INJURY IDENTIFICATION: PRIORITIES FOR DATA TRANSMITTED

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ABSTRACT

The objective of this study was to prioritize the variables that could be transmitted with an ACN (Automatic Crash Notification) signal. The main purpose of transmitting these variables is to assist in early identification of those occupants with time critical injuries. For the purposes of this study, all MAIS 3+ injuries were classified as time critical. The basis for prioritizing crash variables was based on their ability to identify MAIS 3+ injured occupants in the National Automotive Sampling System- Crashworthiness Data System (NASS/CDS) dataset.

In this study, multivariate models to represent crash events were developed based on historical crash data from the years 1997-2003. The analysis established a relationship between crash attributes and crash outcomes for all passenger vehicles in the database.

The resulting analysis provided a ranking of crash variables in order of importance. Crash severity (Delta-V) was found to be the most important variable for all planar crash directions. The addition of other crash variables improved the accuracy of the injury prediction algorithm.

For frontal crashes important secondary crash variables include: 3-point belt usage, multi-impact crashes, occupant age and the presence of more than 6” of intrusion. For near-side crashes, the most important secondary variables were occupant age, narrow object crashes, and the presence of intrusion. For far side crashes, the most important secondary crash variables were 3-point belt usage and the occurrence of a narrow object crash. Rollover was found to be a high risk event that predicted high injury risk independent of Delta-V if 3-point belts were unused.

The paper will show the relative importance of the crash and occupant variables by crash direction.

INTRODUCTION

The emergence of Automatic Crash Notification (ACN) Systems provides the ability to rapidly determine the location of motor vehicle crashes. When a crash occurs that is severe enough to cause injuries, the ACN system automatically transmits GPS position data to a telematics service provider. The exact location of the crash is immediately determined by the service provider who, in turn, notifies the closest rescue center. If the occupants of the crash involved vehicle can communicate verbally, the telematics service provider may interact with them to determine their emergency needs. ACN systems have the potential to greatly reduce notification time and improve the accuracy of location data transmitted to rescue teams [1,2,3].

Improved safety systems in motor vehicles are protecting crash victims from many of the injuries that are recognizable from physiological responses making the detection of residual injuries more difficult [4,5,6]. A growing challenge to acute care providers is the identification of those crash victims who suffer from time critical injuries.

Modern motor vehicles are equipped with sensors to measure a number of factors to permit decisions regarding the deployment of safety systems. Much of the information used to deploy safety systems would also be useful in determining the risk of injury to occupants. The information measured may vary from vehicle to vehicle. However, it generally includes a measurement of the crash severity such as the change in velocity during the crash and the direction from which the vehicle was impacted.

Ongoing research first initiated by the National Highway Traffic Safety Administration (NHTSA) investigated methods to interpret crash attributes that could be recorded in the vehicle and transmitted with an ACN call to assist in identifying the crashes and crash victims that are most likely to suffer time critical injuries [7,8,9].

The transmitted information would be examined by care providers and compared with injury experience in similar crashes to estimate the risk of a time critical injury and a series of injuries which may be present. When the emergency crew arrives on scene, additional information can be obtained and transmitted.

Based on crash circumstances, the potential for occupant injury in the event of a motor vehicle collision depends on three key attributes.

- the magnitude of loading experienced by the occupant
- the means through which the load is transferred to the human body
- individual characteristics of occupants which effect their tolerance for injury

To formulate an algorithm which estimates the potential for injury in the event of a collision, crash attributes must be selected which best characterize the conditions cited above. The methodology used to interpret these crash conditions for prioritization of rescue services is called the URGENCY Algorithm.

Current Automatic Crash Notification Systems (ACN) are triggered following crashes severe enough to deploy airbag systems. This is an approximate severity threshold. If a notification of emergency services was made for every crash exceeding these thresholds, a percentage of the population requiring help would benefit from rapid notification of rescue and subsequently receive care. At the same time, a group of occupants who were not severely injured may also receive care in the event that their crash exceeds this approximate threshold. For many, high level rescue care may not be necessary at all.

It should be noted that additional characteristics regarding crash severity may be obtained by current ACN systems from verbal communications with crash involved occupants as well as on-lookers. For this reason, it should not be assumed that rescue is dispatched for every ACN call exceeding airbag deployment thresholds. For the purpose of this study, the prioritization of crash variables presented below assumes that no other information other than airbag deployment is available from which crash severity can be assessed.

For frontal crashes, the approximate severity necessary for airbag deployment corresponds to a 12 mph deltaV for first generation airbag systems. In recent model year vehicles, the threshold for airbag deployment could vary based on the use of 3-point belts as well as seating position and occupant size. If an adult is properly seated and belted during a frontal crash, the threshold for airbag deployment may be higher due to decreased need for a supplemental restraint. The deltaV may be approximately 16 mph or higher for frontal crashes. Seat belt usage is an example of a factor which may influence the risk of serious injury in a crash. For side impact crashes, the threshold for deployment may be as low as 7-8 mph. Using these approximations, a baseline estimate of injured occupants who would be correctly identified in the field can be made.

