# ESTIMATED TRIAGE IMPROVEMENT AND SOCIETAL COST SAVINGS WITH NATIONWIDE IMPLEMENTATION OF AN ADVANCED AUTOMATIC CRASH NOTIFICATION ALGORITHM IN THE U.S.

**Joel Stitzel**
**Ashley Weaver**
**Jennifer Talton**
**Ryan Barnard**
**Samantha Schoell**
**R. Shayn Martin**
**J. Wayne Meredith**
Wake Forest School of Medicine
United States

Paper Number 17-0319

## ABSTRACT

The objective of the study was to perform a benefits analysis of an injury-based advanced automatic crash notification (AACN) algorithm to estimate the reduction in undertriage (UT) and overtriage (OT) rates if the algorithm was implemented nationwide. In addition, the study sought to estimate the savings in societal costs using the Harm metric score.

Benefits of an existing AACN algorithm were estimated using the differential between the number of motor vehicle crash (MVC) occupants correctly triaged using the AACN algorithm compared to actual triage decisions for real-world occupants. Actual triage decisions were extracted from NASS-CDS 2000-2011 to compare each occupant's ISS (≥ 16 vs. < 16) versus the occupant's actual triage destination (trauma center or non-trauma center). Analyses for the triage benefits included 47,361 unweighted occupants representing 9,763,984 weighted occupants with complete information on the crash mode, hospital destination, and a valid ISS. Analyses for the societal cost benefits included the subset of occupants included in the AACN algorithm resulting in 22,610 unweighted occupants. For each occupant, the Harm scores were summed across all injuries and a lifetime economic cost to society for each fatality value of $1.4 million was applied to derive the societal costs.

The AACN algorithm was optimized and evaluated to minimize triage rates per American College of Surgeons (ACS) recommendations of <5% UT and <50% OT. The developed AACN algorithm resulted in <50% OT and <5% UT in side impacts and 6-16% UT in other crash modes. The weighted analysis of 12 years of NASS-CDS data revealed an UT rate of 20% and an OT rate of 54% among real-world MVC occupants across all crash modes. If the triage rates from the AACN algorithm were applied to these occupants by crash mode, the UT and OT rates would be reduced to 11% and 34%, respectively. Across a 12-year period, this would result in an UT improvement for 32,959 (44%) occupants and OT improvement for 1,947,620 (38%) occupants. For the societal cost benefit analysis, the sample sizes were small for all crash modes except frontal. Application of the AACN algorithm for the frontal cases would reduce UT rates to 7%. Application of the Harm score to the occupants who would benefit from trauma center treatment would result in over $43 million saved in societal costs.

With nationwide implementation of the AACN algorithm, we estimate a potential benefit of improved triage decision-making for 165,048 occupants annually (one-twelfth of the 1.98 million occupants incorrectly triaged predicted to be triaged correctly with the AACN algorithm). Annually, this translates to more appropriate care for 2,747 seriously injured occupants and reduces unnecessary utilization of trauma center resources for 162,302 minimally injured occupants. The projected reduction in UT for the U.S. population attributable to AACN has important implications for decreasing MVC mortality and morbidity, while reduction of OT will lead to better hospital resource utilization and decreased healthcare costs.

## INTRODUCTION

While the advent of passive safety standards (seat belts, airbags, etc.) has lowered the morbidity and mortality of motor vehicle crash (MVC) victims, there are significant barriers to further improvements. Most experts believe that an important future avenue for progress is to improve the trauma triage process, that is, the process whereby patients are given the "right care" at the "right place" at the "right time." Optimizing this process is difficult due to timing, decision making, resources, and access to care.

Advanced Automatic Crash Notification (AACN) algorithms have shown promise in improving the trauma triage process by predicting occupant injury severity using vehicle telemetry data to recommend a transportation decision. Recently, an AACN algorithm known as the Occupant Transportation Decision Algorithm (OTDA) was developed using an injury-based approach that incorporated only crash characteristics obtainable from vehicle sensors [1-5]. This approach differs from previously developed AACN algorithms which use Abbreviated Injury Scale (AIS) severity metrics to define severely injured patients as well as variables such as occupant age or sex that are not obtainable directly from the vehicle [6-12].

