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Disclaimer

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16. Abstract

This document describes recent progress made by the National Highway Traffic Safety Administration to better understand the safety potential and technical considerations of post-crash technologies such as automatic collision notification (ACN) and advanced automatic collision notification (AACN). These technologies provide automatic notification of a crash when that crash reaches a minimum severity such as air bag deployment. Notification to a public safety answering point (PSAP, or 9-1-1 call center) or telematics service provider (TSP) occurs via cellular signal that allows the vehicle to place a call and transmit data.

Research was conducted on the target population who may benefit from AACN, injury prediction algorithms used by AACN systems, and estimates of costs and benefits (i.e. potential lives saved) that could be realized with implementation of AACN. Finally, research was conducted on development of a procedure to test AACN systems.

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Executive Summary

This document describes recent progress made by the National Highway Traffic Safety Administration (NHTSA) to better understand the safety potential and technical considerations of post-crash technologies such as Automatic Collision Notification (ACN) and Advanced Automatic Collision Notification (AACN). These technologies provide automatic notification of a crash when that crash reaches a minimum severity (e.g., air bag deployment). Notification to a public safety answering point (PSAP, or 9-1-1 call center) or telematics service provider (TSP) occurs via cellular signal that allows the vehicle to place a call and transmit data.

The key potential benefits of AACN are faster notification time of the crash, which can lead to emergency medical services (EMS) responding to the scene faster, and the prediction of severe injury. Injury prediction in an AACN system can provide information to EMS on whether or not to transport an occupant to a higher level of care (e.g., a trauma center). Earlier research, as well as updated research conducted for this report, demonstrates that severely injured occupants have significantly higher survival rates when taken to a trauma center compared with being transported to a lower level hospital.

To evaluate the target population, or the group of motor vehicle occupant fatalities that could receive benefit from an AACN system, the agency identified specific characteristics, such as being in a light vehicle and having access to a trauma center within a reasonable time window, that were required in order for these potential benefits to be realized. Another factor necessary for benefits to be realized is for the AACN algorithm to correctly identify the occupant as being severely injured. Research conducted for this report demonstrated that currently recommended thresholds for injury prediction may not be sufficiently sensitive to identifying severely injured or fatal occupants.

Finally, research was conducted on development of a procedure to test AACN systems. Because AACN systems establish voice communications and transmit information from the vehicle, it is possible to detect the presence of these communications without actually obtaining the communications contents, which are typically proprietary. Evaluation criteria were developed and a proof-of-concept test was performed. This research demonstrated the feasibility of developing a repeatable test for AACN.

This report details our findings with respect to ACN and AACN and summarizes our observations to-date about these technologies. The efforts conducted by the agency to date demonstrate that post-crash technologies have the potential to enhance the safety of light vehicles.

I. Introduction

There are two post-crash vehicle technologies that provide automatic notification of a crash when that crash reaches a minimum severity (e.g., air bag deployment): Automatic Collision Notification (ACN) and Advanced Automatic Collision Notification (AACN). Notification to a public safety answering point (PSAP, or 9-1-1 call center) or telematics service provider (TSP) occurs via cellular signal that allows the vehicle to place a call and transmit data.

ACN: With this technology, the data transmitted via cellular signal includes the current vehicle location and vehicle identification information (make, model). ACN systems have the potential enable earlier notification of a motor vehicle crash, allowing quicker Emergency Medical Services (EMS) response, andalso improve location identification for first responders (saving time in locating the vehicle).

AACN: With AACN technology, the data transmitted includes everything transmitted by an ACN system (location, vehicle identification information), as well as a prediction of probability of severe injury. AACN systems produce, at minimum, the same benefits as ACN systems, by decreasing notification time. In addition, it is believed that AACN can provide additional benefits such as improved dispatch decision making (e.g., whether to send basic life support, advanced life support or helicopter to scene) and improved transport decision making (i.e., whether to take a patient to the nearest community hospital or bypass the nearest hospital and go directly to a trauma center).

NHTSA has a long history of conducting research related to post-crash notification technologies. These efforts date back to the late 1990s when the agency funded an ACN Field Operational Test to demonstrate the feasibility and benefits associated with ACN systems.[1] Since 1986, the American College of Surgeons Committee on Trauma (ACS-COT) has published a resource manual that provides guidance for the pre-hospital triage process through a Field Triage Decision Scheme.[2] The Decision Scheme protocol is based on an on-scene, sequential evaluation performed by Emergency Medical Services (EMS), consisting of different aspects of trauma patient presentation, with the outcome being a determination of appropriate transport decision for a patient (e.g., hospital or trauma center). Step 1 is defined by physiologic and level of consciousness indicators (e.g., Glasgow Coma Scale) and Step 2 is defined by anatomic signs of injury (e.g., penetrating injury to the head). In 2006, vehicle telematics "consistent with high risk for injury" was added as a criterion to Step 3 of the protocol, meaning that if a patient is negative for Step 1 and 2, the AACN injury prediction can be used to inform transport decision to either hospital or trauma center. To clarify the definition of this criterion, in 2008 the CDC convened a panel of emergency medical physicians, trauma surgeons, public safety, and vehicle safety experts.[3] The panel considered how real-time crash data from AACN vehicle telematics system and similar systems can be used to determine whether injured patients need care at a trauma center and provided recommendations for telemetry data, such as what data should be transmitted and how to define a "high risk of severe injury." NHTSA participated in this effort, alongside other governmental and industry experts.

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[1] Bachman, L. R., Preziotti, G. R. (2001). Automated Collision Notification (ACN) Field Operational Test: Evaluation Report (Report No. DOT HS 809 304). Washington, DC: National Highway Traffic Safety Administration.
[2] Sasser, S. M., Hunt, R. C., Faul, M., Sugerman, D., Pearson, W. S., Dulski, T., Wald, M. M., Jurkovich, G. J., Newgard, C., Lerner, E. B. & Cooper, A. (2012). Guidelines for field triage of injured patients recommendations of the national expert panel on field triage, 2011. *Morbidity and Mortality Weekly Report*, *61*(RR-1), pp. 1-23.
[3] Recommendations from the expert panel: Advanced automatic collision notification and triage of the injured patient. Centers for Disease Control and Prevention, National Center for Injury Prevention and control, Division of Injury Response. 2008, available at http://stacks.cdc.gov/view/cdc/5304

Since 2008, research has been conducted by the NHTSA on the benefits, technical considerations and testing of ACN/AACN systems. This report focuses on this recent research. Although post-crash notification technologies have made significant advances in recent years and optional offerings are becoming widespread among the current U.S. vehicle fleet, voluntarily-reported manufacturer information indicates that these options are not taken in the majority of new car sales. In addition, most current notification systems require paid subscriptions. Some manufacturers offer free temporary trials at vehicle purchase, though the proportion of individuals who continue the service after the free trial lapses is currently unknown.

Post-crash technologies are also becoming more widespread worldwide. For example, the European Union will be mandating embedded automatic collision notification (known as "eCall") systems beginning in March 2018.[4] This new "eCall" regulation in the E.U. mandates that vehicles must have a permanently installed ACN system that directly calls 112 (the E.U. emergency line) and all owners can opt to use this function or a third party telematics provider. The 112-based eCall service is free of charge (i.e., no subscription fee).

Given worldwide interest along with the NHTSA history with post-crash technology, the agency believes it is now appropriate to update the public on its research efforts and to consider what role the agency should be taking regarding the continued development of AACN systems and their installation in motor vehicles.

