Combining CIREN and NASS-CDS Data to Predict Occupant Outcomes in Frontal Crashes

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ABSTRACT

The National Highway Traffic Safety Administration's (NHTSA) Crash Injury Research and Engineering Network (CIREN) provides detailed outcome and patient care information for a sample of seriously injured case occupants involved in motor vehicle crashes. NHTSA's National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) provides a population-based sample of tow-away crashes that includes both non-injured and seriously injured occupants. This study combines the strengths of CIREN and NASS-CDS to produce predictive models that relate occupant and vehicle measures to treatment and occupant outcomes.

Qualifying frontal impact cases from CIREN involving seriously injured driver and/or front outboard passengers were used to evaluate the significance of the relationship between vehicle crash/occupant parameters and hospital treatment/outcome. A subset of CIREN cases where event data recorder (EDR) information was obtained was also analyzed. Regression analyses were done to assess the significance of predicted variables with regards to the outcomes of interest. Using significant predictors, a set of functions were developed that predict the probabilities of an occupant going to the intensive care unit (ICU), experiencing invasive surgery (OR) within 12 and 24 hours of the crash, or fatality given serious injury. NASS-CDS cases meeting the same CIREN crash and occupant inclusion criteria were used to establish the probability of serious injury given a qualifying frontal impact. This study has shown that the NASS-CDS-based probability of serious injury and the CIREN-based probability of seeing various outcomes given serious injury can be combined to form models that estimate the joint probability that a case occupant involved in a qualifying frontal crash would see an outcome of interest (ICU, OR, or fatality).

INTRODUCTION

It has been shown that the risk of death is 25% lower when care is given to a seriously injured patient at a trauma center versus a non-trauma center (MacKenzie et al., 2006). Over 40% of the patients included in the study by MacKenzie et al. (2006) were injured as the result of a motor vehicle crash. A motor vehicle crash resulting in serious injury requires rapid attention by the responding emergency medical services (EMS), police or appropriate rescue agency. Through observations made at the scene, the responding agency must decide where to transport the patient and by what means. This triage of vehicle occupants involved in motor vehicle crashes is currently done on-scene using the American College of Surgeons (ACS) field triage decision scheme published in 2006 (ACS, 2006) and later supported with detailed rationale (Sasser et al., 2009) . The field triage decision scheme consists of four sections or steps: 1. vital signs and level of consciousness, 2. anatomy of injury, 3. mechanism of injury and evidence of high-energy impact, and 4. special patient or system considerations.

The National Highway Traffic Safety Administration (NHTSA) is tasked with reducing injuries and fatalities that result from motor vehicle crashes. As part of this effort, NHTSA collects and analyzes data from real world crashes. This data is used to assess injury and fatality trends. NHTSA's National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) collects vehicle crash and occupant injury data from a population-based sample of tow-away crashes. The NASS-CDS data set is useful in that the injury rates seen in a particular crash mode can be weighted to estimate the overall population risk of experiencing a given level of injury in a crash configuration of interest. NHTSA's Crash Injury Research and Engineering Network (CIREN) program collects data from a convenience sample of motor vehicle crashes in which there was serious or disabling injury to at least one case occupant. Like NASS-CDS, CIREN cases involve detailed crash reconstructions in which both vehicle and occupant data are collected. Vehicle data includes, among other things, structural deformation, delta V, principal direction of force (PDOF), and restraint system types and usage. Occupant data includes, among other things, case occupant position, demographics, anthropometry, and a description of injuries and their sources. However, CIREN provides a more detailed biomechanical analysis and sourcing of the observed injuries. CIREN also provides detailed hospital care and patient outcome data that is not documented in NASS-CDS cases. Unfortunately, trends seen in CIREN data can't be extrapolated to the general population because CIREN is not a probability sample.

Step 3 in the ACS field triage decision scheme has an entry for assessing crash severity as determined by telemetry data obtained from automatic collision notification (ACN) systems. However, specific telemetry variables or predictive models are not suggested. Others have documented models using vehicle and occupant data in an attempt to predict the probability of a maximum Abbreviated Injury Scale (MAIS) (AAAM, 1998) of 3+ for a case occupant in a given crash scenario. The URGENCY Algorithm is one such model (Malliaris et al., 1997; Augenstein et al., 2001). These models emphasized the change in velocity or delta V of the vehicle that occurred as the result of the crash, but also include many other occupant and vehicle variables that can be obtained from a NASS-CDS or CIREN case. The current study used similar methods to those previously used to predict outcomes of case occupants in motor vehicle crashes. However, the current study aims to relate crash and occupant parameters to fatality and hospital outcomes. The hospital outcome data is available in CIREN, but not in NASS-CDS. The predictive model from CIREN alone can not be used to predict risks for the population at large. Therefore, the current study uses common inclusion criteria between CIREN and NASS-CDS cases to describe a population-based combined probability of the outcomes of interest.

Qualifying frontal crashes were used to complete the modeling of outcomes in the current study. These outcomes of interest include: 1. time in intensive care unit (ICU), 2. fatality, 3. ICU or fatality, 4. invasive surgery or operating room (OR) within 12 hours post crash, and 5. invasive surgery within 24 hours post crash.

METHODS

<u>CIREN Case Analysis</u>

The current study uses CIREN frontal crash data given the following inclusion criteria:

- Most severe event and damage from frontal collision
- PDOF of 11, 12 or 1 o'clock
- 1998+ vehicle model year
- MAIS 3+ injury cases
- Known WinSMASH (Sharma et al., 2007) delta V
- Known hospital outcomes (ICU, OR, etc.)
- Known seat belt use and airbag availability and deployment status. Unknown belt use, misused belts and cases with missing airbags were excluded
- One or fewer 25+ kph delta V events

Cases were limited to those with one or fewer 25+ kph delta V events. This limitation allowed for improved study of the association between a single frontal crash event and the resulting injury and hospital outcomes.

Two CIREN frontal crash data sets were produced. The first included all CIREN cases meeting the criteria above. The second included those where the case vehicle was equipped with an event data recorder (EDR). EDR cases did not require the existence of WinSMASH delta V, but did require a complete velocity-time history data set as obtained from the EDR for the crash event of interest. EDR cases judged to have incomplete velocity-time history data were not included in the current study. As noted previously by Niehoff et al. (2005), older models of General Motors (GM) vehicles collect between 100-150 ms of longitudinal delta V data for airbag deployment cases and in more recent model years 300 ms of longitudinal and lateral delta v data is recorded. Thus, only the longitudinal data was evaluated in the current study. Cases were limited to model year 2001+ EDR equipped vehicles from both GM and Ford Motor Company (Ford).

The aim of this study was to relate vehicle and occupant predictors to outcomes of interest. Fatality, ICU and OR were the outcomes studied. Evaluation of ICU and OR outcomes was restricted to non-fatal cases. However, a case could fall into more than one of the ICU and OR outcome categories.