Table 1 below shows annual counts for injured occupants by crash mode. Table 2 identifies the percentage of injured and non-injured occupants whose crashes fall above the approximated airbag deployment thresholds described above. This data was derived from tow-away crashes in NASS/CDS from 1997-2003 where crash direction is known.

Table 1. Annual tow-Away Crash injuries by crash direction (NASS/CDS 1997-2003 average)

Crash Mode	MAIS3+ Injured	Non-MAIS3+ Injured
Frontal	54,508	2,165,571
Nearside	14,124	260,382
Farside	7,025	257,386
Rear	2,451	339,077
Rollover (w/o planar deltaV)	22,744	336,443

Table 2. Injured and non-injured occupants at or above airbag deployment thresholds by crash direction (NASS/CDS 1997-2003 average)

Crash Mode (cutoff value)	MAIS3+ Injured Exceeding Cutoff DeltaV	Non-MAIS3+ Injured Exceeding Cutoff DeltaV
Frontal (16 MPH)	69.7%	22.5%
Nearside (8 MPH)	98.8%	67.8%
Farside (8 MPH)	98.9%	69.0%
Rear (16 MPH)	78.9%	20.6%
Rollover	0.0%	0.0%

The data shown in Table 2 serves as a baseline for this study. Next, the usefulness of including additional characteristics during the transmission of an ACN signal is quantified through a comparison with the accuracy of current technology.

METHODOLOGY

The goal of this study was to quantify the frequency that today's ACN systems would accurately distinguish occupants who need immediate medical attention from those who do not. Additional parameters were identified that could be transmitted by future ACN systems to refine the criteria used to distinguish occupants in need. The relative rate that occupants are correctly flagged as likely to be severely injured versus non-severely injured are presented with the inclusion of each of these additional variables.

This study addresses passenger vehicle occupants over the age of 16 who may have severe or time critical injuries following a crash. This category includes occupants who sustained at least one or more AIS3 injury or those who were fatally injured during a crash due to trauma. Throughout this text, these occupants will be referred to as MAIS3+ injured occupants.

Source Data

Data including occupant injury severity as well as all details describing the crash event were derived from the National Automotive Sampling System-Crashworthiness Data System (NASS/CDS) [10]. Within NASS/CDS, specific injuries sustained, including their severities, are recorded allowing for the direct association of crash conditions with crash outcomes as used in this study.

NASS/CDS case data has been collected since 1988 by the National Center for Statistics and Analysis and is a sample of tow-away crashes that occur within the US. The data is used to monitor the effectiveness of traffic safety programs and to provide a resource to understand the relationship between the type and seriousness of crashes and their associated injuries. To qualify for inclusion, the crash must have a police report, be reported to the state, involve a "harmful event" (defined as property damage, personal injury, or both) and occur as a result of a non-stable situation deemed accidental (non-intentional, non-disease related or not due to a natural disaster).

Each investigated crash must involve a motor vehicle in transport on a public roadway and must involve at least one towed vehicle. At each sampling site the research team investigates a subset of police reported crashes. One of 24 teams of crash researchers throughout the country investigates the each crash and collects all relevant data. For this investigation, detailed review of police accident reports, hospital records, out-of-hospital care records, photographs of the vehicles, and the vehicles themselves are conducted. With the sampling process, the data are weighted to represent the nationwide incidence of crashes and resulting injuries. Based on the probability of sampling, a weighting factor is assigned to each case so that its characteristics may be projected to the total population.

Model Creation

A review of crash characteristics as well as occupant characteristics available within the NASS/CDS dataset was conducted to identify the most influential variables for crash severity assessment. These characteristics were compiled based on findings from available literature as well as the real life experience of the University of Miami CIREN team during crash case collection since 1991.

In order to take into account multiple factors influencing crash severity and the likelihood of injury, multiple regression techniques were used. Since the outcome of interest could fall into one of two categories (MAIS3+ injured or non-MAIS3+ injured), binary logistic regression is ideally suited for the analysis. In addition, certain high severity crash attributes like the occurrence of complete occupant ejection were assumed to indicate high probability of severe injury even in the absence of other crash factors.

Binary logistic regression relates the contribution of independent predictor variables (crash conditions) with dependant outcomes (injury). Using the Principle of Maximum Likelihood, an estimate of the likelihood of the outcome (injury) is derived on a scale from 0 to 100% probability.

Equations 1-2 show the mathematical relationship between crash characteristics and injury outcome probability following logistic regression model creation. The regression parameters including the *Intercept*, β_1, β_2… shown below are based on a least squares fit of existing historical crash data from NASS/CDS.