II. Quantification of Benefits Associated With AACN

It is generally accepted that decreased EMS response time following trauma such as a motor vehicle crash is beneficial to medical outcome. Several studies have demonstrated improved odds of survival with reduced response time.[5] [6] For the current effort study, the benefits of earlier notification come from a 2015 study by Wu et al. In that study, FARS data from 2009-2012 was used to show that the mean notification and mean EMS arrival time post-crash for fatalities were 6 minutes and 16 minutes, respectively.[7] Using Kaplan-Meier survival analysis, Wu et al. showed that earlier notification within 2 minutes resulted in a 2% higher survival rate compared with notification later than 2 minutes. Similarly, earlier EMS arrival within 5 minutes also resulted in a 2.7% increase in survival rate. Earlier notification within 1 to 2 minutes (which is potentially achievable with ACN and required cellular coverage) significantly improves crash survivability and could save approximately 177-244 lives annually. Earlier notification will also improve EMS arrival times. Similar benefits have been estimated by others. A 2009 report summarized eight earlier studies from across Europe (and Australia) estimating the potential benefits of automatic collision notification.[8] In addition, four in-depth studies were carried out in the

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[4] REGULATION (EU) 2015/758 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2015 concerning type-approval requirements for the deployment of the eCall in-vehicle system based on the 112 service and amending Directive 2007/46/EC

[5] Pons, P. T., Haukoos, J. S., Bludworth, W., et al. (2005). Paramedic response time: Does it affect patient survival? *Academic Emergency Medicine*, 12(7), pp.594-600.

[6] Blackwell, T. H., & Kaufman, J. S. (2002). Response time effectiveness: comparison of response time and survival in an urban emergency medical services system. *Academic Emergency Medicine* 9(4): 288-295

[7] Wu, J., Craig, M., & Longthorne, A. (2015). Updated estimates of potential traffic fatality reductions with automatic collision notification. In: Proceedings from the 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV); Paper No. 15-0269. Available at www.nhtsa.gov/Research/Biomechanics+&+Trauma/Advanced+Automatic+Collision+Notification+-+AACN

[8] Francsics, J., et al. (2009). Impact assessment on the introduction of the eCall service in all new type-approved vehicles in Europe, including liability/legal issues. Final Report, SMART 2008/55.

U.K., Netherlands, Finland and Hungary, to update and/or improve upon the earlier studies. These studies estimated between 1% and 10% reduction in fatalities in Europe due to faster notification and improved identification of the location of the incident. Note that these benefits can be realized with ACN systems as well, and do not specifically require AACN systems.

Another factor in survival is the location of treatment (e.g., trauma center or hospital). Trauma centers have designations (Level I through Level IV) based on the resources required to provide various levels of care for traumatic injuries, with Level I trauma centers being considered to provide the highest level of care regardless of injury severity. Non-trauma centers (e.g., local community hospitals) have less access to the resources for treating severely injured patients. MacKenzie et al. (2006) found a 24% reduction in mortality (for deaths within 30 days) when comparing patients that were admitted to a Level I trauma center versus those admitted to a non-trauma center.[9] In a meta-analysis of studies involving establishment of trauma systems, Celso et al. (2006) found a 15% reduction in mortality in favor of the presence of trauma systems.[10] Others have documented improved survival rates for occupants treated immediately at a trauma center compared with those who were initially transported to a non-trauma center and later transferred.[11] [12] [13] Given this, it follows that the decision of where a severely injured patient is transported after a motor vehicle crash can be aided by information from an AACN system. These benefits are AACN-specific and would not be realized by an ACN system. AACN injury prediction may also provide information on the most appropriate type of emergency response (e.g., Advanced Life Support or Air Medical Services rather than Basic Life Support) required, which may result in highly trained emergency personnel on scene sooner, however these additional benefits are not estimated in the current effort.

To determine the effect of transport decision for the current research, the 2000-2015 NASS-CDS dataset was used to develop relative survival rate ratios between different medical facilities. NASS-CDS documents whether a fatal crash victim was admitted to a Level I or II trauma center (hereafter just "trauma center" versus a Level III center or lower (hereafter just "hospital") using variable "MEDFACIL." Additionally, time to death is recorded in hours (up to 24 hours) or days (1+ days) using the variable "DEATH" and fatal outcome was defined using the variable "TREATMNT"=1,2 in the NASS-CDS database.

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[9] MacKenzie, E. J., Rivara, F. P., Jurkovich, G. J., Nathens, A. B., Frey, K. P., Egleston, B. L., Salkever, D. S. & Scharfstein, D. O., (2006). A national evaluation of the effect of trauma-center care on mortality. *New England Journal of Medicine*, 354(4), pp.366-378

[10] Celso, B., Tepas, J., Langland-Orban, B., Pracht, E., Papa, L., Lottenberg, L. & Flint, L. (2006). -A systematic review and meta-analysis comparing outcome of severely injured patients treated in trauma centers following the establishment of trauma systems. *J Trauma*. 2006; 60(2), 371-378

[11] Garthe, E., Mango, N. (2005). Scene triage criteria associated with fatal crashes and potential for use of event data recorder (EDR) data. In: Proceedings from the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV); Washington, DC. Paper No. 05-0445-O, available at www-nrd.nhtsa.dot.gov/pdf/nrd-01/ESV/esv19/05-0445-O.pdf.

[12] Garwe, T., Cowan, L.D., Neas, B. R., et al. (2011a). Directness of transport of major trauma patients to a level I trauma center: a propensity-adjusted survival analysis of the impact on short-term mortality. *J Trauma Acute Care Surg*; 70: 1118-1127.

[13] Garwe, T., Cowan, L. D., Neas, B. R., et al. (2011b). A propensity score analysis of prehospital factors and directness of transport of major trauma patients to a level I trauma center. *J Trauma Acute Care Surg*; 70: 120-129.

One tool to compare the survival probability over time is a non-parametric method proposed by Kaplan and Meier. The Kaplan-Meier is commonly used for medical research and reliability engineering (Kaplan and Meier, 1958; Hosmer and Lemeshow, 1999). The Kaplan-Meier estimator, or life curve, at any time is described by Equation (1).

$$\hat{S}(t) = \prod_{t_i <= t} (1 - \frac{d_i}{n_i}) = \prod_{t_i <= t} (\frac{s_i}{n_i}) \quad (1)$$

where 'd_i' is 'deceased' subjects or fatalities, and 's_i' is the 'survivor' subjects or alive ('censored') drivers/passengers (but the survival status depends on the time window), and 'n_i' is total subject number (total occupants in the related time window). In CDS data, the only available time variable is time to death, which is recorded in hours (up to 24 hours) or days (1+ days) using the variable "DEATH". The occupant sample for the Kaplan-Meier life curve was any occupant with an available "DEATH" of 1-60. A time window of 24 hours after the crash was considered, such that the occupants within this 24-hour time window had two survival statuses – 'died' and 'still alive' relative to the time window. The effect of relative survival over time was considered important in the context of AACN because the benefits of AACN (e.g., faster transport to trauma center and definitive care, versus transport to hospital and possibly requiring a subsequent transfer to trauma center) are time dependent. It is assumed that the faster response associated with AACN may not be as critical for patients who are able to survive for many days before expiring.

For patients with known time to death, the Kaplan-Meier survival analysis demonstrated better relative survival rates at trauma centers compared with hospital and no treatment (Figure 1). At 24 hours post-crash, the survival rate at hospital was 0.79 that of trauma center (Table 1).