This first step in assessing the relationship between the predictive variables and the outcomes studied involved completing χ^2 tests for each predictor to see if it was associated with the individual outcomes. Variables that were found to be significant at $p < 0.10$ were kept for later use in developing the multivariable probability models. Variables were grouped by vehicle and by occupant. Table 1 shows the list of predictors considered for the χ^2 tests. Many of the predictors are ones that could be collected through telemetry systems or at the crash site by the responding police or fire and rescue personnel. Others, however, would require assessment at the hospital or would come as the result of crash reconstruction. The aim of this study was the modeling of motor vehicle crash occupant outcomes using predictors that can be assessed through use of data collected via telemetry systems or those that can be assessed at the crash site by responding emergency personnel. Thus, the predictive models were limited to these variables. Though WinSMASH delta V is only obtained through crash reconstruction, it was used in the non-EDR data set of the current study as a surrogate for delta V that could be obtained via telemetry systems.

Table 1. Vehicle and occupant variables

Vehicle/Crash Predictors	Occupant Predictors
Entrapped[2]	GCS < 14[1,2]
Entrapped or No Exit[2]	GCS < 14, Tube or Sedated[1,2]
WinSMASH Longitudinal Delta V[4]	Respiration Rate < 10 or > 29[2]
WinSMASH Total Delta V[4]	Systolic Blood Pressure < 90[2]
EDR Longitudinal Delta V[1]	Triage Step 1[2]
EDR - Peak 30 ms Crash Pulse[1]	Triage Step 2[2]
EDR - Peak 50 ms Crash Pulse[1]	Triate Step 1 or 2[2]
EDR - Pre-impact Braking[1]	Triage Step 1 and 2[2]
EDR - Pre-impact Vehicle Speed[1]	BMI[3]
Barrier Equivalent Speed (BES)[4,5]	BMI Ranges[2]
PDOF[1,4]	Age[1,2]
Maximum Crush[4]	Age Ranges[1,2]
Crush Area[4]	Age > 65 Years[1,2]
Average Crush: C1 - C6[4]	Gender[1,2]
Vehicle Curb Weight[1]	Driver / Passenger[1,2]
Vehicle Curb Weight < 1500 kg[1,2]	Belt Use[1,2]
Vehicle Model Year[1]	
Certified Advanced Compliant[1]	
Airbag Deployment[1,2]	
Intrusion at Case Occupant[4]	
Intrusion - Any Position[4]	
Intrusion > 12" at Case Occupant[2]	
Intrusion > 18" in Any Position[2]	
Intrusion > 12" or > 18"[2]	

Notes:
1. Determined via telemetry systems / ACN
2. Determined at crash site or by EMS
3. Determined at hospital
4. Determined through crash investigation
5. BES described by Sharma et al. (2007)

Occupant-related predictors requiring further description include Step 1 (vital signs and consciousness) and Step 2 (anatomy of injury) of the ACS field triage decision scheme. Step 1 is positive if the Glasgow Coma Score (GCS) is less than 14, the respiration rate is less than 10 or greater than 29 or systolic blood pressure (SBP) is less than 90. Cases where the occupant was intubated or sedated were grouped separately and not considered as positive for GCS less than 14. Step 2 was positive if any of the following were true: 1. penetrating injuries to the head, neck, torso, and extremities proximal to the elbow and knee, 2. flail chest, 3. two or more proximal long bone fractures, 4. crushed, degloved or mangled extremity, 5. amputation proximal to the wrist or ankle, 6. pelvic fractures, 7. open or depressed skull fracture, or 8. paralysis. Body mass index or BMI was grouped by those occupants that had BMI less than 25, 25 – 30, 30 – 35, and greater than 35. Age was grouped as under 30 years of age, 30 – 65, and greater than 65 years of age.

On the vehicle side, maximum crush was recorded in the frontal event of interest. Average crush is the average of the crush at the six locations (C1 to C6) measured across the front of the vehicle. Crush area was defined as the product of average crush and vehicle end width. PDOF was separated into three groups; eleven, twelve and one o'clock. Intrusion was evaluated as a continuous variable for the peak values measured at the case occupant's position and for the peak value measured at any position in the vehicle. These values were also grouped by thresholds used in Step 3 of the ACS field triage decision scheme. The compliance status of the case vehicles was also evaluated based on the advanced airbag section of Federal Motor Vehicle Safety Standard No. 208 (NHTSA, 2007). Compliance status was defined as certified advanced compliant (CAC) or not CAC. Manufacturers did not begin certifying their vehicles as CAC until model year 2003.

Five EDR-based variables were assessed for EDR cases included in the current study (Table 1). Post-crash velocity-time history entries were used to calculate EDR longitudinal delta V. The velocity-time history data was also used to calculate a peak slope over both 30 and 50 ms windows. Pre-impact vehicle velocity and pre-impact braking were also collected from the EDR data when possible.

Modeling of the outcomes of interest using promising predictors ($p < 0.10$ from the χ^2 tests) was done next. First, stepwise regressions were done using only the vehicle- and crash-based predictors. Next, stepwise regression was done using only the occupant-based predictors. Finally, the overall predictive model for the individual outcome was created using stepwise regression that included the variables found to be significant in the respective vehicle- and occupant-based models. Backward and forward selection were also used to verify the results of the stepwise selection for the final model. The maximum p value allowed for entering and staying in the model was 0.10. Model fit was assessed using Hosmer and Lemeshow's Goodness-of-Fit test (Hosmer and Lemeshow, 2000). A value of $p > 0.10$ for the Hosmer and Lemeshow test signified an acceptable fit of the model.

NASS-CDS

NASS-CDS cases were queried with the same inclusion criteria used in selecting CIREN cases. The exception was that the NASS-CDS cases included all MAIS levels. The prevalence of MAIS injuries at all levels in CDS cases and the ability to produce a weighted population estimate of the data made it possible for the NASS-CDS query to provide a rate of MAIS 3+ injured case occupants given the inclusion criteria listed earlier for CIREN frontal cases. This rate or probability of experiencing a MAIS 3+ injury could be used in combination with the probability of outcomes modeled using the CIREN data to produce static models of combined probability. However, it was thought more appropriate to produce two unique predictive models for probability of MAIS 3+ injury in NASS-CDS frontal cases; one model for all qualifying model year 1998+ vehicle crash cases, one for model year 2001+ EDR cases. These two NASS-CDS models were then used in combination with the respective CIREN outcome models. The product of the NASS-CDS MAIS 3+ injury and CIREN hospital treatment models was taken to create a combined probability function that can be used to predict the likelihood of a treatment (ICU, OR) or fatality given a qualifying frontal crash.

RESULTS

For the first data set involving all CIREN cases, 482 frontal crash cases met the inclusion criteria. For the second data set involving only EDR equipped vehicles, there were 40 CIREN frontal crash cases that met the inclusion criteria. Though Ford cases were included in the sampling of EDR cases, only cases involving GM vehicles met the inclusion criteria. Of these 40 EDR cases, 33 had available WinSMASH delta V data and thus were cases that were also included in the overall set of 482 cases. The distribution of class variables for the 482 CIREN cases meeting the inclusion criteria are shown in Figures 1 and 2. Table 2 shows the mean and standard deviation for the various occupant-based continuous measures that were evaluated in the current study, grouped by all cases and by individual outcomes. Table 3 shows similar results for the vehicle-based variables.