Eq. 1: $$w = (Intercept) + \beta_1 * deltaV + \beta_2 * factor_2$$

Eq. 2: $$P(MAIS3+) = \frac{1}{(1+\exp(-w))}$$

Each logistic regression model was trained using NASS/CDS 1997-2001 data. 2003 and 2003 datasets were used to evaluate the accuracy of the resulting models. As an example, Table 3 below lists parameter estimates for a model relating the deltaV continuous variable deltaV to the likelihood of MAIS3+ injury. This model assumes average values for all other crash factors which may influence the risk of injury.

Table 3. Logistic Regression model parameters including deltaV only by crash direction

Crash Mode	Parameter	Estimate
Frontal	Intercept	-4.2052
	DeltaV	0.1157
Nearside	Intercept	-4.0652
	DeltaV	0.181
Farside	Intercept	-4.5426
	DeltaV	0.1384
Rear	Intercept	-5.5143
	DeltaV	0.1303

Figure 1 shows the resulting risk of MAIS3+ injury which may be calculated using Equations 1-2 for crashes by deltaV. DeltaV estimates the difference between pre-impact and post-impact velocity as a function of the damage of a vehicle involved in a crash. Figure 1 shows that as deltaV increases, the risk of injury increases from 0 to 100% risk. Crash direction influences these relative values considerably due to differences in available occupant protection, crush space and human tolerance to injury.

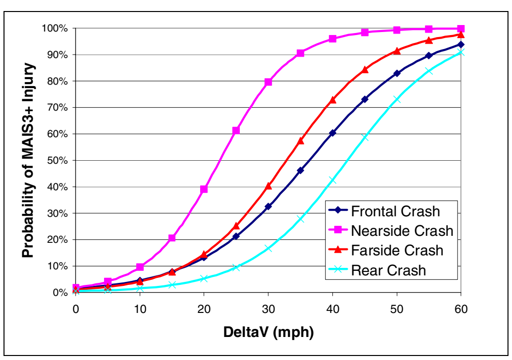

Figure 1. MAIS3+ injury risk by deltaV and crash direction

With the knowledge of additional parameters, logistic regression may be used to simultaneously interpret multiple pieces of crash data in addition to deltaV as shown above. Logistic regression uses the method of least squares to simultaneously consider crash factors that may be influential. As additional parameters that are influential to injury outcome are added to the model, the fit and predictive accuracy will increase. This accuracy includes the correct classification of both injured and uninjured occupants.

Before the creation of each logistic regression model, all relevant crash attributes were reviewed for consistency and reconditioned when appropriate using SAS version 8.2. All regression models were created using SAS callable SUDAAN. SUDAAN is a statistical package which allows for the analysis of complex sample data like NASS/CDS. It allows for the correct interpretation of sample variances for multi-stage, clustered samples.

As previously mentioned, the binary outcome variable MAIS3+ was used in the analysis to distinguish injured from non-injured. For this study MAIS 7 were considered unknown unless a fatality occurred. These occupants were discarded from the analysis. Cases where missing values exist for any model variable are unusable for model training as well as testing and were therefore discarded as well.

Criteria for the Recognition of Injured Occupants

For the purpose of this study, any occupant whose risk of injury exceeds 10% will be classified as potentially injured. This threshold was selected so that any potential improvements in data transmitted could be directly compared with the current performance of existing ACN systems.

As previously explained, current ACN systems are typically triggered at crash severities corresponding to the threshold for airbag deployment. Figure 1 indicates that the risk of MAIS3+ injury for frontal crashes at 16 mph (frontal airbag deployment threshold) is slightly less than 10%. The goal of this study is to identify that additional crash parameters should help to refine a crash severity estimate currently based on a deltaV threshold alone. This threshold corresponds to a 10% risk of MAIS3+ injury. As model improvements are made with the addition of relevant crash characteristics, crashes that may be incorrectly classified above or below this threshold value will be better described and, in turn, more accurately categorized.

As additional data is made available for crash severity assessment by ACN systems, the relative improvement to the classification of injured versus non-injured occupants can be easily evaluated using a similar threshold for ACN triggering.

Crash Characteristics Evaluated

A review of relevant crash characteristics was conducted to identify factors which influence the risk of injury given that a motor vehicle crash has occurred. The review is broken into four primary sections defining impact characteristics, crash outcomes in terms of vehicle performance, occupant attributes and the influence of restraint systems on injury severity.

These characteristics include impact speed or deltaV, crash direction, degree and location of vehicle damage. Some of these characteristics can be measured by existing on-board vehicle sensors, however, verbal collection of many of these crash attributes is possible. Additional information describing occupant characteristics and restraints used during an event provide further insight into an occupant's likelihood for severe injury.

Below, a discussion of the importance of each variable is presented. Additionally, relevant findings of other studies are presented in support of variable selection for further modeling.