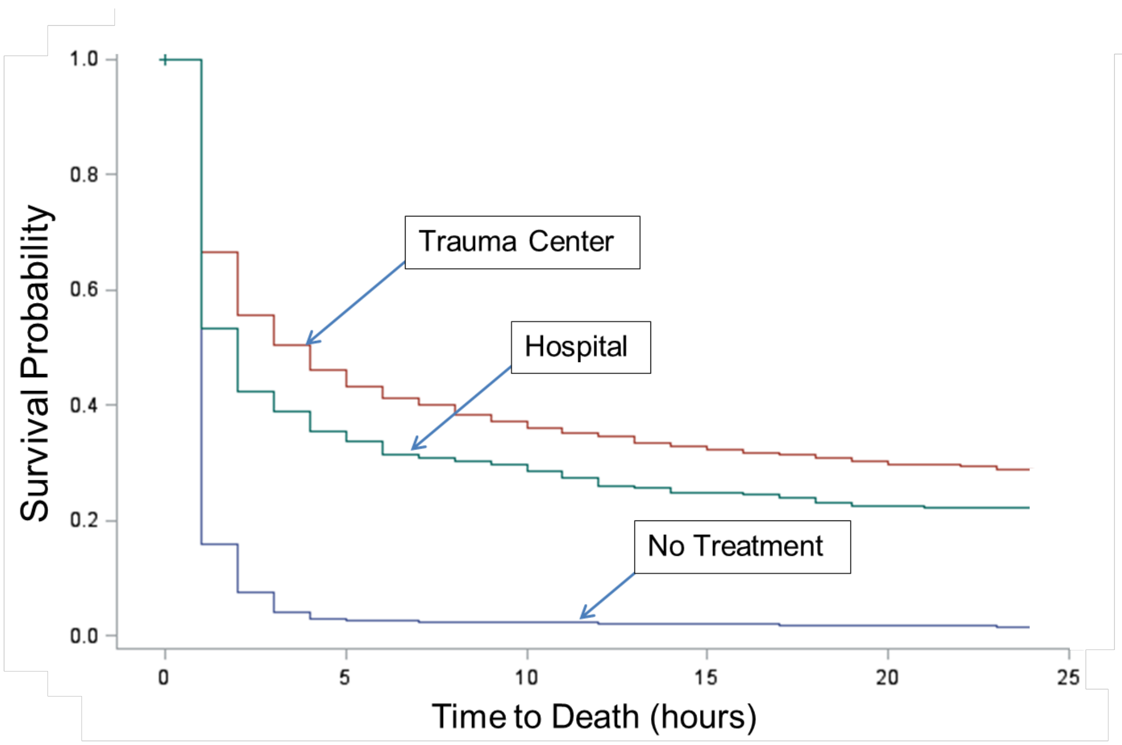

Figure 1. Occupant survival rate vs. time to death for various medical facility destinations (if 'Treatment =1,2' as Fatal), using Kaplan-Meier estimator.

Table 1. Survival rates over time for occupants who died within 30 days, based on Kaplan-Meier estimator

Time Since Crash (Hours)	No Treatment	Trauma Center	Hospital	Survival Rate Ratio (Hospital/Trauma Center)
3	0.0422	0.5046	0.3906	0.774
6	0.0258	0.4111	0.3131	0.762
12	0.0211	0.3447	0.2593	0.752
24	0.00468	0.2674	0.2121	0.793

Because the Kaplan-Meier survival method uses time to death (the only time variable in CDS) to estimate survival rate over time, the analysis does not include any surviving occupants. Therefore, another statistical approach used to include all occupants and to estimate survival ratio was the multiple proportional hazard model, or hazard model. The hazard function, *h(t)*, was introduced by Cox, the hazard, *h(t)*, and survival probability functions, S(t), are closely related to each other, described by: "$h(t) = - S'(t) / S(t)$ ", where S'(t) is the derivative of S(t). Cox proposed that the hazard function can be further expressed in Equation (2), known as the Cox Proportional Hazard Model (Hosmer and Lemeshow, 1999). The goal of this model is to establish a relationship between the hazard function with multiple risk factors simultaneously, while the previously discussed Kaplan-Meier curves explore a single risk factor, *Medical Facility*, only. The model included four independent factors treated as categorical variables: delta-V (> 35 MPH or not), belt use (belted or not), age (> 65 or younger), medical facility (no treatment, hospital, or trauma center). The binary dependent outcome is 'fatal or not' (fatal if "Treatment = 1, 2" in NASS-CDS data).

$$h(t) = h_0 \exp(\beta_1 Age + \beta_2 Facility + \beta_3 Belt + \beta_4 DeltaV) \quad (2)$$

When all dead and surviving patients were considered, the Cox Proportional Hazard model demonstrated that medical facility had a significant effect on survival (Table 3). Specifically, the hazard ratio (hospital versus trauma center) was 1.335, meaning that occupants sent to hospital had 33.5% higher fatality probability (or relative survival rate of 1/1.335=0.75) than if they were sent to trauma center. Other variables considered (belt use, age, delta-V) also had significant effects on survival.

Table 2. Multiple hazard ratios for various independent variables, using Cox Proportional Hazard model

Parameter	Parameter Estimate	Standard Error	Chi-Square	Pr > ChiSq	Hazard Ratio
Hospital versus Trauma Ctr.	0.28885	0.01287	503.3567	<.0001	1.335
No Treat. versus Trauma Ctr.	1.06258	0.00913	13536.8767	<.0001	2.894
Not belted versus Belted	0.20967	0.00798	691.1399	<.0001	1.233
Older (>65) versus Younger	-0.50045	0.00945	2805.3909	<.0001	0.606
Delta-V > 35 versus slower	0.26559	0.00921	832.2262	<.0001	1.304

The results of the current analysis demonstrate that for a given population of crash fatalities that can possibly benefit from AACN, 75% to 79% are still likely to die given a change in destination from hospital to trauma center, while 21% to 25% of the relevant population could potentially be saved. More details are forthcoming in a subsequent section concerning determining this target population that can potentially benefit from AACN. The current analysis demonstrates that the benefits of AACN are above and beyond those associated with ACN.

III. Injury Prediction

As noted, the benefits of AACN systems (above and beyond those associated with ACN) are dependent on the injury prediction capability of the system. A severely injured occupant will not benefit from the additional capabilities of the AACN system if the injury severity prediction algorithm does not identify him/her as having a high risk of severe injury. Thus, the agency's next task was to investigate injury prediction algorithms.

We evaluated three published injury severity predictive algorithms: an algorithm developed by Kononen et al. (2010)[14] for GM OnStar, an algorithm developed by Bahouth et al. (2012)[15] for BMW, and an algorithm developed by Stitzel et al. (2016)[16] for Toyota. These algorithms estimate the probability of severe injury from crash data and each model primarily used the predictors recommended by the CDC expert panel, which are delta-V, multiple versus single impact, seat belt usage, principal direction of force, and airbag deployment. Some models also use additional variables, such as occupant age and gender, which can be determined only through voice contact with the occupant (i.e., not through automatic electronic data transmission). All three algorithms used weighted CDS data to train a logistic regression model, although the models differ in how they define severe injury. Kononen et al. defined severe injury as having an Injury Severity Score (ISS) of 16 or greater (ISS16+), Bahouth et al. defined severe injury as having a maximum Abbreviated Injury Scale score of three or greater (MAIS3+), while Stitzel et al. developed their own outcome metric to predict trauma center need as a function of injury severity, time sensitivity, and predictability. Injury Severity Score is an anatomic scoring system based on the individual's three highest AIS values in different body regions.

While there is no "gold standard" for determining need for trauma center care, an ISS of 15 or greater is widely used for this purpose. This was the outcome of interest specified by the 2008 CDC expert panel, when they defined severe injury in the context of vehicle telematics. Because 15 is an unattainable ISS value, the current study will reference severe injury defined as having ISS 16 or greater (16+). The American College of Surgeons (ACS) periodically publishes a document entitled "Resources for Optimal Care of the Injured Patient," which represents the ACS Committee on Trauma's guidelines and recommendations for all aspects of trauma care, including pre-hospital care. In the 2014 version, the ACS also recommends an ISS of 16+ be used to define major trauma patients (those needing care at a designated trauma center). At this time, the agency's research uses the outcome measure of ISS 16+ for developing and evaluating injury prediction algorithms.