Assessing Variable Significance

Wald χ^2 tests were completed to assess the significance of the individual predictor variables for each of the outcomes of interest. Tables A1 and A2 (see Appendix) show the Wald χ^2 values for predictors with $p < 0.10$ for CIREN frontal cases and CIREN frontal cases with EDR, respectively. Empty cells in the tables signify variables with $p > 0.10$. Variables were grouped into partitions related to vehicle crush or change in velocity, intrusion, vital signs, entrapment, age, position, belt use, gender, vehicle model year and curb weight.

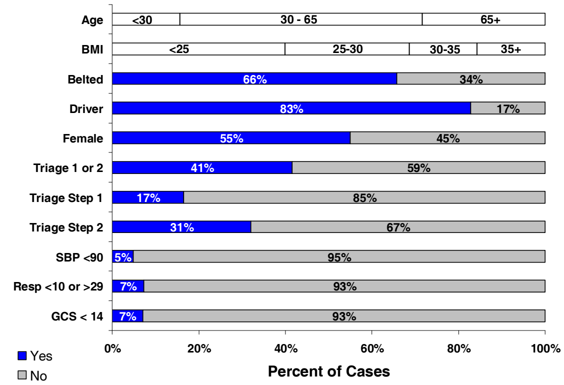

Figure 1. Distribution of occupant class variables

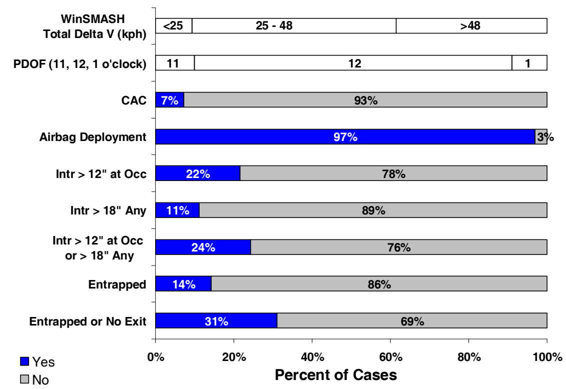

Figure 2. Distribution of vehicle class variables

Table 2. Average occupant measures for CIREN cases by outcome

				Age Yrs		BMI		MAIS		ISS		# of AIS 3+ Injuries		Total Injuries	
	Outcome	Group	N	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
All CIREN Frontals	All	NA	482	43.9	18.3	28.4	7.8	3.4	0.8	20.3	13.5	2.5	2.0	10.0	5.9
	ICU	No	304	42.0	16.6	28.5	8.2	3.1	0.4	15.0	6.7	1.8	1.1	8.1	4.0
		Yes	140	46.7	19.7	28.1	7.0	3.6	0.7	23.5	10.2	3.4	2.3	12.6	7.1
	Fatal or ICU	No	304	42.0	16.6	28.5	8.2	3.1	0.4	15.0	6.7	1.8	1.1	8.1	4.0
		Yes	178	47.1	20.6	28.4	7.2	3.9	1.0	29.2	17.1	3.8	2.5	13.2	7.2
	Fatal	No	444	43.5	17.8	28.3	7.9	3.3	0.6	17.7	8.9	2.3	1.7	9.5	5.6
		Yes	38	48.4	23.8	29.6	7.6	5.0	0.9	50.9	20.5	5.1	3.0	15.5	7.2
	OR < 12 hrs	No	230	45.7	18.7	27.8	7.9	3.2	0.5	17.2	8.2	2.1	1.4	8.9	4.7
		Yes	195	41.7	16.6	29.0	7.9	3.3	0.6	18.1	9.3	2.5	2.0	10.3	6.1
	OR < 24 hrs	No	151	47.8	19.6	28.3	8.8	3.3	0.5	17.5	7.9	1.9	1.2	8.6	4.3
		Yes	280	41.5	16.5	28.5	7.5	3.3	0.6	17.8	9.3	2.5	1.9	9.9	6.0
CIREN EDR Frontals	All	NA	40	49.8	19.7	28.2	7.1	3.5	0.8	20.7	12.0	2.7	1.8	9.8	5.3
	ICU	No	19	53.6	16.5	26.9	5.8	3.2	0.5	17.1	8.8	2.0	0.9	6.6	2.7
		Yes	19	46.0	20.8	29.6	8.5	3.5	0.8	22.3	13.1	3.0	1.9	12.4	5.3
	Fatal or ICU	No	19	53.6	16.5	26.9	5.8	3.2	0.5	17.1	8.8	2.0	0.9	6.6	2.7
		Yes	21	46.4	22.0	29.4	8.1	3.7	0.9	24.1	13.6	3.3	2.2	12.9	5.4
	Fatal	No	38	49.8	18.9	28.3	7.3	3.4	0.7	19.7	11.3	2.5	1.6	9.4	5.0
		Yes	2	49.8	42.7	27.5	2.2	5.0	0.0	40.5	3.5	6.0	4.2	20.0	.
	OR < 12 hrs	No	18	50.3	20.7	28.3	8.5	3.3	0.6	19.8	10.8	2.4	1.7	8.4	4.9
		Yes	20	49.3	17.7	28.3	6.3	3.4	0.8	19.6	12.1	2.6	1.5	10.4	5.2
	OR < 24 hrs	No	9	56.8	17.4	29.4	10.4	3.1	0.3	15.8	4.7	1.8	1.0	6.3	3.3
		Yes	28	47.4	19.4	27.9	6.4	3.5	0.7	21.3	12.6	2.8	1.6	10.7	5.2