<u>DeltaV</u>- Pre impact speed has been recognized as an indicator of injury severity due to its direct relationship with occupant loading during a crash. In order to estimate the change in vehicle speed that occurs during a crash, the delta velocity or deltaV is calculated by crash investigators. This parameter quantifies the magnitude of impact energy absorbed by a vehicle structure in the lateral and longitudinal directions during a collision. For this calculation, post crash vehicle measurements of deformation are used in conjunction with vehicle stiffness values and post impact trajectory to estimate the impact energy absorbed. Based on the mass of the vehicle, the energy absorbed may be used to estimate the pre-impact vehicle speed or deltaV.

DeltaV in the longitudinal and lateral directions have been identified as the best general predictors of crash severity. All calculations using deltaV are in MPH.

<u>Crash Mode</u>- The ability to manage the kinetic energy of a vehicle and occupant depends largely on the primary direction that decelerating forces are applied. For example, frontal crush zones, seatbelts and frontal airbag systems help to manage energy along the longitudinal axis of the vehicle. Similarly, these features like seatbelts and frontal airbags do not provide significant protection or benefit for high severity lateral crashes.

For this study, crash mode has been categorized using Collision Deformation Classification (CDC) data collected by NASS/CDS investigators. Each mode is categorized as follows:

Frontal: (PDOF≥11 and PDOF≤1, Any Seating Position) or (PDOF=10 or 2 where General Area of Damage is Front)

Nearside: (PDOF≥2 and PDOF≤4, Right Seating Position, General Area of Damage is Right) or (PDOF≥8 and PDOF≤10 and, Left Seating Position, General Area of Damage is Left)

Farside: (PDOF≥2 and PDOF≤4, Left or Middle Seating Position, General Area of Damage is Right) or (PDOF≥8 and PDOF≤10 and, Right or Middle Seating Position, General Area of Damage is Left)

Rear: PDOF≥ 5and PDOF≤7

These crash categories were published and applied by NHTSA during the Final Economic assessment of the FMVSS Advanced Airbag Final Rule [11].

<u>3-Point Belt Use</u>- The kinetic energy of the occupant, which is also proportional to his or her mass, must be similarly transferred or dissipated. The goal of energy absorbing restraint systems is to match the deceleration of the occupant closely with the controlled deceleration of the vehicle structure but also to absorb a portion of the occupant's kinetic energy such that their overall deceleration and force distribution falls below their threshold for injury.

The influence of safety belt usage on injury and fatality outcomes has been well documented. In a 2000 report by NHTSA, 3-point belt effectiveness was evaluated using the double-pair comparison method [12]. The study examined fatality counts for drivers and right front passengers where one, neither, or both occupants are wearing safety belts during a crash event. Fatality differences for the belted population vs. the unbelted population provide an accurate means to assess seatbelt effectiveness based on individual case outcomes. Overall, the total reported value for seatbelt effectiveness was 45.2% for all impact types combined.

Of particular interest is the variation in 3-point belt effectiveness for frontal, rear and rollover crash types when compared with nearside and farside crashes. Findings of the NHTSA study identify that different mechanisms of injury occur by crash type. According to these findings, the contribution of belt usage varies in its influence of outcome based on impact direction and seating position. This data further supports the need for separate predictive models based on crash mode. This approach takes into account considerable differences between occupant kinematics or loading and crash mode.

Other studies support the effectiveness estimates shown in the NHTSA study. Three-point belt usage was reported to reduce fatality risk by over 50% by Bedard et. al. for all crash modes combined [13].

For the purpose of this study, any occupant (16 years and older) whose manual belt use is coded as lap and shoulder is considered to be belted. The use of automatic belts is considered belted as long as both lap and shoulder systems are used.

<u>Rollover</u>- Following ejections, the occurrence of rollover is the second most prominent crash attribute leading to occupant injury per occurrence. Yet rollovers are far more numerous. Occupant involvement in rollover crashes exceeds 350,000 annually with 224,000 injured or killed during these events. Of these, 200,000 occupants suffered minor to moderate injuries, 14,100 suffered from serious to critical injuries, and approximately 9,000 occupants are killed annually. Further, rollover crashes were found to constitute 2.2% of the crashes, but 33% of all costs due to injury [14].

In some US counties, the independent use of rollover as a mechanism of injury meeting trauma criteria further supports its importance in the prediction of crash injury. Based on NASS/CDS 1997-2003 data, nearly 8% of unbelted occupants involved in a rollover crash sustained MASI3+ injuries.

A rollover crash event is defined as any crash involving one or more quarter turns about the roll or pitch axis of the vehicle. When a rollover crash occurs in combination with a planar crash before or after the roll occurs, the risk of injury is compounded in proportion with each significant event that has occurred. For the purpose of this study, if a planar crash event is coded as the highest severity event where the CDC indicates front, side or back damage, yet a rollover has occurred, the crash is classified as a planar event. If no damage due to a planar impact is coded, and a rollover has occurred, the collision is considered a rollover.

<u>Multiple Impacts</u>- To correctly estimate the risk of injury during motor vehicle crashes, it is necessary to recognize when multiple impacts have occurred. By neglecting other impacts which may be considered less severe, an occupant's total crash exposure and exposure to crash energy is not accurately established.