Performance of an injury prediction algorithm is closely related to under- and over-triage rates. The 2014 edition of the American College of Surgeons (ACS) Resources for Optimal Care[17] defines undertriage as severely injured patients transported to lower-level trauma centers or other facilities, and overtriage as minimally injured patients transported to higher-level trauma centers. The ACS gives higher priority to reduction of undertriage, because undertriage may result in preventable mortality or morbidity from

[14] Kononen, D. W., Flannagan, C. A. & Wang, S. C. (2011). Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes. *Accident Analysis & Prevention*, *43*(1), pp.112-122.
[15] Bahouth, G., Digges, K. and Schulman, C. (2012, October). Influence of injury risk thresholds on the performance of an algorithm to predict crashes with serious injuries. In *Annals of Advances in Automotive Medicine/Annual Scientific Conference* (Vol. 56, p. 223). Association for the Advancement of Automotive Medicine.
[16] Stitzel, J. D., Weaver, A. A., Talton, J. W., Barnard, R. T., Schoell, S. L., Doud, A. N., Martin, R. S. & Meredith, J. W. (2016). An injury severity-, time sensitivity-, and predictability-based advanced automatic crash notification algorithm improves motor vehicle crash occupant triage. *Journal of the American College of Surgeons*, *222*(6), pp.1211-1219.
[17] American College of Surgeons. (2014). Resources for optimal care of the injured patient.

delays in definitive care. The recommended level for undertriage is 5%. Overtriage may result in higher costs and also increase the burden for higher-level trauma centers because resources needed for more severely injured patients are unnecessarily being used for minimally injured patients. Acceptable rates for overtriage are in the range of 25-35%, according to the ACS.

The sensitivity of an injury severity prediction algorithm is equal to 100% minus the undertriage rate (i.e., a sensitivity of 95% will result in 95% of ISS 16+ occupants being *correctly triaged* to a trauma center, and 5% being *undertriaged* to a hospital). Specificity, or the true negative rate (proportion of occupants with ISS < 16 who are correctly identified by the algorithm as having a low risk of injury), is equal to 100% minus the overtriage rate (i.e., a specificity of 65% means that 65% of minimally injured occupants are *correctly triaged* to a hospital and 35% are *overtriaged* to a trauma center).

The risk threshold defined for a predictive algorithm also impacts the performance and resulting under- and overtriage. The CDC expert panel recommended a risk threshold of 20% be used to identify high risk of severe injury. At the 20% risk level, the performance of various injury severity prediction algorithms falls well short of meeting ACS recommendations for under- and overtriage. For example, at the 20% risk level, the algorithm published by Kononen et al. (2010) had a sensitivity of about 40% for ISS 16+, meaning that 60% of serious injuries were not identified. The URGENCY algorithm published by Bahouth et al. (2012) used a different dependent outcome (MAIS 3+) but also demonstrated sensitivities between 30% and 37%, for different crash types, at the 20% risk threshold. Authors concluded that the 20% threshold was not sufficiently sensitive, and recommended thresholds of 10% for frontal collisions and 5% for side crashes. Bahouth et al. (2014)[18] recommended that the improved sensitivity of a 10% risk threshold should trigger delta-level dispatch (i.e., advanced life support), where life-threatening injuries are suspected and an immediate response with lights and sirens occur, while the 20% threshold, because of its high specificity, should be used to trigger automatic trauma center transport.

The agency has studied threshold levels that would produce higher sensitivity rates more in line with the ACS recommendations than the CDC recommended threshold of 20%. To that end, a model was developed for this research that follows the basic approach laid out by the Centers for Disease Control and Prevention (CDC) Expert Panel on Field Triage. We used the CDC recommendations for predictor variables and risk thresholds as a starting point and performed tests to assess their validity and adequacy.

The predictive model was developed using the Crashworthiness Data System (CDS). It is the only source of data that provides detailed information on injuries as well as crash severity. We appended CDS years 1999–2015 and applied the following filter criteria:

1. Passenger vehicles only (passenger cars, SUVs, vans, and pickups).
2. Sampling weight no greater than 5,000.
3. Deformation locations are front, right, left, and back only (no top or under).
4. Direction of force is between impact points 1 o'clock and 12 o'clock.
5. Vehicle model years 2000–2016.
6. Front row passengers only.
7. Passenger ages <98.
8. Planar crashes (no rollovers).

In addition to these filters, each record must also meet the crash conditions required for the AACN system to make a notification call. We used the condition of delta-V ≥ 15 mph or airbag deployment. After removing observations with missing data, the final data set has 12,292 records, with a weighted total of

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[18] Bahouth, G., Graygo, J., Digges, K., Schulman, C. and Baur, P. (2014). The benefits and tradeoffs for varied high-severity injury risk thresholds for advanced automatic crash notification systems. *Traffic injury prevention*, *15*(sup1), pp.S134-S140.

3,210,222. Each record represents a unique vehicle. Logistic regression was used to estimate the probability that a crashed vehicle contained a seriously injured or fatal occupant, conditional on the values of the predictor variables. The logistic regression model is,

$$P(Y=1|\boldsymbol{x}) = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_p x_p}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_p x_p}} \quad (3)$$

where p is the total number of predictor variables), $\mathbf{x}' = (x_1, x_2, \dots, x_{\mathrm{p}})$ is a vector of predictor variables, and $\beta_0, \dots, \beta_p$ are parameters. The predictors used were those recommended by the CDC expert panel (Table 3).

Table 3. Selected predictors for the logistic regression model and their descriptions

Variable name	Type	Values	Description
LN_DVMPH	Continuous	0 – 100	Change in the vehicle velocity. Log of delta-V.
DOF1	Categorical	Front, Left, Right, Rear	Direction of force.
CBELT	Categorical	Yes, No	Seat belt usage. Yes = all occupants belted. No = at least one occupant unbelted.
BODY	Categorical	Car, SUV, Pickup, Passenger van	Type of vehicle.
ACCSEQ	Categorical	Multiple, Single	Number of significant impacts to a vehicle.

Note: The variable names are specific to this study and are not the same as in CDS.

Nine independent variables were used instead of the initial five since design variables were created for the BODY (vehicle body type) and DOF1 (direction of force) variables. The model was fit using the maximum likelihood method, which produces an estimate for the parameters that maximizes the probability of obtaining the observed set of data. The SURVEYLOGISTIC procedure in SAS was used to incorporate the CDS survey design by specifying the primary sampling unit (PSU), the PSU stratum, and weight variables. Results of the model are shown in Table 4.

Table 4. Maximum likelihood estimates for logistic regression model

Parameter		DF	Estimate	Std. Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	95% Confidence Limits
Intercept		1	-14.4707	0.9508	231.6557	<.0001		(-16.3341, -12.6072)
ACCSEQ	Multiple	1	0.5392	0.1734	9.6657	0.0019	2.3948	(0.1993, 0.8792)
BODY	Pickups	1	-0.5337	0.2015	7.0141	0.0081	-1.4104	(-0.9287, -0.1387)
BODY	SUV	1	-0.7507	0.2056	13.3315	0.0003	-2.8966	(-1.1537, -0.3477)
BODY	Vans	1	-0.4891	0.4739	1.0654	0.3020	-1.1083	(-1.4179, 0.4397)
CBELT	All Belted	1	-1.4283	0.1182	145.9042	<.0001	-5.1421	(-1.6601, -1.1966)
DOF1	Front	1	1.0557	0.3984	7.0230	0.0080	4.0478	(0.2749, 1.8366)
DOF1	Left	1	2.6775	0.4530	34.9351	<.0001	6.0612	(1.7897, 3.5654)
DOF1	Right	1	1.7839	0.4048	19.4198	<.0001	4.3774	(0.9905, 2.5774)
LN_DVMPH		1	3.5073	0.2376	217.8784	<.0001	13.6964	(3.0416, 3.9730

Note: The column between Parameter and DF specifies the comparison group. For example, Multiple is indicated for the variable ACCSEQ because the estimate corresponds to that of multiple event crashes in reference to single event crashes.

