DEVELOPMENT AND VALIDATION OF THE URGENCY ALGORITHM TO PREDICT COMPELLING INJURIES

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ABSTRACT

The URGENCY algorithm uses data from on-board crash recorders to assist in identifying crashes that are most likely to have time critical (compelling) injuries. The injury risks projected by using the NASS/CDS data are the basis for the URGENCY algorithm. This study applied the algorithm retrospectively to a population of injured occupants in the database from the University of Miami School of Medicine, William Lehman Injury Research Center (WLIRC). The population selected was adult occupants in frontal crashes that were protected by three point belts plus an air bag.

For the cases with greater than 50% predicted MAIS 3+ injury probability, 96% of the occupants in the study had MAIS 3+ injuries. . For the cases with less than 10% predicted MAIS 3+ injury probability, 63% did not have MAIS 3+ injuries. Most of the of MAIS 3+ injuries not predicted involved injuries in multiple impact crashes, pole crashes or close-in occupants injured by air bag deployment. Modifications to the URGENCY algorithm to include predictors for these three factors significantly improved accuracy of the MAIS 3+ injury predictions.

INTRODUCTION

The emergence of Automatic Crash Notification (ACN) systems has provided the ability to rapidly determine the occurrence and location of crashes that are severe enough to deploy the vehicle's air bags. This capability can greatly reduce the time required to rescue injured occupants and initiate medical treatment.

The purpose of URGENCY software is to improve triage, transport and treatment decision making for crash victims by adding actionable information to time saving Automatic Crash Notification messages. URGENCY is intended to help EMS providers to instantly, and automatically, differentiate the approximately 250,000 people in serious injury crashes from the nearly 27 million vehicles involved in crashes each year in the U.S. Differentiation of crashes by URGENCY would improve the ability of the EMS system to provide priority medical care to those who critically need it to reduce deaths and disabilities.

Based on the national crash data system maintained by the National Highway Traffic Safety Administration, approximately 2% of the tow-away crashes produce injuries that require time critical medical attention. A challenge is to identify those crashes and deploy the appropriate rescue and treatment capabilities.

In 1996, NHTSA initiated efforts to improve the criteria for recognizing time critical injuries at the crash scene, based on data from the crashed vehicles. The research team, led by Dr. Howard Champion, published several technical papers that highlighted the study results. (Champion, et.al. 1998, 1999). Another result of the study was published by Malliaris, et. al.(1997). In the Malliaris study, relationships between crash attributes and crash injuries were postulated. The probability relationships for MAIS 3+ injuries and selected crash attributes were subsequently incorporated into a user-friendly software program called the URGENCY algorithm. This algorithm projects the probability of the presence of MAIS 3+ injuries, based on crash attributes such as deltaV, restraint use, and occupant age and gender. The algorithm has been used by NHTSA research activities involved in evaluating ACN technology (Kanianthra, 2000; Prasad, 2000).

In this study, the algorithm is applied to trauma cases in the database at the William Lehman Injury Research Center.

DATA SOURCES FOR THE URGENCY ALGORITHM

The basis for the URGENCY algorithm is contained in the paper published by Malliaris, et.al.(1997). The data were based on NASS/CDS 1988-1995. The NASS weights, necessary for national projections were used as weighing factors in the processing.

A maximum likelihood procedure, specifically a logistic regression with weighing factors, was used to fit various algorithms of raw data. In this procedure, the probability of casualty was projected as:

$$P = 1/[1+ \exp(-w)] \quad (1)$$

$$w = A0 + A1*PRED1 + A2*PRED2 + \ldots\ldots\ldots (2)$$

where PRED1, PRED 2, etc. are the selected predictors and A0, A1, and A2 are coefficients estimated by logistic regression.

The NASS data concerning car occupants involved in tow away crashes was used for the derivation of algorithms that estimate the probability of a crash involved occupant with at least one injury of maximum severity MAIS 3+. For frontal crashes with occupants protected by belts plus air bags, the equation 2 coefficients for MAIS 3+ casualties are listed in Table 1. Additional factors, such as Occupant Ejection and Vehicle Rollover were not applied to the cases in the database.