Optimization of the OTDA involved minimizing undertriage (UT) and overtriage (OT) rates with the goal of producing UT rates less than 5% and OT rates less than 50% [13]. The UT metric computed from the OTDA was 6% for frontal crashes, 5% for near side crashes, 3% for far side crashes, 7% for rear crashes, and 16% for rollover crashes. The OT metric computed from the OTDA was 50% for frontal crashes, 48% for near side crashes, 49% for far side crashes, 44% for rear crashes, and 50% for rollover crashes.

The objective of the study was to perform a benefits analysis of the recently developed injury-based AACN algorithm to estimate the reduction in UT and OT rates if the algorithm was implemented nationwide. In addition, the study sought to estimate the savings in societal costs using the Harm metric score.

## METHODS

### AACN Algorithm Development and Validation

The developed AACN algorithm, the OTDA, uses measurements obtainable from vehicle telemetry to predict risk of overall occupant injury and recommend a transportation decision for the occupant, particularly whether transport to a Level I/II trauma center is recommended. A list of injuries associated with a patient's need for treatment at a Level I/II trauma center was determined using an injury-based approach based on three facets (severity, time sensitivity, and predictability). Severity was scored based on mortality risks (MRs) obtained from the National Trauma Data Bank (NTDB) [5]. Time sensitivity was scored using expert physician survey data which incorporated the recommended treatment location and a rank of urgency for treatment [3]. Predictability was scored using two components: an occult score and a transfer score [2, 4]. The occult score is a measure of the likelihood that an injury is missed using expert survey data from physicians and emergency medical services (EMS) professionals. The transfer score is a measure of the likelihood that an injury is present in patients that require transfer from a non-trauma center to a Level I/II trauma center using the National Inpatient Sample (NIS) database. Scores of each of these facets (severity, time sensitivity, and predictability) were computed for each of the 240 frequent MVC AIS 2+ injuries and normalized on a zero to one scale in which scores closer to one were more severe, more time sensitive, and less predictable.

The OTDA inputs include a Target Injury List and 38,970 National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) 2000-2011 occupants used to train and evaluate the algorithm (Figure 1). The Target Injury List is determined by multiplying the severity, time sensitivity, and predictability scores by a weighting coefficient and then summing these values to produce an injury score. Injuries meeting or exceeding a variable injury score threshold are included on the Target Injury List.

The OTDA uses multivariable logistic regression to predict an occupant's risk of sustaining an injury on the Target Injury List from the following model variables: longitudinal delta-v (in frontal and rear crash modes), lateral delta-v (in near side and far side crash modes), number of quarter turns (in rollover crash mode), belt status, multiple impacts, and airbag deployment (frontal airbag deployment for all crash modes and side airbag deployment for near side and rollover crash modes). The algorithm features five tunable variable parameters allowing for extensive optimization. These include severity, time sensitivity, and predictability multipliers; an injury score threshold; and a risk threshold. The severity, time sensitivity, and predictability multipliers are coefficients used to weight each injury's contribution to the injury score.