With the exception of the Vans design variable for BODY (vehicle body type), all variables were significant with a p-value less than 0.05 for the univariate Wald test, and a confidence interval that did not include zero (Table 4). To assess the predictive accuracy of the model, the k-fold cross-validation method was used. In this method the data was split into k = 10 equal-sized subsets. One of the subsets was chosen for testing the model, while the remaining nine subsets were used for training the model. This was repeated k = 10 times so that each record was used for training exactly nine times and testing exactly once. The resulting estimated probability of each record was used to assess the discrimination and accuracy of the model. Discrimination refers to the model's ability to distinguish low from high-risk vehicles. This means vehicles with y = 1 should have higher probability estimates than vehicles with y = 0. Discrimination can be quantified by the area under the receiver operating characteristic curve (AUC), which is a curve constructed by plotting sensitivity against 1-specificity for different cut-offs. An intuitive explanation of the AUC is that if each vehicle with y = 1 is paired with each vehicle with y = 0, then the AUC is the proportion of the pairings where the vehicle with y = 1 has a higher estimated probability than the vehicle with y = 0. The AUC for this model is 0.843, which is considered excellent discrimination.[19]

Next, we computed the sensitivity and specificity rates at different thresholds (Figure 2). It shows that lowering the threshold produces higher sensitivity rates. At the CDC recommended threshold of 20%, the model produces a sensitivity rate of 26% and specificity of 99%. Aside from sensitivity and specificity, the model was also assessed in how well it identified vehicles with a fatally injured occupant, referred to as fatal vehicles. Fatal vehicles are a subset of the y = 1 group, and should have a prediction of 1. The proportion of fatal vehicles identified by the model (having a predicted value of 1) was 41%, using the 20% threshold.

[19] Hosmer, D. W., Jr. and Lemeshow, S. (2000). Applied Logistic Regression, Second Edition, New York: John Wiley & Sons.

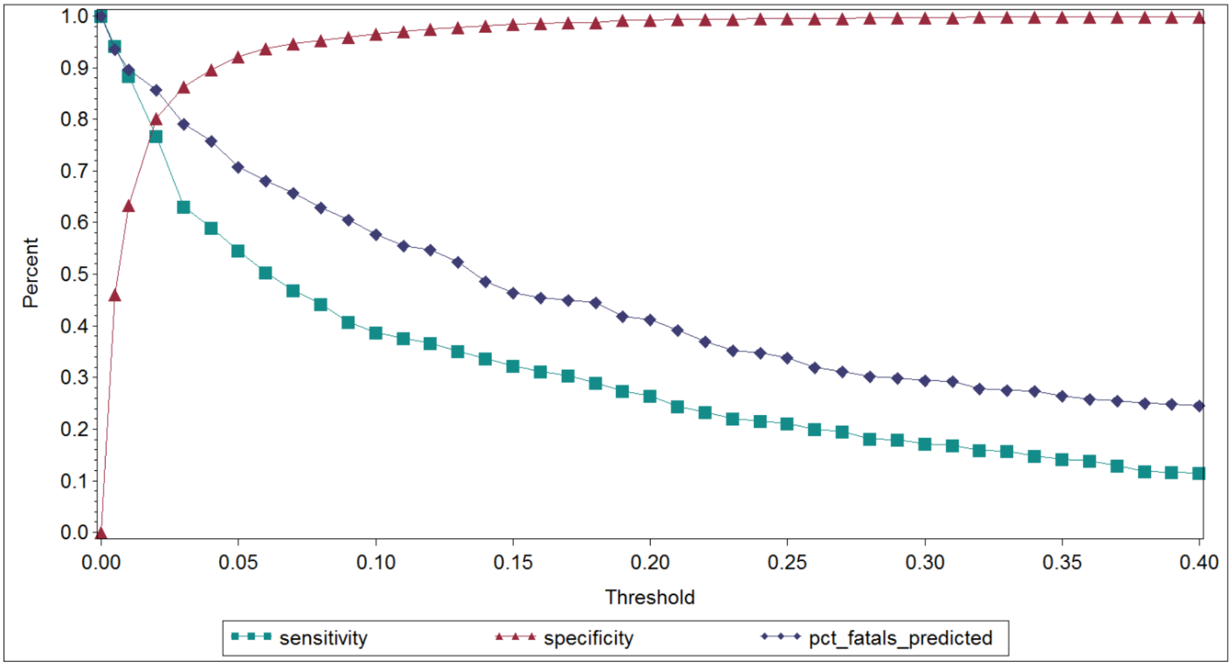

Figure 2. Sensitivity rate, specificity rate, and proportion of fatal vehicles identified by the algorithm, at various threshold levels or cutpoints.

To put these results into perspective, recall that the American College of Surgeons recommended 5% undertriage and 25-35% overtriage, whereas the logistic regression model predicted 74% undertriage and 1% overtriage. Achieving a 5% undertriage rate (95% algorithm sensitivity) requires lowering the risk threshold from the CDC recommended 20%, to about 1%. However, this also yields an overtriage rate of 55% (specificity of 45%), which is above ACS recommendations. Achieving an overtriage rate close to 35% (specificity of 65%) was achieved with a risk threshold of 2% and corresponding undertriage rate of close to 10% (sensitivity of 90%). Although the ACS guidelines for under- and overtriage are still not met, these results show that rates close to those recommendations are achievable with a risk threshold lowered from the original CDC recommendation.

The intention of the current study is not to recommend a specific algorithm, but rather to demonstrate the interplay between factors such as the chosen risk threshold, and resulting under- and over-triage, as well as to inform potential benefits estimates. These results support reducing the risk threshold to achieve better sensitivity rates more in line with the ACS recommendations. Therefore, an algorithm sensitivity of 90% is being used for benefits analysis because it is achievable by an injury prediction algorithm that also meets the specificity requirement of 65%, while achieving 95% sensitivity required a reduction in specificity below 65%.

IV. Target population and estimated lives saved

Following research conducted on the benefits of trauma center care and the prediction capabilities of injury prediction algorithms, the agency next conducted research to define the target population of fatalities that may benefit from AACN. The target population is the entire group of fatalities that share key characteristics, such as being in a light vehicle (currently only light vehicles have available AACN) and having access to a trauma center within a reasonable amount of time. Those characteristics will be described and will be used to determine a reasonable estimate range of how many lives could be saved with full implementation of AACN. This research combines both the benefits of trauma center care for severely injured patients and the benefits of faster crash notification.

To determine the population of vehicle occupants that could benefit from AACN (target population), data from both the Fatality Analysis Reporting System (FARS) and National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) were obtained. Being a census of fatalities that occurred on public roads, FARS data can provide estimates of absolute numbers of fatalities. For both overall fatalities and light vehicle occupant fatalities, trends indicate a significant decrease in fatalities between the year 2000 and 2014, followed by an increase in 2015 (Figure 3). In order for the benefits estimates derived here to be consistent with this trend, only the most recent seven years of FARS data were used in this analysis. There was an average of 21,934 light vehicle occupant fatalities for this period (Table 5). Light vehicles were examined because AACN is currently only available in this sector of the fleet.

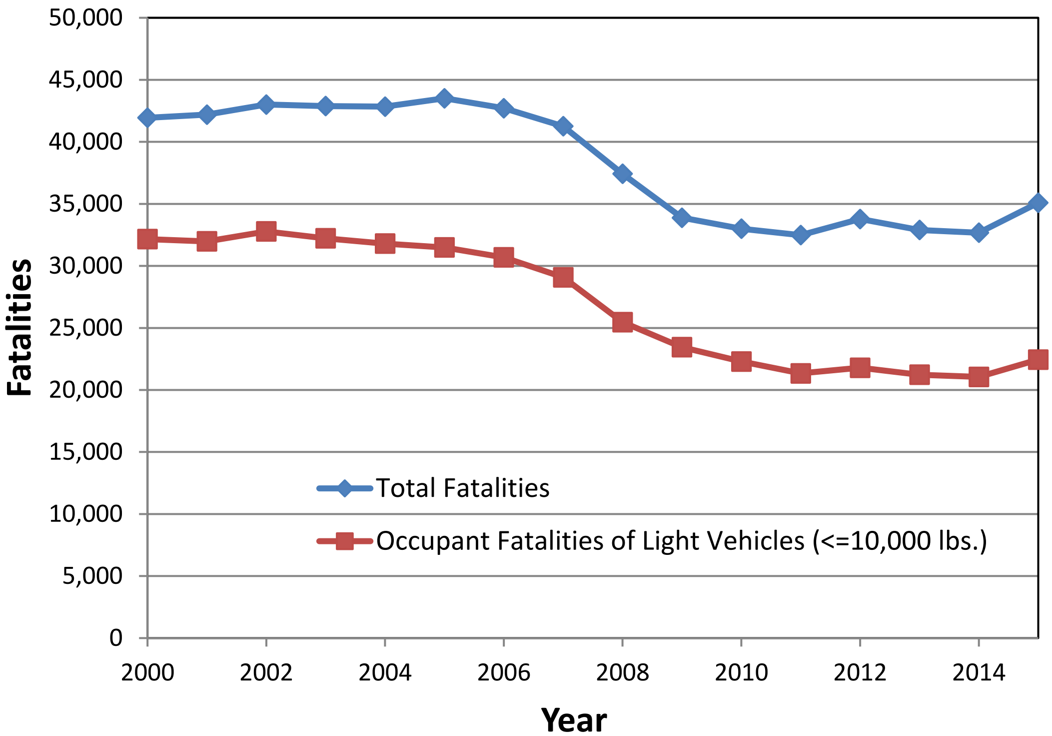

Figure 3. Fatalities (total) and light vehicle occupant fatalities (vehicle weight <=10,000 lbs.) using FARS 2000-2015.