In order to accurately estimate the risk of injury as a result of a crash event, the primary direction of loading is fundamental. The correct classification of crash type has traditionally been based on the principle direction of force (PDOF) and general area of damage (GAD) for the most harmful event. This event typically corresponds to the highest deltaV collision if multiple impacts occur. If a second event occurs where its severity is considered less than the first, the added risk due to this second impact would often go unnoticed during most analyses. If this second event occurs in a crash direction which is different than the first (i.e. front then side), occupants would be exposed to a new set of risk factors between events. It is necessary to consider each distinct event which occurs during a crash to estimate injury potential.

Fay et. al. recognized that multiple impacts represent the greatest proportion of serious injury accidents in German data and the second highest proportion in UK data. It was suggested that the effectiveness of restraint systems could decrease due to multiple impacts [15]. A 2002 study by Digges et. al. indicates that injury risk increases if multiple consequential events have taken place [16].

To address the occurrence of multiple impacts, models must account for this added risk. Ideally, a deltaV value for each impact event could be analyzed to estimate injury risk by crash direction. Unfortunately, only the highest deltaV value is recorded for publicly available NASS/CDS cases. For this reason, a dichotomous variable indicating that more than one damage causing event has taken place is used.

<u>Narrow Object Impacts</u>- Impacts with narrow objects including posts, poles and trees are more likely to lead to serious injury due to an inability of the vehicle structure to safely absorb impact energy. With little structural interaction between narrow

objects and structural features of vehicles, greater crush depths and potential for compartment intrusion are significantly more likely.

A 1998 study by Pilkington found that pole crashes were six times more likely than other crashes to lead to fatality and three times more likely to lead to an injury when compared with car-to-car crashes [17]. Side impact crashes with posts and poles are particularly devastating due to limited crush space and close proximity of occupants to these intruding features.

During frontal collisions, narrow object impacts pose a significant threat to occupants due to short duration high severity decelerations of vehicle structures. This more dangerous crash pulse results because narrow objects often do not interact with structural members designed to absorb impact energy. Rather, poles and trees easily penetrate engine compartments until contact with the engine and other non-energy absorbing structures occurs.

Once this interaction takes place, the vehicle and occupant inside are rapidly decelerated. This short duration, high magnitude deceleration often exceeds the expected performance of energy absorbing interior components designed to protect occupants. Injury often results under these conditions.

Intrusion- During collisions where intrusion into the occupant compartment occurs, the risk for serious injury greatly increases. In the event of a collision with a fixed or non-fixed object, the principle direction of force experienced by the occupant is often in a direction exactly opposite from the trajectory of intruding interior components. For this reason, the reduction in “flail space” is particularly important due to increased risk of contact with the component by the occupant.

This risk is especially evident in nearside crashes where little distance separates the occupant’s head, thorax and pelvis from potentially intruding structures. During frontal and rear crashes the likelihood that intrusion will occur is somewhat reduced; however, motion of the toepan, steering column, a-pillar, instrument panel and roof header toward the occupant can greatly increase chances of severe injury.

Within NASS/CDS, intrusion is coded in ranges of 1-3 inches, 3-6 inches, 6-12 inches, 12-18 inches and 18-24 inches. This data is collected in centimeters equivalent to these ranges. Because these classifications are not continuous, adapting them to a continuous scale is not straight forward. Further, the contribution of intrusion to injury potential for some crashes may have different implications for some crash modes versus others. For example, use of intrusion as a continuous variable for frontal and nearside collisions seems reasonable. For farside and rear impact crashes, intrusion levels do not become critical until large values are reached. This behavior suggests different treatment of this variable based on crash direction.

In order to select the best cutoff criteria for intrusion for farside and rear crashes, the correlation of 6", 12" and 18" intrusion ranges were examined as they relate to outcome. The result of this analysis indicates that intrusion greater than 12" should be used for farside and rear crashes to account for the possibility of occupant loading by intruding structures. For frontal and nearside crashes, intrusion on a continuous scale is used.

Ejection- Each year 7,800 people are killed and 7,100 are seriously injured due to partial or complete occupant ejections [18]. The majority of those fatally injured are unbelted and many are ejected during rollover crashes. An investigation of rollover crashes and associated risk identified that 65 percent of rollover fatalities occur in the 8 percent of rollovers involving either complete or partial ejection. A 1996 analysis of state data by NHTSA identified that the relative risk of fatality is 72% less for non-ejected drivers versus those ejected and 68% less for non-ejected front seat passengers versus those who are ejected.

Like rollover crashes, complete occupant ejection injury mechanisms automatically meet trauma criteria in most jurisdictions. Due to the great threat of serious injury for ejected occupants, knowledge of ejection occurrence is important to capture high risk occupants during even minor collisions.