Table 3. Average vehicle measures for CIREN cases by outcome

	Outcome	Group	N	BES		EDR Longitudinal Delta V (kph)		WinSMASH Total Delta V (kph)		WinSMASH Longitudinal Delta V (kph)		Intrusion Occupant Position (cm)		Intrusion Any Position (cm)		Max Crush (cm)		Crush Area (cm^2)		Average Crush C1 to C6 (cm)		Vehicle Model Year		Vehicle Curb Weight (kg)	
				Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
All CIREN Frontals	All	NA	482	43.8	17.4	-	-	45.5	17.3	44.5	17.4	16.3	16.9	21.5	19.1	65.7	29.6	5902	3233	37.6	20.2	2001.0	2.4	1465	319.2
	ICU	No	304	41.0	14.7	-	-	43.3	15.3	42.2	15.4	13.7	15.3	19.2	18.4	61.4	25.6	5353	2664	34.2	16.6	2000.9	2.4	1460	336.9
		Yes	140	47.2	19.7	-	-	48.1	19.5	47.4	19.4	21.4	18.9	25.9	19.7	71.1	31.2	6764	3818	42.3	23.6	2001.5	2.4	1494	294.1
	Fatal or ICU	No	304	41.0	14.7	-	-	43.3	15.3	42.2	15.4	13.7	15.3	19.2	18.4	61.4	25.6	5353	2664	34.2	16.6	2000.9	2.4	1460	336.9
		Yes	178	48.5	20.3	-	-	49.4	19.8	48.5	19.7	20.7	18.7	25.4	19.7	73.0	34.1	6870	3869	43.4	24.2	2001.2	2.4	1473	287.2
	Fatal	No	444	43.0	16.7	-	-	44.8	16.9	43.8	16.9	16.1	16.9	21.3	19.0	64.5	27.9	5791	3134	36.8	19.4	2001.1	2.4	1470	324.1
		Yes	38	53.3	22.2	-	-	53.9	20.7	52.6	20.6	18.1	17.8	23.8	19.6	79.9	42.9	7281	4089	47.7	26.4	2000.0	1.9	1398	249.1
	OR < 12 hrs	No	230	42.3	16.8	-	-	44.3	17.2	43.5	17.2	14.3	16.2	20.5	19.1	64.4	29.5	5642	3001	35.6	18.5	2001.2	2.4	1492	345.8
		Yes	195	43.6	16.6	-	-	45.4	16.4	44.3	16.5	18.5	17.9	22.5	19.3	64.2	26.3	5994	3295	38.1	20.3	2001.0	2.3	1455	304.9
	OR < 24 hrs	No	151	40.4	17.0	-	-	42.4	17.1	41.5	17.1	11.7	14.9	17.9	17.9	61.1	30.5	5346	3071	33.2	18.7	2001.3	2.4	1490	329.8
		Yes	280	44.4	16.2	-	-	46.2	16.5	45.2	16.6	18.3	16.8	22.7	18.8	66.7	26.2	6079	3146	38.9	19.6	2001.0	2.4	1465	323.8
CIREN EDR Frontals	All	NA	40	45.8	17.8	53.4	14.6	46.6	19.1	45.7	19.0	18.6	16.7	23.8	16.7	69.6	28.1	6115	3424	38.8	20.7	2002.8	1.6	1521	345.5
	ICU	No	19	39.7	14.9	46.2	9.2	40.4	17.4	39.5	17.3	11.6	14.8	17.1	15.2	67.3	27.0	5433	2620	34.9	15.7	2002.6	1.8	1564	366.8
		Yes	19	54.4	17.8	59.4	16.1	55.1	18.3	54.1	18.1	27.0	15.4	32.6	14.2	74.7	29.3	7112	3996	44.7	24.2	2002.9	1.5	1499	340.8
	Fatal or ICU	No	19	39.7	14.9	46.2	9.2	40.4	17.4	39.5	17.3	11.6	14.8	17.1	15.2	67.3	27.0	5433	2620	34.9	15.7	2002.6	1.8	1564	366.8
		Yes	21	52.7	18.6	59.9	15.7	53.2	19.2	52.3	19.0	24.8	16.1	29.9	15.9	71.6	29.6	6732	3980	42.3	24.2	2003.0	1.4	1483	329.2
	Fatal	No	38	46.4	17.7	52.8	14.5	47.3	19.0	46.3	18.9	19.3	16.8	24.8	16.5	71.0	28.0	6272	3440	39.8	20.7	2002.7	1.6	1531	350.8
		Yes	2	25.0	.	65.0	16.1	25.0	.	25.0	.	4.5	3.5	4.5	3.5	42.0	11.3	3122	676	19.6	0.6	2004.0	0.0	1329	157.0
	OR < 12 hrs	No	18	43.9	14.0	47.4	11.6	44.6	15.2	43.8	15.1	16.2	17.1	22.8	17.3	70.9	27.1	5949	2945	38.5	18.4	2002.2	1.2	1449	321.6
		Yes	20	48.7	20.7	57.6	15.4	50.0	22.4	48.9	22.3	22.1	16.4	26.6	15.9	71.2	29.6	6563	3885	41.0	23.1	2003.2	1.8	1605	367.3
	OR < 24 hrs	No	9	38.9	13.4	41.4	7.9	37.9	15.7	37.1	15.1	12.3	13.9	17.4	15.4	63.9	29.3	5010	3205	32.1	18.9	2002.2	1.4	1534	399.0
		Yes	28	48.0	18.5	56.4	14.6	49.8	19.4	48.7	19.4	22.1	17.2	27.6	16.4	73.3	28.3	6619	3524	41.9	21.3	2002.9	1.7	1547	336.4

There are a number of significant observations that can be made in looking at the relationships between single variables and the outcomes studied for the full set of qualifying CIREN frontal cases (Appendix - Table A1). First, delta V, whether total or longitudinal, is consistently a significant predictor of outcome. The only exception is for those with invasive surgery within 12 hours of the crash. Post-test crush measures such as peak crush, average crush, and crush area were generally even more significantly associated with the outcomes studied than delta V measures, as evidenced by higher χ^2 values for the crush measures. However, these measures may not be appropriate for on-site triage and are not available for measure through telemetry, but instead require crash reconstruction to be calculated. Thus, these crush-based variables were not included in the predictive models. The field triage decision scheme Step 1 and Step 2 measures were also consistently strong predictors, with at least one being significantly related to each of the outcomes. It was also noteworthy that intrusion at the case occupant position was always a better predictor of outcome than peak intrusion at any position in the vehicle. Step 3 of the triage decision scheme assesses whether intrusion is greater than 12 inches at the occupant position or 18 inches at any position. However, independently the 18 inches threshold for any position was not significant at $p < 0.05$ for any outcome, while the 12 inch threshold at the occupant position was significantly related ($p < 0.05$) to all outcomes other than fatality.

The CIREN EDR cases saw many fewer significant variables (Appendix - Table A2). For instance, Triage Step 1 was not significant for any outcomes and Step 2 was only significant for two outcomes. The small number of qualifying EDR cases (n=40) available is likely the cause. It was noteworthy that EDR longitudinal delta V was shown to be a stronger predictor of outcome than WinSMASH longitudinal delta V, WinSMASH total delta V and barrier equivalent speed when comparing χ^2 values. Other EDR-based variables also were significant for certain outcomes including crash pulse severity measures and pre-impact braking. Of note, pre-impact braking was significant for a reduced probability of going to the ICU. Pre-impact velocity was not found to be significant for any outcome. Regression analyses related to fatality were not done on the EDR data set given only two fatal cases out of the 40 EDR cases included in the study.

Those variables with the highest Wald χ^2 value were selected for use in the predictive modeling for the outcomes of interest as described in the next section. For instance, there were many cases for the respective outcomes in which total delta V and longitudinal delta V were both significant predictors. For these instances, the predictor with the maximum χ^2 value was used. There were also cases where a predictor such as crush area or average crush had a larger χ^2 value than delta V or max crush. However, as noted earlier, the emphasis of the current study was to produce models with predictors that can be assessed at the crash scene or via telemetry.