Table 5. Occupant Fatalities (Drivers and Passengers) From Light Vehicles (weight <=10,000 lbs), FARS 2009-2015

Year	Occupant Fatalities
2009	23,411
2010	22,244
2011	21,287
2012	21,751
2013	21,112
2014	21,050
2015	22,441
average	**21,934**

NASS-CDS was used to provide relative comparisons between different groups (e.g. different medical facilities or treatments). For this analysis, NASS-CDS data was compiled from case years 2000 to 2015. Only occupants within light passenger vehicles (weight <=10,000 lbs.) were considered. A greater range of years was used from NASS-CDS due to small sample sizes in the most recent years.

Not all of the 21,934 annual average fatalities can benefit from AACN. To identify the subset of the population who can receive benefit, a number of "reduction factors" were applied to the overall population. These factors will be described in detail in the following subsections.

Instant Deaths

Previous research demonstrated that, when examining light vehicle occupant fatalities within 6 hours of the crash, 30% die instantly (defined in FARS when crash time minus death time equals zero).[20] Note that this does not include all on-scene deaths, as some of those may be able to be helped by ACN/AACN. Expanding the time window to deaths within 24 hours (Figure 4) demonstrates that approximately 28% of occupant fatalities are instant deaths. Since these will not be helped by earlier notification or injury prediction associated with an AACN system, a reduction factor of 0.72 was applied to exclude instant deaths from the total target population.

AACN Activation Threshold

A severely injured occupant will not benefit from the AACN system if an automatic call/notification is not made. Air bag deployment and 15 mph delta-V have been cited as the threshold for AACN notification.[21] Thus, fatalities occurring below this threshold will not benefit and the target population needs to be reduced accordingly. For the NASS-CDS population examined in this study, approximately 97% of fatalities had either an air bag deployment of occurred at a delta-V greater than 15 mph (reduction factor = 0.97).

Vehicles equipped with ACN systems

It is acknowledged that not all new vehicles can be assumed to benefit from AACN, because some already have the technology. For this effort, NHTSA estimated that approximately 35% and 20% of the model year 2016 fleet were predicted to be equipped with ACN and AACN, respectively. This accounts for vehicle technology but not necessarily active subscription status (due to lack of available information),

[20] Wu, J., Craig, M., Longthorne, A. (2015). Updated estimates of potential traffic fatality reductions with automatic collision notification. In: *Proceedings from the 24th International Technical Conference on the Enhanced Safety of Vehicles,* Paper No. 15-0269

[21] Kononen, D. W., Flannagan, C. A. and Wang, S. C. (2011). Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes. *Accident Analysis & Prevention*, *43*(1), pp.112-122.

which may reduce these percentages. Therefore, 45% of the fleet can be assumed to benefit from earlier notification (ACN reduction factor = 0.45).

Pre-admission vs. Post-admission deaths
After excluding instant deaths and those in which the AACN activation threshold (airbag deployment or delta-V ≥ 15 mph) is not met, the remaining population was divided into pre-admission and post-admission deaths. This was defined using the NASS-CDS variable "STAY", where hospital stay greater than or equal to 1 indicated a post-admission death. Most fatalities (73%) occurred pre-admission and 27% occurred post-admission. This is not a reduction factor, but rather a split in the target population. This was done because there are additional factors to identify whether the occupant can benefit from an injury severity prediction that results in transport to a trauma center, which vary depending on whether the occupant died before or after reaching a hospital/trauma center.

Original transport decision
While all post-admission deaths may gain some benefit from earlier crash notification, it is necessary to consider the original transport decision to determine whether additional AACN benefits can be derived. If the occupant was already transferred to a trauma center, the injury prediction supplied by the AACN system is assumed to have no effect on transport decision. However, for occupants transported to hospitals, the injury risk prediction might result in a change in transport, from hospital to trauma center. Using the NASS-CDS dataset, the percentage of fatally injured occupants who are admitted to either a trauma center or hospital is 74% and 26%, respectively. Thus, a reduction factor of 0.26 is applied to determine those occupants who could benefit from a change in destination.

Travel Time to Trauma Centers
Not all crashes occur within a reasonable distance to a trauma center that would allow serious or fatal occupants to be transported there. In such an instance, patients will likely be transported to the same destination regardless of the injury severity prediction of the AACN system, and therefore may benefit only from earlier crash notification but not from a destination decision informed by the injury prediction. Previous studies have found that the odds of fatality are significantly greater for occupants outside a 60-minute coverage area, compared with a 45-minute coverage area.[22] Thus, for this analysis, a time window of 45 to 60 minutes for transport to a trauma center is therefore assumed to be a reasonable time window for which benefits of change in destination may be realized. Geospatial analysis demonstrated that 80% of fatal crashes occur within a 20-minute coverage area of helicopter emergency medical response (equivalent of 60-minute response given 20-minute flight time, out and back, and flight preparation time).[23] A reduction factor of 0.80 was applied.

Injury Prediction Algorithm
A severely injured occupant will not benefit from the AACN system (besides earlier notification) if the injury severity prediction algorithm does not identify him as having a high risk of severe injury. Thus, the sensitivity of the algorithm, or true positive rate (proportion of occupants with ISS 16+ who are correctly identified by the algorithm as having a high risk of injury), is an important consideration in target population development.

As described in detail in the preceding section, an algorithm sensitivity of 90% (reduction factor = 0.9) will be used for this analysis. This sensitivity is achievable by an injury prediction algorithm that also

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[22] NHTSA. (2012a). The association between crash proximity to level 1 and 2 trauma centers and crash scene mortality of drivers injured in fatal crashes (Report No. DOT HS 811 599). Washington, DC: National Highway Traffic Administration.
[23] NHTSA. (2012b). Analysis of the proximity of fatal motor vehicle crash locations to the availability of helicopter emergency medical service response (Report No. DOT HS 811 542). Washington, DC: National Highway Traffic Administration.

meets the specificity requirement of 65%, while achieving 95% sensitivity required a reduction in specificity below 65%. Note that because injury prediction algorithms are optimized to identify severely injured patients (ISS 16+) the sensitivity and specificity rates do not directly apply to fatal occupants. Nonetheless, it is assumed here that an algorithm that correctly identifies 90% of ISS 16+ patients will also correctly identify at least that proportion of fatal occupants.

Time to Destination

Previous research reported that the median time for fatalities to reach a hospital or trauma center was between 45 and 60 minutes and the mean time to death was 67 minutes.[20] Using the previously published survival curve, expanded for the time window of 24 hours (Figure 3), the survival rates at 45 and 60-minutes post-crash were 40 and 31%, respectively. Excluding the 28% instant deaths yields survival rates of 56% and 43%, for 45 minutes and 60 minutes post-crash, respectively. The assumption here is that the 44% to 57% of occupants who expired prior to this time frame have injuries that are simply untreatable, or could not have been saved even with trauma center treatment. Thus, a reduction factor range of 0.43 to 0.56 was used to represent the proportion of pre-admission occupants who can benefit from improved care. For the post-admission group, this factor is not relevant since these occupants did in fact, reach a destination alive.