Occupant Age- A number of studies have identified occupant characteristics which directly impact the seriousness of crash related injury. It has been established that the elderly driving population has a significantly higher risk of injury and subsequent complications compared with younger drivers [19,7,20,21]. Miltner et. al. recognized increased risk for abdominal, thoracic and extremity injury for the restrained elderly population in frontal crashes [22]. A 1997 study by Farmer et. al. found that occupants age 65 and older are three times as likely to be injured in all collisions compared with occupants 25 and younger [23].

Increased fatality risk for elderly populations has been shown in a number of studies including those by Evans, Miltner and Bedard. The Miltner study reported a 30-45% increased fatality rate for occupants older than 59 when compared to those under 20. Finelli established that trauma mortality rates increased at age 55 (15% compared to 10% for those < 54 years of age) and doubled at age 75 (20%). Bedard reported an odds ratio of 4.98 for the driving population over 80 compared with those who are 40-49 years old. Both Evans and Malliaris report fatality risk to increase linearly as a function of age while others suggest that the true nature of this relationship exhibits some non-linearity particularly for the very old.

For this study, occupants 16 years and older were included. The study by Zhou et. al. indicated that occupants ages 16-35, 35-65 and 65 years and higher showed similar thoracic injury tolerances. These age categories were considered to simplify age evaluations that may take place in the field; however, age used on a continuous scale provides a better estimate of increasing injury risk with age.

Occupant Gender- Occupant gender and its relationship with injury has been evaluated by many. Differences in the relative frequency of involvement by gender for each crash type and crash severity often mask the true nature of injury risk for males versus females. An early study by Evans, using the double pair comparison method, provides a good indication of outcome differences seen by gender given that each group is exposed to the same crash environment. This study identified that fatality risk is 25% greater for females compared with males who are 15-45 years old.

More recent findings by Bedard support those of Evans showing an increased fatality risk for female drivers with an odds ratio of 1.54 when compared with males for single vehicle crashes [13]. In the 1997 study by Farmer, increased odds for AIS3+ injury were reported for nearside crash involved females while a decreased odds ratio was reported for far-side crash involved females. The far side findings were not shown to be statistically significant [23].

Height and Weight- Mock et. al. investigated the combined effect of occupant body weight and height using the Body Mass Index (BMI). This study identified an increased risk of mortality with increasing BMI during serious crash events [24]. The odds ratio for fatality was reported to be 1.013 for each kilogram increase in body weight using a 60 kg reference category. An odds ratio of 1.037 was found for each unit increase in BMI (reference value BMI=20). BMI is calculated by dividing body weight in kilograms by the square of body height in meters. A BMI < 27 is considered normal, BMI > 27 and BMI < 31 is considered overweight while a BMI > 31 is considered obese. Findings of the Mock study support the concept that overweight and obese vehicle occupants are at a higher risk for injury than occupants with a normal body mass index. Augenstein et. al. identified increased risk for occult liver injury for obese occupants based on investigation of injury patterns for CIREN crash cases [5].

Based on NASS/CDS analysis results, no conclusive evidence of the influence of BMI on injury was found when odds ratios for MAIS2+ and MAIS3+ injuries were reviewed. Unlike the odds ratio for injury, the fatality estimates comparing occupants who have a BMI > 31 and those having a BMI < 31, showed that the obese group had fatality odds 1.42 (95% CI 1.393,1.449) times that of the non-obese group.

RESULTS

During this study, crash factors that are not currently in use by ACN systems were evaluated to understand the degree to which they could improve accuracy of MAIS3+ injury recognition. Changes in accuracy can be assessed by comparing the sensitivity and specificity for the baseline criteria including only a deltaV threshold by crash direction to potentially enhanced models including other crash attributes. Those variables which directly increase the number of injured occupants recognized were prioritized ahead of those variables whose impact on increasing model specificity was more significant.

Model sensitivity is defined as the number of correctly identified injured occupants divided by the complete population of injured occupants. A sensitivity of 75% would indicate that three quarters of all those injured were correctly identified. While one quarter of the injured population were incorrectly flagged as uninjured. The specificity of a model indicates the percentage of a population which is correctly diagnosed as uninjured when they are, in fact, not injured. High sensitivity and high specificity are desirable characteristics for a predictive model.

Table 4 shows the baseline capture rates for a model including only deltaV, crash direction and knowledge of occupant seating position. A 10% threshold for serious injury is applied here.

Table 4. Baseline model performance by crash mode: includes deltaV, crash direction, seating position

Crash Mode	Sensitivity	Specificity
Frontal	63.0%	82.0%
Nearside	92.1%	53.9%
Farside	54.1%	85.4%
Rear	41.6%	95.8%
Rollover	0.0%	0.0%

An evaluation of models including baseline data (i.e. deltaV and crash direction) was conducted plus each of the following crash attributes individually. Each variable combination was applied against NASS/CDS data from 2002 and 2003 for frontal, nearside, farside and rear crashes.