<u>Predictive Modeling – All CIREN Cases (n=482)</u>

Stepwise regressions were done in combination with forward and backward selection of variables to establish models of treatment given injury. The threshold for both entering and staying in the model was $p < 0.10$. Table 4 shows the results for the final models produced for each of the five groupings of outcomes of interest. The significant predictors and their respective maximum likelihood estimates, Wald χ^2, p values, point estimates and 95% confidence intervals are shown. The Hosmer and Lemeshow Goodness-of-Fit tests found good fit for all models with p values greater than 0.1 in all cases.

Most variables were directionally associated with the outcomes of interest as would be considered logical. Delta V, intrusion and the field triage decision scheme vital sign (Step 1) and injury (Step 2) measures all were consistent in that, when significant, they were associated with an increased likelihood of the outcomes studied. In contrast, seat belt use was associated with a lower probability of the respective outcomes when it was a significant predictor. One exception was the over-65 age group. This group predicts an increase in probability of fatality, but a reduced probability of OR. Of all injured body regions, OR was most significantly associated with lower extremity injuries ($\chi^2 = 21.5$, $p < 0.0001$), but was also significant for not having AIS 3+ spine injuries ($\chi^2 = 8.8$, $p < 0.01$). Conversely, spine injuries were found to be significantly associated with being over 65 ($\chi^2 = 20.6$, $p < 0.0001$) while lower extremity injuries were found to be significantly associated with those under age 65 ($\chi^2 = 5.4$, $p < 0.05$). While it is not possible to assess injury probability or risk in CIREN, these relationships within the injured population help explain why the elderly group was less and not more likely to have invasive surgery within 24 hours of a crash. A reduced ability of the older population to endure invasive surgery soon after a traumatic event may also contribute to a lower probability of OR within 24 hours for the elderly population.

The models provide the maximum likelihood estimates for the intercept (Q_i) and for the significant predictors ($Q_1, Q_2 \ldots Q_n$) that can be used to predict the probability (P_{CIREN}) of the outcome of interest per the following equations. X_1 to X_n would represent the values for the respective predictors for a given case.

$$P_{CIREN} = \frac{1}{(1+e^{-L})} \qquad (1)$$

$$L = Q_i + Q_1 X_1 + Q_2 X_2 \ldots Q_n X_n \qquad (2)$$

Table 4. Model results for all qualifying CIREN frontal cases

Outcome	Predictor	Predictor Values[1]	-2 Log L	Maximum Likelihood Estimate	Wald $\chi2$	Pr > $\chi2$	Odds Ratio [95% CI]	Model Fit[2]
ICU	Intercept		463.9	-283.000	8.451	0.0036	NA	0.7719
	Intrusion > 12" at Occ.	1=yes, 0=no		-0.477	12.080	0.0005	0.385 [0.225 - 0.660]	
	Vehicle Model Year	Continuous		0.141	8.404	0.0037	1.151 [1.047 - 1.267]	
	Occ. Age - Years	Continuous		0.023	12.279	0.0005	1.023 [1.010 - 1.036]	
	Triage Step 1	1=yes, 0=no		-1.031	41.819	< 0.0001	0.127 [0.068 - 0.238]	
	Triage Step 2	1=yes, 0=no		-0.292	5.671	0.0173	0.558 [0.345 - 0.902]	
ICU or Fatal	Intercept		498.3	-1.703	12.031	0.0005	NA	0.8772
	Longitudinal Delta V (KPH)	Continuous		0.020	8.238	0.0041	1.020 [1.006 - 1.034]	
	Intrusion > 12" at Occ.	1=yes, 0=no		-0.307	4.885	0.0271	0.541 [0.314 - 0.933]	
	Occ. Age - Years	Continuous		0.026	16.676	< 0.0001	1.026 [1.013 - 1.039]	
	Triage Step 1	1=yes, 0=no		-1.056	47.553	< 0.0001	0.121 [0.066 - 0.220]	
	Triage Step 2	1=yes, 0=no		-0.287	5.985	0.0144	0.564 [0.356 - 0.892]	
Fatal	Intercept		116.6	-4.848	22.616	< 0.0001	NA	0.9319
	Total Delta V (KPH)	Continuous		0.032	3.964	0.0465	1.033 [1.000 - 1.066]	
	Entrapped or No Exit	1=yes, 0=no		1.095	4.111	0.0426	8.941 [1.076 - 74.307]	
	Age > 65 Years	1=yes, 0=no		-0.698	4.937	0.0263	0.247 [0.072 - 0.848]	
	Belted	1=yes, 0=no		1.380	16.649	< 0.0001	15.812 [4.198 - 59.553]	
	Triage Step 1	1=yes, 0=no		-0.996	14.715	0.0001	0.136 [0.049 - 0.377]	
OR within 12 hrs	Intercept		562.3	-2.154	1.061	0.3030	NA	0.7116
	Age > 65 Years	1=yes, 0=no		0.294	3.856	0.0496	1.801 [1.001 - 3.242]	
	Occ. Position	Driver=1, Pssgr=0		-2.632	3.541	0.0599	.0591 [0.341 - 1.022]	
	Triage Step 1	1=yes, 0=no		-0.244	2.798	0.0944	0.614 [0.346 - 1.087]	
	Curb Wt < 1500 kg	1=yes, 0=no		-0.190	3.333	0.0679	0.684 [0.454 - 1.028]	
	Entrapped or No Exit	1=yes, 0=no		-0.211	3.505	0.0612	0.656 [0.422 - 1.020]	
	Intrusion > 12" at Occ.	1=yes, 0=no		-0.222	2.859	0.0908	0.383 [0.383 - 1.073]	
OR within 24 hrs	Intercept		515.6	0.802	17.064	< 0.0001	NA	0.9398
	Age > 65 Years	1=yes, 0=no		0.405	7.959	0.0048	2.246 [1.280 - 3.941]	
	Triage Step 2	1=yes, 0=no		-0.254	4.291	0.0383	0.602 [0.372 - 0.973]	
	Curb Wt < 1500 kg	1=yes, 0=no		-0.285	6.808	0.0091	0.565 [0.368 - 0.868]	
	Entrapped or No Exit	1=yes, 0=no		-0.312	6.313	0.0120	0.536 [0.330 - 0.872]	
	Intrusion > 12" at Occ.	1=yes, 0=no		-0.416	6.981	0.0082	0.435 [0.235 - 0.807]	

Notes:
1. All class level predictors modeled as 0 vs. 1.
2. Hosmer and Lemeshow Goodness-of-Fit: Pr > $\chi2$

Predictive Modeling – CIREN EDR Cases (n=40)

Stepwise regressions were also done for the 40 EDR cases using the significant variables documented in Table 5. Only two significant multi-variable models were produced using the EDR data. EDR delta V was positively associated with an increase probability of seeing all outcomes studied. Only the ICU and ICU or fatal models included additional significant ($p < 0.10$) predictors other than EDR delta V after completing stepwise, backward and forward selections. A model was not created for fatal cases given there were only two fatal cases in the EDR data set.