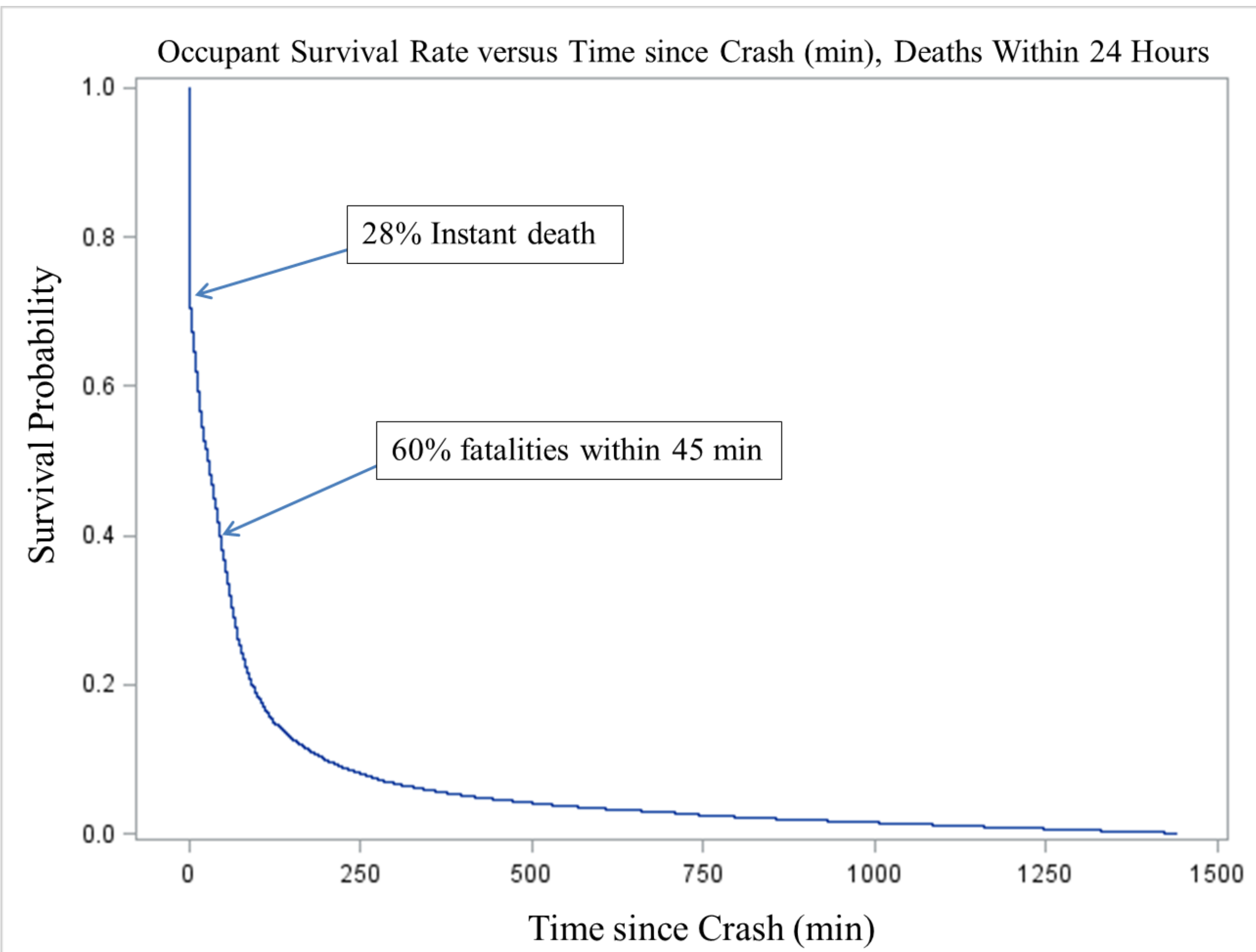

Figure 4. Survival analysis demonstrating time to death for all fatalities within 24 hours (FARS 2009-2012), figure adapted from Wu et al. (2015).[20] At 45 minutes, the survival rate is 40%. Excluding the 28% instant deaths, the survival rate at 45-minutes post-crash is 56%.

Triage Protocol

As previously discussed, the American College of Surgeons Committee on Trauma (ACS-COT) has published a resource manual that provides guidance for the field triage process through a Field Triage Decision Scheme.[2] Vehicle telematics "consistent with high risk for injury" is currently listed in Step 3 of the protocol, meaning that if a patient is negative for Step 1 and 2, the AACN injury prediction can be used to inform transport decision to either hospital or trauma center. While the AACN injury prediction would provide *a priori* information concerning likelihood of injury, and could therefore be evaluated before either Step 1 or 2 of the Decision Scheme, for this analysis it is conservatively assumed that EMS protocols are unchanged. Therefore patients presenting positive for Step 1 or 2 are assumed not to benefit from the AACN injury prediction.

A multi-site assessment of the Field Triage Decision Scheme determined that Step 1 and 2 were cumulatively 45% sensitive for identifying patients with Injury Severity Score (ISS) 16 or greater (16+).[24] An analysis using NASS-CDS data found that Steps 1 and 2 combined identified about 52% of ISS 16+ patients.[25] Similarly, an analysis using the National Trauma Databank (NTDB) found that Steps 1 and 2 combined were 56% sensitive for identifying patients with ISS 16+.[26] Because 45% to 56% of severely injured patients are being identified by the first two steps in the Decision Scheme, the 44% to 55% who are not could receive benefit from an AACN system that correctly identifies them as high risk of severe injury (reduction factor: 0.44 to 0.55). Note that fatalities may be Step 1 or 2 positive more often than severely injured non-fatal occupants, but this has not been specifically evaluated in any published studies.

Vehicles equipped With AACN systems

As noted above, approximately 20% of the model year 2016 fleet were predicted to be equipped with AACN. Thus, 80% of the fleet can benefit from AACN implementation (AACN reduction factor = 0.80). Although penetration of the use of AACN injury predictions by emergency medical personnel may be as or more important than the penetration of the technology within the vehicle fleet, such predictions are beyond the scope of the current effort. As such, this factor only accounts for penetration of the technology within the future vehicle fleet.

Estimate of Target Population and Lives Saved

Once the relevant reduction factors (summarized in Table 6) were identified, they were applied to the original target population of 21,934 fatalities in successive order as shown in Figure 5.

[24] Newgard, C. D., Zive, D., Holmes, J. F., Bulger, E. M., Staudenmayer, K., Liao, M., Rea, T., Hsia, R. Y., Wang, N. E., Fleischman, R. & Jui, J. (2011). A multi-site assessment of the ACSCOT field triage decision scheme for identifying seriously injured children and adults. *Journal of the American College of Surgeons*, *213*(6), p.709.

[25] Davidson, G. H., Rivara, F. P., Mack, C. D., Kaufman, R., Jurkovich, G. J. & Bulger, E. M., 2014. Validation of prehospital trauma triage criteria for motor vehicle collisions. *Journal of Trauma and Acute Care Surgery*, *76*(3), pp. 755-761.

[26] Brown, J. B., Stassen, N. A., Bankey, P. E., Sangosanya, A. T., Cheng, J. D. and Gestring, M. L. (2011). Mechanism of injury and special consideration criteria still matter: an evaluation of the National Trauma Triage Protocol. *Journal of Trauma and Acute Care Surgery*, *70*(1), pp. 38-45.