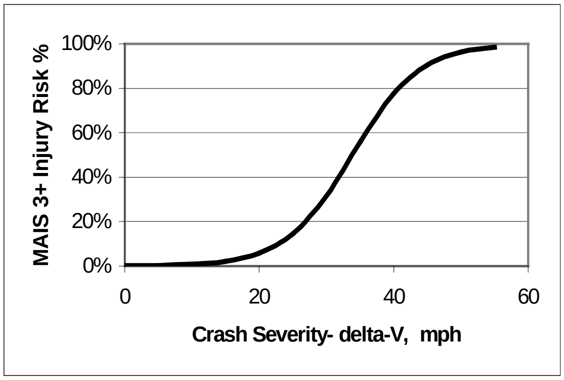
The predictors in Equation 2 are both continuous and binary. The variables Single Vehicle Crash, Occupant Gender, and Occupant Entrapment are binary variables. For a single vehicle crash, a female occupant, and an entrapped occupant the coefficients are assigned values of 1. Otherwise, the values of these variables are zero. The continuous variable coefficients assume values with units shown in Table 1. Positive values of coefficients increase the injury risk.

Table 1.
Logistic Regression Coefficients for the URGENCY Algorithm

Predictor	Coefficient, Ai
Intercept	-8.056
Vehicle Delta V, mph	0.164
Max. Vehicle Crush, in.	0.037
Single Vehicle Crash	0.322
Vehicle Curb Weight, lbs.	-0.027
Occupant Age, years	0.042
Occupant Gender	0.464
Occupant Entrapment	2.378

A plot of delta-V and predicted injury risk is shown in Figure 1. In this Figure the binary variables were zero, the crush and delta-V were assumed to have similar values, the occupant age was 30, and the vehicle weight was 3200 lbs. The occupant was restrained by a safety belt plus air bag. The relationship depicted in Figure 1 will vary depending on the values of the predictor variables in Equation 2. An earlier paper provides examples of variations in the relationship (Malliaris 1997)

Figure 1.
Probability of MAIS 3+ Outcome as a Function of Crash Severity for Baseline Conditions



THE WILLIAM LEHMAN INJURY RESEARCH CENTER DATA

The Lehman Injury Research Center at the University of Miami has investigated more than 300 frontal crashes in which the occupant was restrained by a safety belt and/or by an air bag. Data is collected from the crash scene, the damaged vehicle, and the occupant. The URGENCY algorithm accepts the input of specific values of the predictor variables measured in a crash and provides a projected injury risk associated with that set of variables. The purpose of this study is to assess how well the prediction identifies time critical injuries in real world cases at the William Lehman Injury Research Center.

The criteria for admission to the study is as follows: (1) the subject must have been involved in a frontal collision; (2) the subject must have been protected by a safety belt, an air bag, or both; (3) at the crash scene, the subject must have met triage criteria for injuries of a severity which justified transporting to the Ryder Trauma Center; and (4) the subject must have agreed to have the records included in the study. The study included 100% of the subjects transported to the Ryder Trauma Center, which met the criteria. Less than 10% of the subjects refused to participate in the study. The triage criteria are shown in Table 2.

There are now about 100 million vehicles on the roads in the United States with air bags. Future ACN systems will operate in vehicles equipped with frontal air bags. To investigate the most frequent restraint mode, cases involving frontal crashes and with adult occupants restrained by belts and air bags were studied. The database contained 57 cases that met the criteria. Twenty cases were transported to the Trauma Center because they met one or more of the physiological criteria listed in Table 2. Thirty-one cases were transported due to high suspicion of injury. Seven cases were dead at the scene and were transported directly to the medical examiner's office. The URGENCY algorithm was applied to each group of cases and the results are presented in the following sections.

Table 2.
Trauma Criteria-State of Florida

Systolic BP ≤ 90 (Shock)
Respiratory rate < 10 per minute or > 29 per minute
Glasgow Coma Scale ≤ 12
Penetrating injury to head, neck, chest, abdomen or groin
Paralysis
Second or third degree burns ≥ 15% Total Body Surface Area
Amputation proximal to wrist or ankle
Ejection from motor vehicle
Paramedic Judgment-High Index of Suspicion of Injury

CASES THAT MET PHYSIOLOGICAL TRAUMA CRITERIA

The WLIRC data contained 20 adult occupants in frontal crashes restrained by belts plus air bag that met physiological trauma criteria. Systolic blood pressure less than 90 was the most frequent criteria with 10 cases. Low Glasgow Coma Scale accounted for 7, and abnormal Respiratory Rate accounted for 3. Of the 20 occupants that met trauma criteria, 4 did not have MAIS 3+ injuries. The URGENCY algorithm predicted injury risks of less than 10% for all 4 of these occupants.

There were 4 cases with MAIS 3+ injuries in which the URGENCY algorithm predicted an injury risk that was less than 10%. In all of these cases, the injuries were caused by occupants' being close to the air bag at the time of deployment. Two of the cases involved pole crashes. Three of the occupants were short statured females.

There were four occupants with time critical injuries in which the URGENCY algorithm predicted the injury probability between 10% and 40%. Three were restraint contact injuries, associated with late deployments or small close-in occupants. One involved a frail 81-year-old man. Pole crashes were involved in half of these cases.