NASS-CDS

Given the same inclusion criteria as used in collecting CIREN frontal cases for the current study, a population-based estimate of the rate of MAIS 3+ injury for all qualifying model year 1998+ vehicles was found to be 2.1%. The same estimate for model year 2001+ GM vehicles, which corresponds to the cases included in the CIREN EDR analysis, was found to be 2.2%. Regression analysis produced two models, one for all qualifying 1998+ model year vehicles and one for 2001+ model year EDR equipped GM vehicles (Table 6). These models predict the probability of MAIS 3+ injury given the frontal crash inclusion criteria used. They can be used in combination with the CIREN-based models to produce a combined probability for the outcomes evaluated in the current study.

Combined Probability Models

A population-based probability of outcomes of interest given a frontal crash meeting the inclusion criteria of the current study can be formulated as the product of the risk of sustaining an MAIS 3+ injury (P_{CDS}) as established from the NASS-CDS data and the probability of outcome ($P_{CIR.EN} = P(ICU|MAIS3+)$). The formula (A1) and sample calculation for probability of MAIS 3+ injury (A2) and ICU given MAIS 3+ injury (A3) are located in the appendix.

Table 5. Model results for all qualifying CIREN EDR frontal cases

Outcome	Predictor	Predictor Values	-2 Log L	Maximum Likelihood Estimate	Wald $\chi 2$	Pr > $\chi 2$	Odds Ratio [95% CI]	Model Fit[1]
ICU	Intercept		28.6	-5.123	4.241	0.0395	NA	0.8768
	Intrusion > 12" at Occ	1=yes, 0=no		-1.043	3.938	0.0472	0.124 [0.016 - 0.975]	
	Triage Step 1	1=yes, 0=no		-1.582	7.103	0.0077	0.042 [0.004 - 0.433]	
	EDR Delta V (KPH)	Continuous		0.107	5.173	0.0229	1.113 [1.015 - 1.221]	
ICU or Fatal	Intercept		15.5	-14.688	5.277	0.0216	NA	0.7692
	EDR Delta V (KPH)	Continuous		0.320	5.427	0.0198	1.377 [1.052 - 1.801]	
	Pre-impact Braking	1=yes, 0=no		2.243	3.872	0.0491	88.827 [1.018 - >999.999]	
	Triage Step 2	1=yes, 0=no		-3.033	5.564	0.0183	0.002 [<0.001 - 0.359]	

Notes:
1. Hosmer and Lemeshow Goodness-of-Fit: Pr > $\chi 2$

Table 6. Model results for MAIS 3+ injury in NASS-CDS frontal cases

	Outcome	Predictor	Predictor Values	-2 Log L	Maximum Likelihood Estimate	Wald $\chi 2$	Pr > $\chi 2$	Odds Ratio [95% CI]
All 1998+ Vehicles	MAIS 3+	Intercept		470193.1	-7.383	505.226	< 0.0001	NA
		Age	Continuous		0.031	27.474	< 0.0001	1.032 [1.020 - 1.044]
		Delta V (MPH)	Continuous		0.158	323.608	< 0.0001	1.171 [1.151 - 1.191]
		Airbag deployed , not belted	1=yes, 0=no		1.044	29.269	< 0.0001	2.841 [1.946 - 4.147]
		Belted, no airbag deployment	1=yes, 0=no		0.981	1.857	0.1730	2.668 [0.650 - 10.948]
		Gender	1=male, 0=female		-0.536	15.423	< 0.001	0.585 [0.448 - 0.764]
All 2001+ GM EDR Vehicles	MAIS 3+	Intercept		49098.2	-540.300	5.647	0.0194	NA
		Age	Continuous		0.023	6.592	0.0102	1.024 [1.006 - 1.042]
		Delta V (MPH)	Continuous		0.181	39.042	< 0.0001	1.198 [1.132 - 1.268]
		Model Year	Continuous		0.266	5.326	0.0210	1.305 [1.041 - 1.635]
		Airbag deployed , not belted	1=yes, 0=no		1.499	13.677	0.0002	4.475 [2.023 - 9.903]
		Belted, no airbag deployment	1=yes, 0=no		-31.080	135.690	< 0.0001	<0.001 [<0.001 - <0.001]
		PDOF - 1 o'clock	1=yes, 0=no		-2.375	14.023	0.0002	0.093 [0.027 - 0.322]
		PDOF - 11 o'clock	1=yes, 0=no		-0.386	1.199	0.2735	0.680 [0.341 - 1.356]
		Gender	1=male, 0=female		-0.937	7.172	0.0074	0.392 [0.197 - 0.778]

CONCLUSIONS

This study shows an example in which NASS-CDS and CIREN data sets can be used together to project probability of certain outcomes in frontal crashes. The CIREN data analysis of all qualifying frontal cases produced models using numerous vehicle- and occupant-based variables and for all outcomes of interest showed good model fit as evaluated using the Hosmer and Lemeshow Goodness-of-Fit test. All of the models included at least two occupant and two vehicle or crash-based variables. Modeling of EDR cases, where fewer cases where available, produced models for two of five outcomes studied.

Many typical factors generally thought to be positively associated with severity of injury such as delta V and intrusion proved to consistently be related to the treatment and injury outcomes evaluated in the current study. Additionally, measures currently used in the ACS field triage decision scheme related to vital signs and injury also proved to be significant predictors. There were exceptions where factors that may logically be thought to produce a positive relationship related to the treatment outcome in fact had a negative outcome. The prime example was age and invasive surgery where being over 65 years old reduced the likelihood of a case occupant needing invasive surgery in the first 12 or 24 hours following a crash. This exception could be explained in either of two ways. First, the older population tends to sustain more spinal injuries and fewer lower extremity injuries, compared to younger patients. However, the majority of injuries treated in the OR are lower-extremity injuries. Second, older occupants may require a greater period of time to stabilize before invasive surgery.

EDR delta V was shown in the 40 cases studied to be significantly associated with outcome. The 30 and 50 ms pulse evaluations were also significant predictors of outcome, but in no instance were they better than EDR delta V. The 50 ms window is associated with the acceleration severity index (CEN, 1998), which was also not found to be a better predictor of injury as compared to delta V by Gabauer and Gabler (2007). In single predictor logistic regressions, EDR delta V was a better predictor of the outcomes studied than WinSMASH delta V. However, both WinSMASH- and EDR-based delta V were shown to be significant predictors of motor vehicle crash occupant outcome. Future study with a larger data set of EDR cases should be done to further assess the predictive performance of all EDR-based variables including delta V, braking and pre-impact speed.