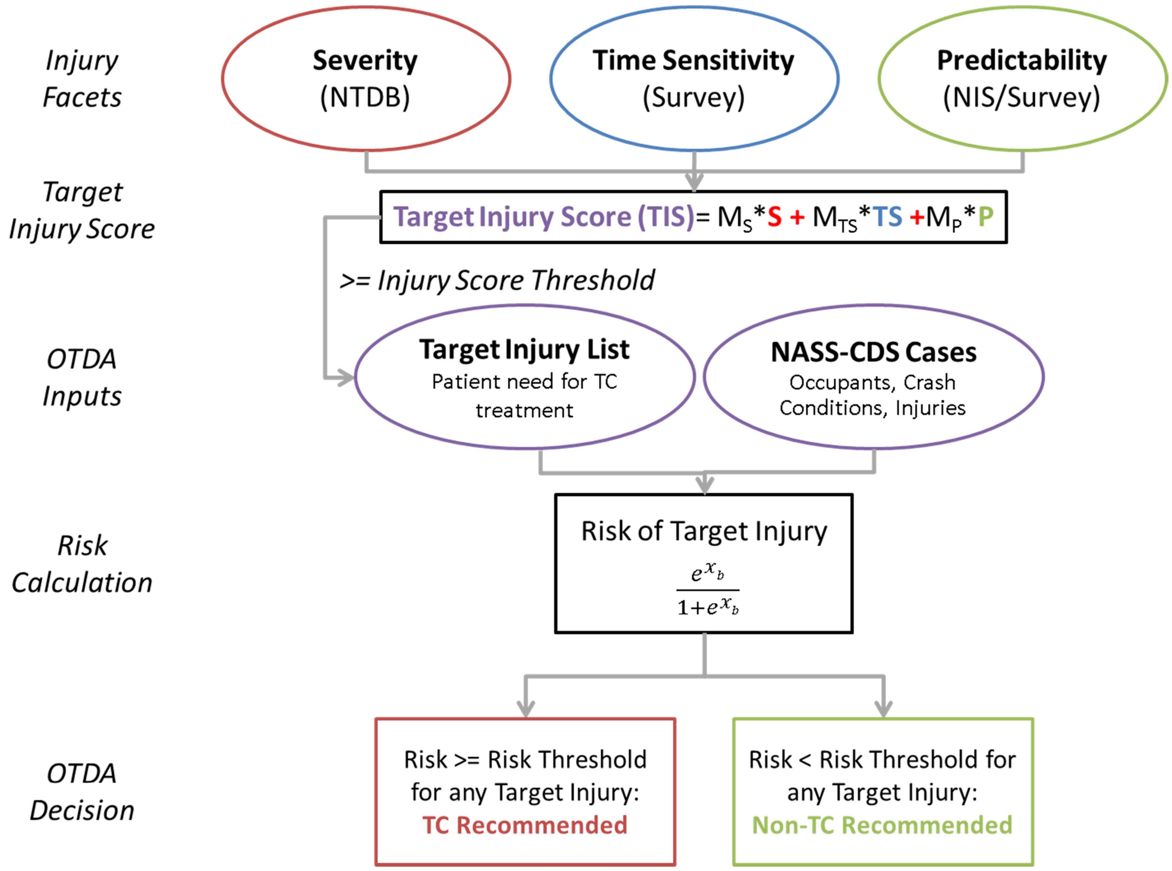


**Figure 1. Overview of OTDA. (Abbreviations $M_P$, predictability score multiplier; $M_s$, severity score multiplier; $M_{TS}$, time sensitivity score multiplier; NASS-CDS, National Automotive Sampling System - Crashworthiness Data System; NIS, National Inpatient Sample; NTDB, National Trauma Data Bank; TC, trauma center)**

Above the injury score threshold, an injury is included on the Target Injury List. The risk threshold is the tolerable risk for any target injury. At or above this threshold, the algorithm recommends triage to a Level I/II trauma center. The OTDA decision, for each NASS-CDS occupant, is compared to a dichotomous representation of their Injury Severity Score (ISS). Occupants with ISS 16+ should be transported to a Level I/II trauma center. The optimization algorithm minimized UT and OT with the goal of producing UT < 5% and OT < 50% as recommended by the ACS [13].

Following optimization of the algorithm, the UT metric computed from the OTDA was 6% for frontal crashes, 5% for near side crashes, 3% for far side crashes, 7% for rear crashes, and 16% for rollover crashes. The OT metric computed from the OTDA was 50% for frontal crashes, 48% for near side crashes, 49% for far side crashes, 44% for rear crashes, and 50% for rollover crashes. Comparing to previously developed AACN algorithms, the OTDA produced lower UT rates. UT rates for URGENCY ranged from 6-71% and OnStar ranged from 28-85% [6, 9-11, 14, 15]. OT rates for URGENCY ranged from 25-50% and OnStar ranged from 0-11%.