Crash Attributes:

3-Point Belt Usage
Rollover Occurrence
Complete Occupant Ejection
Occupant Age
Multiple-Impact Crash Events
Narrow Object Collision
Occupant Compartment Intrusion

Table 5 shows the performance of a model including deltaV, crash direction, occupant seating position and seatbelt usage. The addition of 3-point belt usage to the baseline model showed the highest improvement in model sensitivity and specificity across all planar crash modes. The addition of seatbelt usage was also critical for subsequent variables like rollover occurrence to be effectively interpreted.

Table 5. Baseline plus seatbelt usage model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	69.8%	84.2%
Nearside	93.1%	55.4%
Farside	73.2%	85.9%
Rear	62.5%	95.9%
Rollover	0.0%	0.0%

Due to the high rate of injury for rollover crash involved occupants, the occurrence of rollover was the next most influential variable in capturing MAIS3+ injured occupants. As discussed above, unbelted occupants involved in rollover crashes make up a large percentage of the severe and fatally injured occupants for this mode. Without knowledge of seatbelt usage, a rollover crash in the absence of other information does not exceed the 10% threshold for injury as applied in this study. However, if seatbelt usage is known, the occurrence of rollover for an unbelted occupant identifies over 2/3 of the MAIS3+ injured occupants with a 73.3% specificity as shown in Table 6. Current technology relies on verbal information to recognize that a rollover has occurred in the absence of a significant planar crash.

Table 6. Baseline, seatbelt usage and rollover model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	68.8%	85.1%
Nearside	92.4%	60.2%
Farside	64.3%	86.6%
Rear	60.6%	96.3%
Rollover	67.4%	73.3%

Table 7 shows the effect of monitoring and recording more than one significant impact event.

Table 7. Baseline, seatbelt usage, rollover and multiple impact model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	69.9%	84.4%
Nearside	92.4%	60.2%
Farside	64.3%	86.6%
Rear	60.6%	96.3%
Rollover	67.4%	73.3%

In Table 8 below, occupant age was introduced. The effect on improved model sensitivity and specificity is noticeable for all modes, however this information is not readily available from sensor systems currently used in vehicles. This information can be derived from verbal communication between telematics service providers if occupants are present and alert following a crash.

Table 8. Baseline, seatbelt usage, rollover, multiple impact and occupant age model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.8%	83.5%
Nearside	96.8%	62.2%
Farside	66.7%	88.6%
Rear	62.7%	95.6%
Rollover	67.4%	73.3%

The occurrence of a narrow object impact was added next. Table 9 shows the relative effect on injured occupant capture rate with this variable. Like occupant age, knowledge that a narrow object collision has occurred is not readily available from vehicle sensor information. This data may be provided through verbal exchange with crash involved occupants or eyewitness reports. Use of crash pulse may not be an effective way to derive crash partner (i.e. trees, poles, posts) information at this time.

Table 9. Baseline, seatbelt usage, rollover, multiple impact, occupant age and narrow object impact model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	72.2%	84.1%
Nearside	93.8%	65.5%
Farside	79.7%	88.6%
Rear	63.1%	96.4%
Rollover	67.4%	73.3%

Occupant compartment intrusion was added next. The effect of compartment intrusion knowledge leads to an increase in sensitivity for side impact crashes while reducing the capture rate for frontal crash occupants.

Table 10. Baseline, seatbelt usage, rollover, multiple impact, occupant age, narrow object and intrusion model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.5%	87.1%
Nearside	96.2%	71.5%
Farside	79.8%	88.7%
Rear	68.7%	95.8%
Rollover	67.4%	73.3%

Next, knowledge that an occupant has been ejected was most influential in capturing additional injured occupants for each crash mode. This information should raise rescue priority considerably, however knowledge of seatbelt usage and the occurrence of rollover effectively captures over 68% of the ejected population without direct knowledge that an ejection has occurred. These occupants would be flagged as high risk rollover occupants due to non-belt usage.

Table 11 identifies the improvement in model sensitivity and specificity based on knowledge of ejection.

Table 11. Baseline, seatbelt usage, rollover, multiple impact, occupant age, narrow object crash, intrusion and ejection occurrence model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.6%	87.9%
Nearside	94.4%	73.1%
Farside	81.2%	88.6%
Rear	73.4%	96.1%
Rollover	72.4%	71.2%

DISCUSSION

The use of airbag deployment by crash direction as an approximate threshold for ACN system triggering currently provides a highly sensitive criteria for the recognition of MAIS3+ injured occupants. Based on the information presented in Tables 1 and 2, nearly 61,000 (60.3% of total) tow-away crash involved occupants who sustain MAIS3 and higher injuries would be correctly identified each year based on this criterion alone. This calculation assumes that all vehicles are equipped with ACN technology and no additional information is available from which to make rescue decisions.

Table 2 also indicates that this simplified filtering method is only 54% specific for frontal crashes and only 31% specific for nearside crashes. This corresponds to a 16 mph deltaV for frontal and rear crashes and an 8 mph threshold for side impacts as evaluated.