Prior studies have proposed the need to combine telematics data from ACN systems with the URGENCY Algorithm for improving the emergency response for potentially seriously injured motor vehicle crash victims (Augenstein et al., 2001; Augenstein et al., 2003; Augenstein et al., 2005; Augenstein et al., 2006; Augenstein et al., 2007; Champion et al., 2003; Champion et al., 2005). The URGENCY Algorithm predicts a probability of MAIS 3+ injury for motor vehicle crash victims through the application of regression models developed using various vehicle, crash and occupant data. The current study has shown that similar techniques can be used to combine a probability of MAIS 3+ injury with the probability of invasive surgery within 12 or 24 hours, time spent in ICU or fatality. However, unlike the URGENCY Algorithm, the CDS-based models produced in the current study were limited to frontal crashes.

Study Limitations

Study limitations include the fact that only frontal cases involving 1998+ model year vehicles were included in the analysis qualifying CIREN cases. Similar methods of producing models combining the probabilities of MAIS 3+ injury in CDS with probabilities for outcome in CIREN could be done for other crash modes and groupings of vehicle model years. The majority of AIS 3+ injuries occur in frontal crashes, making analysis of this crash type a good starting point. While the model year 1998 break point was chosen to coincide with second generation or depowered frontal airbags and to allow for sufficient quantity of cases for analysis.

This study was also limited in that only 36 of 482 cases analyzed were for vehicles that were certified to the advanced airbag requirements of FMVSS No. 208 (NHTSA, 2007). Thus the relationships between crash and occupant variables and outcome presented here may not extend to new CAC vehicles. Manufacturers did not begin certifying their vehicles as CAC until the 2003 model year. The average model year evaluated in the current study was 2001±2.4.

In addition to differences in FMVSS No. 208 compliance, there are other differences in vehicle content that would differentiate the average vehicle in this study from the average vehicle available new for purchase today. The Insurance Institute for Highway Safety (IIHS) provides another example of how different a model year 2001 vehicle may be versus a current vehicle. Brumbelow (2007) showed that only 50% of 2001 model year vehicles tested were "good" performers in the IIHS's frontal offset crash condition, whereas, over 90% of tested model year 2007 vehicles were considered "good" performers. So, one possible difference between earlier model vehicles that did not rate as "good" in IIHS evaluations versus current models that do is that earlier vehicles could be expected on average to have greater intrusion into the occupant compartment and a "softer" crash pulse as compared to a similarly sized "good" performing vehicle. This could translate to a different distribution of injuries for newer vehicles that would have less intrusion into the occupant compartment, but possibly a "stiffer" crash pulse.

The CIREN MAIS 3+ injury cases used in the current study may have a different distribution of vehicle/crash and occupant variables than a set of NASS-CDS MAIS 3+ injury cases obtained using the same vehicle- and crash-based inclusion criteria. For starters, all CIREN case occupants went to a level I trauma center. Thus, on average, the ISS, MAIS, and crash measures such as delta V are likely to be higher in CIREN than NASS-CDS. However, there is no reason to believe that CIREN would be biased in a way that would alter the relationships between outcomes of interest and the significant predictors documented in the current study.

Future Study

Although the models produced show good fit based on statistical measures, future work will be required to assess the sensitivity and specificity of the respective models. Receiver operating characteristic (ROC) curves will be produced for this purpose. Future work should also compare the NASS-CDS-based models for predicting probability of MAIS 3+ injury from the current study versus those of the URGENCY Algorithm. The URGENCY Algorithm comprehends multiple impact directions. Thus, direct comparison of the predictive capabilities of URGENCY Algorithm versus the current CDS-based models may not be appropriate given the restrictions on case types used in the current study per the inclusion criteria. However, the methods used in the current study could be expanded to produce combined probability models for multiple impact scenarios (front, side, rear and/or rollover, e.g.).

Future work could also involve improved grouping or filtering of outcomes. This could include filtering of outcomes by the occurrence of more serious or compelling Abbreviated Injury Scale (AIS) 3+ injuries to further improve the predictive capability of the models by refining the relationships between the types of injuries sustained and the possible vehicle and occupant predictors. For instance, CIREN data provides additional detail beyond the AIS coding to document whether an AIS 3 long bone fracture was open or closed or whether an AIS 3+ internal organ or vessel injury required invasive surgery. Looking at the relationship between occupant and vehicle/crash predictors and these more compelling injuries may provide additional insight into the predictors that could be used in the triage of motor vehicle crash victims. Additionally, there may be other significant predictors or means by which to refine or re-group the predictors from the current study to further improve the predictive capabilities of the individual models.

The current study has modeled and found significant many of the variables used in the ACS field triage decision scheme. However, related to telemetry data field in Step 3 of the field triage decision scheme, future study of EDR cases in CIREN would require a larger set of data to better study the relationship between the outcomes of interest from the current study and EDR variables such as delta V, 50 ms crash pulse, pre-impact braking, and pre-impact vehicle speed.