### Benefits Analysis for Real-World Occupants

A benefits analysis was performed, and benefits of the OTDA were estimated using the differential between the number of MVC occupants correctly triaged using the OTDA compared to actual triage decisions for real-world occupants. Actual triage decisions were extracted from NASS-CDS 2000-2011 to compare each occupant's ISS (≥ 16 vs. < 16) versus the occupant's actual triage destination (non-trauma center (non-TC) vs. trauma center (TC)). Analyses included 47,361 unweighted occupants representing 9,763,984 weighted occupants with complete information on the crash mode (frontal, far side, near side, rear, rollover), TC destination (TC or hospital only), and a valid ISS.

## Harm Metric Benefits Analysis

We sought to estimate the improvement in the number of MVC occupants who would be correctly triaged using our AACN algorithm compared to the actual field triage decision and apply an associated Harm metric score to these cases which would generate an estimated savings in societal costs [16]. The Harm metric developed by Gabler et al. assigns a cost to the maximum injury in a single body region. To do this we used NASS-CDS 2000-2011 data and compared each occupant's ISS (≥ 16 vs < 16) to the occupant's actual triage destination (non-TC vs TC). Analyses were limited to occupants that met the criteria to be included in our OTDA algorithm and those that had actual TC destination information available (TC or hospital only). There were 22,610 cases meeting these criteria (11,772 frontal; 5,069 rollover; 2,483 near side; 1,845 far side; 1,441 rear).

For each crash mode, two 2x2 tables were produced and UT/OT rates within each table were calculated. The first table examined the actual TC destination of the occupant (TC vs non-TC) versus the occupant's ISS categories (≥ 16 vs < 16). The second table examined the predicted TC destination for the occupant from the OTDA versus the occupant's ISS grouping. Next, the Harm score was calculated using the average cost per injury normalized to the cost of a fatal injury per Gabler et. al. For each occupant we then summed the Harm scores across all injuries and applied a lifetime economic cost to society for each fatality value of $1.4 million to derive the societal costs associated with the occupants [16].

## RESULTS

### Benefits Analysis for Real-World Occupants

A summary of the benefits analysis is provided in Table 1. The unweighted analysis of 12 years of NASS-CDS data revealed an UT rate of 15% and an OT rate of 60% among real-world MVC occupants across all crash modes. If the triage rates from the OTDA were applied to these occupants by crash mode, the UT and OT rates would be reduced to 8% and 49%, respectively. Thus, we estimate with the OTDA, a TC recommendation would be made for 348 seriously injured occupants who were incorrectly triaged to a non-TC in NASS-CDS (45% improvement). Likewise, a non-TC recommendation would be made for 4,533 minimally injured occupants who were incorrectly triaged to a TC in NASS-CDS (18% improvement). In total, there would be an estimated 4,881 occupants who would be correctly triaged with the OTDA that were not previously. Application of the same exercise using weighted NASS-CDS data translates to 20% UT and 54% OT in a U.S. population-weighted sample of real-world MVCs. Application of the OTDA would be expected to reduce UT to 11% and OT to 34% within the population. Across a 12-year period, this would result in an UT improvement for 32,959 (44%) occupants and OT improvement for 1,947,620 (38%) occupants for an estimated total of 1,980,579 occupants who would now be triaged correctly with the OTDA. Thus, with nationwide implementation of the OTDA, we estimate a potential benefit of improved triage decision-making for 165,048 occupants annually (one-twelfth of the 1.98 million occupants).

### Harm Metric Benefits Analysis

The sample sizes were small for all crash modes except frontal (Table 2). Within the frontal crash mode, the UT rate using the actual TC destination was 14%. Using the TC destination predicted from the OTDA, the UT rate decreases to 7%. This translates to 58 occupants who would not be under-triaged using the TC destination predicted from the OTDA. If we assume that an occupant receiving their initial treatment at the right place in a quicker timeframe prevents injury severity and disability, then applying the Harm scores to these occupants estimates that over $43 million would be saved in societal costs.