All eight cases with an injury risk above 50% had AIS 3+ injuries.

CASES THAT WERE TRANSPORTED DUE TO HIGH SUSPICION OF INJURY

There were 30 adult occupants who were transported due to high suspicion of injury. These occupants did not meet the physiological trauma criteria when examined at the crash scene. Eighteen of these cases had MAIS 3+ injuries.

The URGENCY algorithm predicted an injury risk of less than 10% for eight cases. Six of these had no MAIS 3+ injuries. The two crashes with MAIS 3+ injuries were multiple impact crashes that reduced the effectiveness of the restraint systems.

There were 11 cases with risks ranging from 11% to 48%. Five of these had only MAIS 2 injuries. Two cases had MAIS 3 lower extremity injuries, and four cases had time critical head or chest injuries. The URGENCY algorithm did not adequately identify these latter six MAIS 3+ cases. When examining the crash characteristics of these cases, one was a head injury from debris penetrating the windshield, three were multiple impacts, and two were pole crashes. The crash with the most severe time critical injury was an offside frontal crash that also involved multiple impacts. The offside frontal crash causes the occupant to move forward and toward the centerline of the vehicle.

There were eleven cases with the URGENCY risk of 50% or greater. Ten of these eleven cases contained AIS 3+ injuries. None of these occupants met the physiological trauma criteria at crash scene. This group of injuries is summarized in Table 3. The probability of MAIS 3+ injury is shown in the Risk column. The time critical injuries chest/abdominal injuries are designated as yes in the Occult (Occ.) column. These injuries are the most difficult to detect at the scene. The ability to predict the presence of occult lung, liver and spleen injuries would be a valuable asset in improving triage criteria. Eight of eleven cases identified with 50%+ injury risk had time critical chest/abdominal injuries that were not obvious in the field.

At the WLIRC there has been a multi-year program to educate emergency responders to the potential presence of occult injuries. This program may have increased the number of High Suspicion of Injury cases brought to the Ryder Trauma Center. The URGENCY algorithm is expected to be even more effective for identifying high injury risk crashes in jurisdictions with less experience in the identification of these injuries.

Table 3.
Most Critical Injury in Cases with Probability of Injury MAIS 3+ Greater than 50% and Suspicion Of Injury Triage Criteria

Case	Risk	Injury	Other	Occ
96-028B	50	AIS3 LUNG		Y
00-002	59	AIS3 LUNG		Y
96-013J	67	AIS3 HD	AIS 3 LX	Y
98-047A	75	AIS3 LX		N
D023-00	86	AIS3 LX		N
96-09A2	87	AIS4 HEAD		Y
98-020J	94	AIS2 LX		N
99-09AD	95	AIS3 LUNG	AIS 3 LX	Y
D015-99	95	AIS2 LIVER	AIS 3 RIB	Y
98-008K	96	AIS4 LIVER	AIS 3 LX	Y
98-038K	99	AIS3 SPLEEN	AIS 2 LX	Y

DEAD AT THE SCENE CASES

Seven cases involved occupants that were dead at the scene. The URGENCY algorithm predicted all cases with a risk over 50%. Six of seven had an injury risk of 70% or greater.

DISCUSSION

The goal of URGENCY is to get people with serious injuries to a trauma center while minimizing both under triage that misses serious injuries and over triage that transports people not seriously injured to the trauma center unnecessarily.

Table 4 summarizes the results of the study. The three columns group the injury probabilities predicted by the URGENCY algorithm. The injury probabilities are: 0 to 10% (low); 11% to 49% (moderate); and 50+% (high). The three rows group the occupants based on the triage criteria that caused them to be in the study. The triage criteria are: occupants dead at the scene (DOS); occupants that met physiological trauma criteria (Trauma); and occupants transported to the Trauma Center because of high suspicion of injury (Hi Sus). Each cell in the table shows in the numerator, the number occupants predicted by the URGENCY algorithm for that cell. The actual number of MAIS 3+ cases for the cell is shown in the denominator. For low values of MAIS 3+ injury probability, the denominator should approach zero. For high values of MAIS 3+ injury probability, the fraction should approach one.

The URGENCY algorithm predicted a probability of injury greater than 50% for all seven of the occupants that were dead at the scene. For the occupants that met physiological triage criteria, the prediction was not as good. For the 50%+ probability of MAIS 3+ injury group the algorithm predicted all 8 occupants with MAIS 3+ injuries. For the low probability group (0%-10%), the algorithm predicted the four occupants without MAIS3+ injuries. However, there were eight occupants with MAIS 3+ injuries that were predicted with injury probabilities less than 50%. Algorithm improvements to assist in predicting the missed AIS 3+ injuries are highly desirable.