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APPENDIX

Table A1. Results of binary logistic regression tests for all CIREN cases

		Data Source				Occupant Outcome									
						ICU		Fatal		ICU or Fatal		OR < 12 hrs		OR < 24 hrs	
	Variable	ACN	Crash Site / EMS	Hospital	Crash Investigation	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Vehicle & Crash Data	Entrapped		x			3.1	0.0780	-	-	-	-	3.0	0.0843	-	-
	Entrapped or No Exit		x			4.0	0.0462	3.9	0.0488	-	-	6.3	0.0118	10.9	0.0009
	WinSMASH Long. Delta V				x	8.7	0.0032	8.5	0.0035	14.1	0.0002	-	-	4.6	0.0325
	WinSMASH Total Delta V				x	7.8	0.0052	9.2	0.0024	13.3	0.0003	-	-	5.1	0.0244
	BES				x	12.6	0.0004	11.6	0.0007	19.5	< 0.0001	-	-	5.7	0.0166
	PDOF	x			x	-	-	-	-	-	-	-	-	-	-
	Maximum Crush				x	11.2	0.0008	8.8	0.0030	16.1	< 0.0001	-	-	4.0	0.0451
	Crush Area				x	17.8	< 0.0001	6.7	0.0098	22.2	< 0.0001	-	-	5.2	0.0225
	Average Crush: C1 - C6				x	15.9	< 0.0001	9.5	0.0021	21.8	< 0.0001	-	-	8.3	0.0039
	Vehicle Curb Wt	x				-	-	-	-	-	-	-	-	-	-
	Vehicle Curb Wt < 1500 kg	x	x			-	-	-	-	-	-	2.9	0.0898	5.0	0.0261
	Vehicle Model Year	x				5.3	0.0210	7.3	0.0070	-	-	-	-	-	-
	CAC[1]	x				-	-	ID[1]	ID[1]	-	-	-	-	-	-
	Airbag Deployment[2]	x				-	-	ID[2]	ID[2]	-	-	-	-	-	-
	Intrusion at Case Occupant				x	18.8	< 0.0001	-	-	18.4	< 0.0001	6.0	0.0140	15.2	< 0.0001
	Intrusion - Any Position				x	11.3	0.0008	-	-	11.5	0.0007	-	-	6.5	0.0111
	Intrusion > 12" at Case Occ		x			17.6	< 0.0001	-	-	19.4	< 0.0001	7.0	0.0081	13.0	0.0003
	Intrsusion > 18" in Any Position		x			3.2	0.0730	-	-	3.2	0.0721	-	-	-	-
	Intr. > 12" at Occ or > 18" Any		x			13.7	0.0002	3.4	0.0634	16.6	< 0.0001	6.4	0.0112	13.0	0.0003
Occupant Data	GCS < 14	x	x			20.6	< 0.0001	23.5	< 0.0001	23.8	< 0.0001	-	-	-	-
	GCS < 14, Tubed or Sedated	x	x			41.9	< 0.0001	35.8	< 0.0001	53.1	< 0.0001	-	-	-	-
	Respiration Rate <10 or >29		x			2.8	0.0959	11.6	0.0007	6.3	0.0122	4.6	0.0321	-	-
	Systolic Blood Pressure < 90		x			15.8	<0.001	5.9	0.0153	17.5	< 0.0001	2.9	0.0877	-	-
	Triage Step 1		x			44.7	< 0.0001	17.8	< 0.0001	53.7	< 0.0001	4.2	0.0406	-	-
	Triage Step 2		x			8.8	0.0031	-	-	10.8	0.0010	3.1	0.0799	7.9	0.0050
	Triage Step 1 or 2		x			25.4	< 0.0001	7.5	0.0061	32.3	< 0.0001	3.9	0.0487	5.0	0.0249
	Triage Step 1 and 2		x			20.0	< 0.0001	4.2	0.0398	20.3	< 0.0001	6.0	0.0141	4.1	0.0435
	BMI			x		-	-	-	-	-	-	-	-	-	-
	BMI Ranges	x	x			-	-	-	-	-	-	3.4	0.0652	-	-
	Age	x	x			6.7	0.0097	-	-	8.5	0.0036	5.2	0.0229	12.1	0.0005
	Age Ranges	x	x			-	-	6.5	0.0105	3.2	0.0738	4.1	0.0442	13.5	0.0012
	Age > 65 Years	x	x			5.1	0.0244	5.3	0.0209	8.4	0.0037	3.6	0.0588	12.2	0.0005
	Gender	x	x			-	-	3.9	0.0486	-	-	-	-	-	-
	Driver / Passenger	x	x			-	-	-	-	-	-	3.9	0.0496	-	-
	Belt Use	x	x			-	-	18.4	< 0.0001	-	-	-	-	-	-

Notes:
1. Only two fatals on certified advanced compliant (CAC) vehicles
2. Only 15 non-deployments in 482 cases. This resulted in quasi-complete separate in some analyses.

Table A2. Results of binary logistic regression tests for CIREN EDR cases

		Data Source				Occupant Outcome							
						ICU		ICU or Fatal		OR < 12 hrs		OR < 24 hrs	
	Variable	ACN	Crash Site / EMS	Hospital	Crash Investigation	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Vehicle & Crash Data	Entrapped		x			-	-	-	-	-	-	-	-
	Entrapped or No Exit		x			3.2	0.0742	-	-	-	-	-	-
	EDR - Long. Delta V	x				6.4	0.0112	6.1	0.0135	3.2	0.0730	3.7	0.0545
	EDR - 30 ms pulse	x				4.0	0.0463	-	-	-	-	-	-
	EDR - 50 ms pulse	x				4.8	0.0282	3.2	0.0748	-	-	-	-
	EDR - Avg Decel Gs	x				4.9	0.0267	5.5	0.0194	-	-	3.2	0.0745
	EDR - Pre-Impact Veh Speed	x				-	-	-	-	-	-	-	-
	EDR - Pre-Impact Braking	x				3.5	0.0627	4.0	0.0445	-	-	-	-
	WinSMASH Long. Delta V				x	4.3	0.0384	3.5	0.0621	-	-	2.8	0.0932
	WinSMASH Total Delta V				x	4.3	0.0376	3.5	0.0623	-	-	2.9	0.0870
	BES				x	5.3	0.0219	4.4	0.0370	-	-	-	-
	PDOF	x			x	-	-	-	-	-	-	-	-
	Maximum Crush				x	-	-	-	-	-	-	-	-
	Crush Area				x	-	-	-	-	-	-	-	-
	Average Crush: C1 - C6				x	-	-	-	-	-	-	-	-
	Vehicle Curb Wt	x				-	-	-	-	-	-	-	-
	Vehicle Curb Wt < 1500 kg	x	x			-	-	-	-	-	-	-	-
	Intrusion at Case Occupant		x			7.1	0.0077	5.8	0.0163	-	-	3.3	0.0698
	Intrusion - Any Position				x	7.4	0.0064	5.5	0.0188	-	-	4.1	0.0431
	Intrusion > 12" at Case Occupant		x			6.5	0.0109	5.3	0.0209	-	-	3.7	0.0528
	Intrsusion > 18" in Any Position		x			-	-	-	-	-	-	-	-
	Intr. > 12" at Occ or > 18" Any		x			7.9	0.0050	6.5	0.0107	-	-	4.3	0.0389
Occupant Data	GCS < 14	x	x			-	-	-	-	-	-	-	-
	GCS < 14, Tubed or Sedated	x	x			-	-	-	-	-	-	-	-
	Respiration Rate <10 or >29		x			-	-	-	-	-	-	-	-
	Systolic Blood Pressure < 90		x			-	-	-	-	-	-	-	-
	Triage Step 1		x			-	-	-	-	-	-	-	-
	Triage Step 2		x			3.9	0.0495	3.0	0.0852	-	-	-	-
	Triage Step 1 or 2		x			-	-	-	-	-	-	-	-
	Triage Step 1 and 2		x			-	-	-	-	-	-	-	-
	BMI			x		-	-	-	-	-	-	-	-
	BMI Range	x	x			-	-	-	-	-	-	-	-
	Age	x	x			-	-	-	-	-	-	-	-
	Age Ranges	x	x			-	-	-	-	-	-	-	-
	Age > 65 Years	x	x			-	-	-	-	-	-	-	-
	Gender	x	x			-	-	-	-	-	-	-	-
	Driver / Passenger	x	x			-	-	-	-	-	-	-	-
	Belt Use	x	x			-	-	-	-	2.9	0.0863	3.0	0.0854

Combined Probability Equations:

$$P(ICU) = P(AIS3+) * P(ICU \mid AIS3+) \quad \text{(A1)}$$

$$P(AIS3+) = \frac{1}{(1+\exp^{-(-7.383+0.031*X_1+0.158*X_2+1.044*X_3+0.981*X_4-0.536*X_5)})} \quad \text{(A2)}$$

Where X_1 to X_5 represent the respective predictors as ordered in Table 6.

$$P(ICU \mid AIS3+) = \frac{1}{(1+\exp^{-(-283.0-0.477*X_1+0.141*X_2+0.023*X_3-1.031*X_4-0.292*X_5)})} \quad \text{(A3)}$$

Where X_1 to X_5 represent the respective predictors as ordered in Table 4.