISS database allows large-scale comparisons of EDR and reconstructed delta-v. A comparison of the two for frontal impacts shows that CISS reconstructions overestimate delta-v at lower speeds and underestimate delta-v at higher speeds when compared to EDR delta-v. This effect on injury risk curves developed with CISS reconstructed delta-v is an overestimate of risk at higher delta-v. AACNs use injury risk data to determine if a crash has the potential for serious injury with the goal of providing quicker notification for emergency services. AACN systems have used NASS-CDS reconstructed delta-v to train their algorithms. Comparison of AACN algorithm output on CISS reconstructed delta-v to their output on EDR delta-v showed improved predictive performance in undertriage and overtriage.

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