For the occupants that were transported due to high suspicion of injury, the algorithm predicted 11 with 50%+ probability of injury. Ten of these had MAIS 3 + injuries. The algorithm predicted 8 with low injury probability, and six of these did not have MAIS 3+ injuries. In the 11% to 49% range, there were 6 of 11 with MAIS 3+ injuries.

Table 4
Number of Cases with MAIS 3+ Injuries in Each Injury Risk Grouping – Baseline Prediction

Baseline Criteria	Low Risk 0-10%	Med Risk 11-49%	Hi Risk 50+%
DOS	0/0	0/0	7/7
Trauma	8/4	4/4	8/8
Hi Sus	8/2	11/6	11/10

In examining the cases with MAIS 3+ injuries and moderate injury probabilities, several patterns emerged. The first was that occupants exposed to crashes with fixed narrow objects had more serious injuries than predicted. By adjusting the algorithm to increase the weighting for narrow object impacts, the improvements shown in Table 5 resulted. The improvements were among the group in the 11% to 49% category.

Table 5
Number of Cases And AIS 3+ Injuries in Each Injury Risk Grouping with Revised Pole Impact Weighting

Pole + Criteria	Low Risk 0-10%	Med Risk 11-49%	Hi Risk 50%+
DOS	0/0	0/0	7/7
Trauma	8/4	2/2	10/10
Hi Sus	8/2	9/4	13/12

A second improvement in the algorithm would be the introduction of a predictor of injuries associated with multiple impact crashes. These crashes frequently reduce the effectiveness of the restraint system. If these injuries could be better predicted, the results would be as shown in Table 6. Most of the improvements were associated with the high suspicion of injury group.

Table 6
Number of Cases of MAIS 3+ Injuries in Each Injury Risk Grouping with Revised Multiple Impact Weighting

Multiple+ Criteria	Low Risk 0-10%	Med Risk 11-49%	Hi Risk 50%+
DOS	0/0	0/0	7/7
Trauma	8/4	2/2	10/10
Hi Sus	6/0	6/1	18/17

The cases of AIS 3 injury that remain undetected in Table 6 involve the following: a very frail individual, and penetration of occupant compartment by a foreign object

To improve the prediction in the low risk category, better predictors are needed for air bag injuries from close-in occupants and late deployments. If such predictions were available the prediction results would be as in Table 7. To achieve these predictions, additional crash attributes are needed. These include crash pulse, air bag deployment time, seat position, and occupant size.

Table 7
Number of Cases of MAIS 3+ Injuries in Each Injury Risk Grouping with Revised Close-in + Occupant Weighting

Close-in Criteria	Low Risk 0-10%	Med Risk 11-49%	Hi Risk 50%+
DOS	0/0	0/0	7/7
Trauma	4/0	1/1	15/15
Hi Sus	6/0	6/1	18/17

One MAIS 4 case with low predicted probability of injury involved a belt-induced injury in an offside frontal crash. In this type of crash, the occupant moves forward and toward the vehicle centerline. Increased injury risk from two-point belts in this type of crash has been reported earlier (Augenstein 2000). Additional investigation of this crash mode regarding three point belts is now underway.

CONCLUSIONS

The conclusions are applicable to the URGENCY algorithm applied to all William Lehman Injury Research Center cases of frontal crashes with occupants protected by belts and air bags. This research with WLIRC cases found confirmation that URGENCY can differentiate crashes with serious injuries from non-serious injury crashes, but that improvement in the algorithm is both necessary and possible.

For the cases with greater than 50% predicted MAIS 3+ injury probability, 96% had MAIS 3+ injuries. For the cases with less than 10% predicted MAIS 3+ injury probability, 63% did not have MAIS 3+ injuries. Most of the of MAIS 3+ injuries not predicted involved injuries in multiple impact crashes, pole crashes or air bag deployment injuries.

Improvements in the algorithm to introduce predictors for pole crashes and multiple impacts significantly improved the prediction capabilities. Further improvements in the algorithm are necessary to predict air bag deployment related injuries associated with close-in occupants. To predict these injuries factors such as crash pulse, air bag deployment time, and occupant/seat position may be required.

Overall, the predictive capability of the URGENCY algorithm was considered to be satisfactory for use as an aid in identifying occult injuries among occupants that do not meet physiological triage criteria at the crash scene. Additional, refinements identified by this study are being incorporated.

Validation for other crash modes and restraint conditions using a more extensive database is required to more completely assess the validity of the URGENCY algorithm when applied to the spectrum of real world crashes.

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