**Table 1. Benefit Analysis Summary for NASS-CDS Years 2000-2011.**

| | **Unweighted (N = 47,361)** | | **Weighted (N = 9,763,984)** | |
|---|---|---|---|---|
| Number/Proportion Occupants Triaged | **UT** | **OT** | **UT** | **OT** |
| Occupants incorrectly triaged in NASS-CDS, n (%) | 771 (15) | 25,162 (60) | 74,151 (20) | 5,095,358 (54) |
| Occupants incorrectly triaged based on OTDA, n (%) | 423 (8) | 20,629 (49) | 41,192 (11) | 3,147,738 (34) |
| Incorrectly triaged occupants predicted to be triaged correctly with the OTDA, n | 348 | 4,533 | 32,959 | 1,947,620 |
| Proportion of incorrectly triaged occupants predicted to be triaged correctly with the OTDA, % | 45 | 18 | 44 | 38 |

**Table 2. Harm metric benefits analysis summary.**

| | NASS* | | OTDA** | | |
|---|---|---|---|---|---|
| **Crash Mode** | **UT<br>%<br>Societal cost+** | **OT<br>%<br>Societal cost+** | **UT<br>%<br>Societal cost+** | **OT<br>%<br>Societal cost+** | **UT difference<br>$ saved** |
| Far side | 34/203<br>17%<br>$30,028,320 | 977/1642<br>60%<br>$53,153,660 | 7/203<br>3%<br>$3,607,660 | 1050/1642<br>64%<br>$59,388,700 | 27 occupants<br>($26,420,660) |
| Frontal | 112/814<br>14%<br>$83,321,280 | 6350/10958<br>58%<br>$492,513,840 | 54/814<br>7%<br>$40,040,840 | 6889/10958<br>63%<br>$551,760,860 | 58 occupants<br>($43,280,440) |
| Near side | 55/470<br>12%<br>$50,219,960 | 1181/2013<br>59%<br>$91,429,240 | 27/470<br>6%<br>$22,595,440 | 1186/2013<br>59%<br>$95,102,000 | 28 occupants<br>($27,624,520) |
| Rear | 2/36<br>6%<br>$1,215,620 | 725/1405<br>52%<br>$22,484,140 | 3/36<br>7%<br>$1,268,960 | 715/1405<br>44%<br>$22,362,340 | +1 occupant<br>+$53,340 |
| Rollover | 106/762<br>14%<br>$129,463,460 | 2822/4307<br>66%<br>$216,692,280 | 141/762<br>19%<br>$158,248,300 | 2323/4307<br>54%<br>$196,499,240 | +35 occupants<br>+$28,784,840 |

*"What actually happened" – using the actual TC destination vs. ISS categories

**"What we predicted" – using the predicted TC destination from the OTDA vs. ISS categories

+Fatality-adjusted Harm score from Gabler*$1.4 million

## CONCLUSIONS

A recently developed injury-based AACN algorithm was developed with an injury-based approach that examined three injury facets to identify injuries necessitating treatment at a Level I/II TC. Large hospital and survey datasets containing information on injuries, mortality risk, treatment urgency, and hospital transfers were used in conjunction with large crash datasets with crash, vehicle, occupant, and injury data. The OTDA was rigorously optimized and has demonstrated improved UT rates compared to other AACN algorithms in the literature and OT rates meeting ACS recommendations. The OTDA achieved OT rates less than 50% for all crash modes and UT rates less than 5% for side impacts with other crash modes ranging from 6 to 16%. These results are very encouraging as the OTDA uses only crash characteristics that are obtainable from vehicle sensors, whereas the majority of AACN algorithms in the literature use variables such as occupant age or gender that are not obtainable directly from the vehicle.

With nationwide implementation of the developed injury-based AACN algorithm, 165,048 occupants annually would benefit with improved triage decision-making. Annually, this translates to more appropriate care for 2,747 seriously injured occupants and reduces unnecessary utilization of trauma center resources for 162,302 minimally injured occupants. The projected reduction in UT for the U.S. population attributable to AACN has important implications for decreasing MVC mortality and morbidity, while reduction of OT will lead to better hospital resource utilization and decreased healthcare costs. Application of the Harm score to the occupants who would benefit from trauma center treatment would result in over $43 million saved in societal costs. The AACN algorithm developed in this study will aid emergency personnel in making the correct triage decision for an occupant after a MVC, and once incorporated into the trauma triage network it can reduce response times, increase triage efficiency, and improve overall patient outcome.