In the absence of additional information, a large percentage of occupants will be classified as potentially injured when, in fact, they may not be. If all vehicles were equipped with ACN technology, and dispatch decisions were based only on transmitted data, over 910,000 (27% of all non-MAIS3+ injured) tow-away crash involved occupants would exceed ACN system deployment thresholds each year without any AIS3 or higher injuries. It should be mentioned that tow-away crash occupants make up only ¼ of the total crash population across all severities. A large number of property damage crashes occur that were not included in this study. Without improved information describing crash events, an unnecessary waste of resources may result.

As the prevalence of ACN technology increases, greater numbers of these non-injured calls will take place if more accurate assessments of crash severity are not made. Without using readily available crash information like the use of seatbelts, the occurrence of multiple impacts or that a rollover has occurred, ACN calls may not receive the highest priority necessary.

If each of the parameters listed in Table 11 were available for use during the dispatch of rescue, 75,816 MAIS3+ injured occupants (75.1% of total) could be recognized remotely without the introduction of other information. Even with these known parameters, 471,000 tow-away crash involved occupants would exceed ACN system deployment thresholds each year without any AIS3 or higher injuries.

Use of Crash Information for Medical Treatment

So far, the primary focus of this text has been to highlight the potential benefit of transmitting an expanded set of crash attributes to remotely identify occupants in need. However, in-hospital medical staff and rescue providers may also significantly benefit from additional information describing an occupant's mechanism of injury. This information may be valuable during on-scene triage of occupants, in preparation for occupants in transport to emergency rooms/trauma centers and during decision making for in-hospital diagnostic testing.

A subset of injuries, known as occult injuries, go undetected by rescue providers where no external signs of occupant trauma (i.e. external bleeding, lacerations, abrasions, bruises and broken bones) are observed on-scene or even during preliminary in-hospital assessment. Without overt signs of trauma, occupants who have sustained these potentially life threatening and occult injuries could be improperly triaged to medical care facilities not equipped to diagnose or adequately treat these injured occupants. Also, life threatening delays in treatment may take place before some serious injuries are diagnosed.

Ongoing research by the 10 centers of NHTSA's Crash Injury Research and Engineering Network (CIREN) has focused on the identification of occult injuries and crash characteristics that could be associated with them. A series of injuries have been studied and documented in detail.

Among these is the occurrence of occult liver or abdominal injury common during some frontal and farside crashes. Crash characteristics which lead to heart and aortic injuries were studied in detail. These injuries are common during certain nearside crash events and severe injury risk was found to increase for the elderly and often lead to fatality if undetected and untreated. During farside crash events involving unbelted occupants, severe head injuries are prominent. Recognition that this injury mechanism may have occurred is important so that necessary diagnostic testing can be performed followed by treatment before irreversible damage occurs.

In an effort to improve recognition of serious injuries in the field and improve in-hospital medical care, the William Lehman Injury Research Center has compiled a series of crash descriptors in order to improve rescue care decisions and to help educate practitioners about these common injury mechanisms. The pneumonic "SCENE" has been suggested to help rescue providers screen for crash conditions associated with certain occult injuries.

These criteria are as follows:

S teering wheel deformation- Lift the air bag and look for a bent steering wheel rim. Internal injuries to the abdomen, thorax may be likely.

C lose proximity of the driver to the steering wheel- Occupants of small stature or large girth sitting close to the steering wheel are at greater risk of internal injuries particularly during frontal collisions with airbag deployment.

E nergy of the crash- Twenty or more inches of vehicle crush indicate high crash forces that can cause serious internal injuries.

N on-use of seat belts- Non-use of lap or lap/shoulder belts in combination with high energy events could result in multiple impacts within the occupant compartment and greater probability of internal injuries.

E yewitness reports including accounts of the object struck and the principle direction of crash force- This data suggests that verbal reports, photos, and video images of the interior and exterior of the crash vehicle graphically conveys the severity of the crash, and can indicate the probability and type of internal trauma.

CONCLUSIONS

Current ACN technology aids dispatch and rescue care providers to effectively identify and accurately locate occupants who may be injured in the event of a crash. The introduction of additional crash parameters during the transmission and interpretation of crash characteristics has the potential to improve this recognition process significantly. The following information has been identified as important for the recognition of seriously injured occupants:

1. crash severity (deltaV)
2. impact direction
3. use of 3-point belts for each occupant
4. occurrence of a rollover crash
5. occurrence of multiple impact events
6. age of occupants involved in the collision
7. narrow object impact
8. extent of compartment intrusion
9. occupant ejection

If the use of 3-point belts, occurrence of rollover and the occurrence of multiple impact events is supplied in addition to the fact that an airbag has occurred, ACN systems could identify 73.1% of the MAIS3+ injured occupants with full deployment across the vehicle fleet. This assumes knowledge of crash direction as well.

The inclusion of additional parameters as shown above would aid to improve this capture rate for injured occupants however this data may not be available through on-board vehicle sensors in the near term for use by remote dispatch personnel.

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