## ACKNOWLEDGEMENTS

Funding has been provided by Toyota Motor Corporation and Toyota's Collaborative Safety Research Center. Views expressed are those of the authors and do not represent the views of any of the sponsors. The authors acknowledge Clay Gabler, Eddie Ip, Patrick Kilgo, Kathryn Loftis, and Katrina Swett for their contributions to the study design and data analyses.


## REFERENCES


[1] Stitzel JD, Weaver AA, Talton JW, Barnard RT, Schoell SL, Doud AN, et al. An injury severity-, time sensitivity-, and predictability-based advanced automatic crash notification algorithm improves

motor vehicle crash occupant triage. *J Am Coll Surg*. 2016;**222**:1211-9. e6.
[2] Schoell SL, Doud AN, Weaver AA, Talton JW, Barnard RT, Winslow JE, et al. Characterization of the occult nature of injury for frequently occurring motor vehicle crash injuries. *Accid Anal Prev*. 2017;**98**:149-56.
[3] Schoell SL, Doud AN, Weaver AA, Talton JW, Barnard RT, Martin RS, et al. Development of a time sensitivity score for frequently occurring motor vehicle crash injuries. *J Am Coll Surg*. 2015;**220**:305-12.
[4] Schoell SL, Doud AN, Weaver AA, Barnard RT, Meredith JW, Stitzel JD, et al. Predicting patients that require care at a trauma center: analysis of injuries and other factors. *Injury*. 2015;**46**:558-63.
[5] Weaver A, Barnard R, Kilgo P, Martin R, Stitzel J. Mortality-based quantification of injury severity for frequently occurring motor vehicle crash injuries. *Ann Adv Automot Med*. 2013;**57**:235-45.
[6] Kononen DW, Flannagan CA, Wang SC. Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes. *Accid Anal Prev*. 2011;**43**:112-22.
[7] Malliaris AC, Digges KH, DeBlois JH. Relationships between crash casualties and crash attributes. SAE International Congress & Exposition. Detroit, MI: Society of Automotive Engineers; 1997.
[8] Augenstein J, Digges K, Ogata S, Perdeck E, Stratton J. Development and validation of the URGENCY algorithm to predict compelling injuries. Enhanced Safety of Vehicles2001.
[9] Bahouth G, Digges K, Schulman C. Influence of injury risk thresholds on the performance of an algorithm to predict crashes with serious injuries. *Ann Adv Automot Med*. 2012;**56**:223-30.
[10] Bahouth GT, Digges KH, Bedewi NE, Kuznetsov A, Augenstein JS, Perdeck E. Devleopment of URGENCY 2.1 for the prediction of crash injury severity. *Top Emerg Med*. 2004;**26**:157-65.
[11] Rauscher S, Messner G, Baur P, Augenstein J, Digges K, Perdeck E, et al. Enhanced automatic collision notification system - improved rescue care due to injury prediction - first field experience. Enhanced Safety of Vehicle Conference. Stuttgart, Germany2009.
[12] Augenstein J, Perdeck E, Bahouth GT, Digges KH, Borchers N, Baur P. Injury identification: priorities for data transmitted. Enhanced Safety of Vehicles2005.
[13] American College of Surgeons Committee on Trauma. Resources for Optimal Care of the Injured Patient. Chicago, IL2006.
[14] Augenstein J, Perdeck E, Stratton J, Digges K, Bahouth G. Characteristics of crashes that increase the risk of serious injuries. *Annu Proc Assoc Adv Automot Med*. 2003;**47**:561-76.
[15] Augenstein J, Perdeck E, Stratton J, Digges K, Steps J, Bahouth G. Validation of the urgency algorithm for near-side crashes. *Annu Proc Assoc Adv Automot Med*. 2002;**46**:305-14.
[16] Gabler HC, Digges K, Fildes BN, Sparke L. Side impact injury risk for belted far side passenger vehicle occupants. SAE Technical Paper; 2005.