Table 6. Summary of reduction factors for AACN target population

	Reduction Factor	Overall	Pre-admission	Post-admission	Source of estimate
1	Instant deaths	0.72	-	-	FARS
2	AACN activation threshold	0.97	-	-	NASS-CDS
3	Vehicles equipped with ACN	0.45	-	-	NHTSA
4	Original transport decision	-	-	0.26	NASS-CDS
5	Access to trauma center	-	0.8	0.8	Published data
6	Injury prediction algorithm	-	0.9	0.9	ACS guidelines
7	Time to destination	-	0.43 to 0.56	-	FARS
8	Triage protocol	-	0.44 to 0.55	0.44 to 0.55	Published data
9	Vehicles equipped with AACN	0.8	-	-	NHTSA

After excluding instant deaths, those in which the activation threshold (airbag deployment or delta-V ≥ 15 mph) is not met, and the portion of the current fleet that already has ACN technology, the resulting 6893 fatalities (group B from Figure 5) can all receive some benefit from implementation of either an ACN or an AACN system, specifically the benefit of earlier notification. Only a small subgroup (group A from Figure 4) meets all the AACN criteria (access to trauma center, survivable injuries, negative for Step 1 and 2 of the Field Triage Decision Scheme, and positive for being predicted by the injury severity prediction algorithm) and therefore benefits from both earlier notification and injury severity prediction via a change in destination. This group encompassed between 1,495 and 2,330 occupants, given the range of reduction factors used. There is also some overlap between occupants in groups A and B.

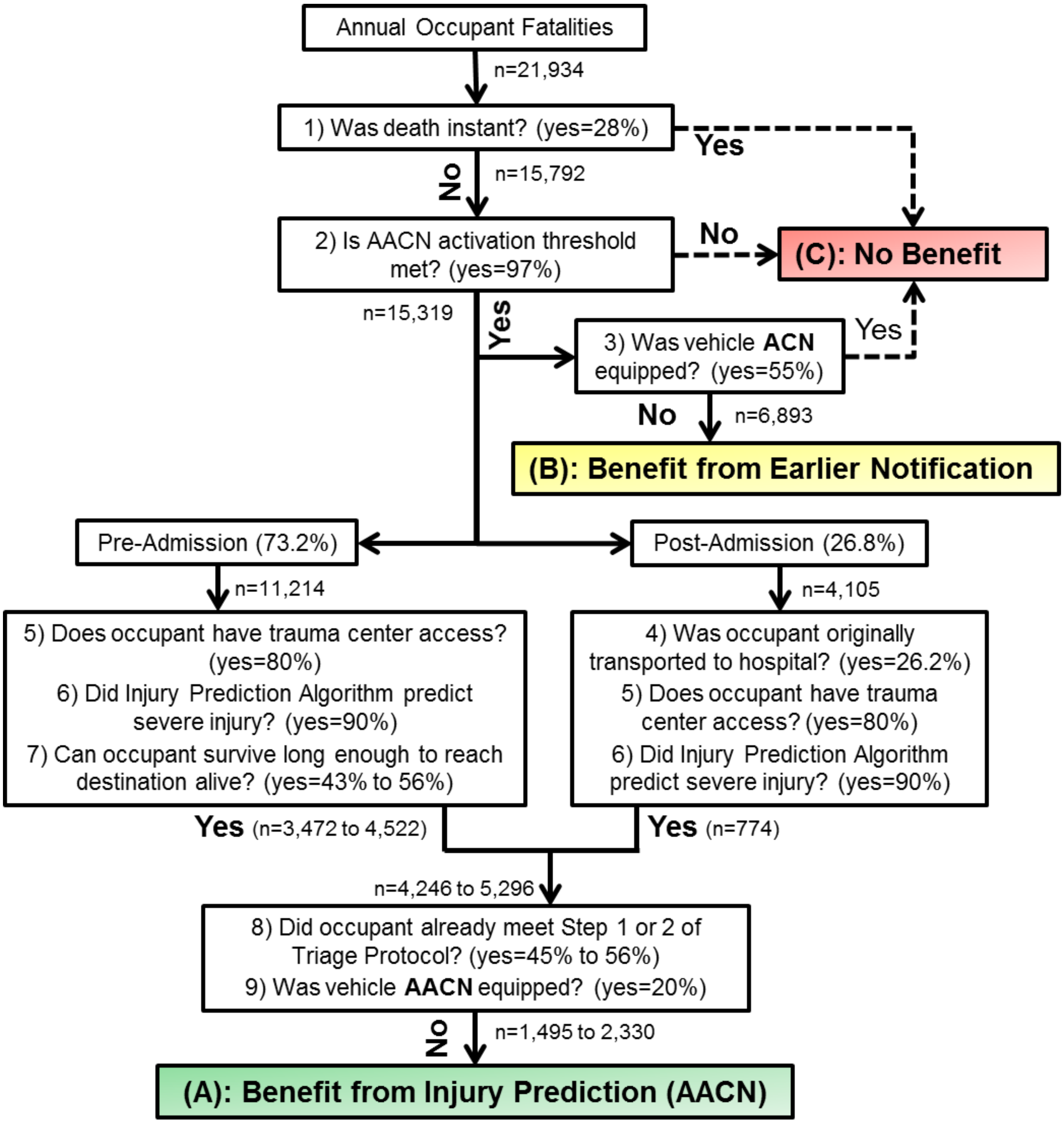

Figure 5. Flowchart of reduction factors applied to target population and demonstration of which occupants do not benefit from AACN (group C), which occupants benefit from earlier notification (group B, n=6,893), and which occupants benefit from the AACN injury prediction via change in destination to trauma center (group A, n=1,495 to 2,330). There is some overlap among occupants in groups A and B.

An upper and lower bound of possible lives saved was determined using the two target population groups identified above, along with the previously discussed fatality reduction rates. For the benefits of earlier notification, the current study assumed 1-2% fatality reduction, based on Wu et al. (2015). The fatality reduction rate associated with change in destination from hospital to trauma center was determined earlier to be 21% to 25%. For the lower bound of the estimate range, group A was assumed to exclusively derive benefits from injury prediction and not from earlier notification. Thus, the occupants in group A (n=1495 to 2330) were removed from group B (n=6893), to ensure no overlap, and the number of occupants benefitting from earlier notification was 4563 to 5398. For the upper bound, group A was assumed to derive additive benefits from earlier notification and injury prediction. Thus, the number of occupants benefitting from earlier notification was from the entire group B (n=6893). Thus, the portion of lives saved by earlier notification is approximately 46 (4563 * 0.01) to 138 (6893 * 0.02). A total of between 360 (314+46) and 721 (583+138) total lives could potentially be saved given AACN.

The estimate of lives saved (360 to 721) represents a fatality reduction of approximately 1.6% to 3.3% per year, and more than double the potential lives saved by earlier notification alone. While there are limitations to this analysis, these estimates demonstrate that AACN shows a promising potential for safety benefit based on the current research.

Limitations of Benefits Analysis

One limitation to the current work is that it estimates benefits only for fatally injured occupants. Other benefits can be realized with respect to seriously, non-fatally injured occupants, though these are difficult to predict and therefore have not been included in the current study. For example, many injuries, such as brain hemorrhage or aorta laceration, are time sensitive.[27] Time sensitive injuries in particular will benefit both from earlier crash notification and a prediction of severe injury that prompts immediate transport to a trauma center rather than a local hospital. Trauma center care can also result in better outcomes and reduced readmissions for severely injured patients.[28] For injuries such as hemorrhaging, Abbreviated Injury Scale severity levels are often based on blood volume. Since faster treatment may result in reduced blood volume, this can also reduce maximum (MAIS) score, leading to better outcomes. While the benefits for severely injured non-fatal occupants are not estimated in the current research, it is clear that AACN can benefit this group of occupants by improving response time and triage/transport decisions. Since non-fatally injured occupants greatly outnumber fatally injured occupants, the actual societal benefit is likely much greater than the fatality reductions estimated in this paper.

Other benefits can be realized for nonoccupants (e.g., pedestrians, pedal cyclists and motorcyclists) or occupants of the non-AACN equipped vehicle in a crash. In these situations, the AACN system can be used (either through automatic call or manual call) to contact emergency services. Finally, the benefits of AACN injury prediction estimated here were limited to the change in destination (from hospital to trauma center) based on injury prediction outcome. However, AACN injury prediction could also provide benefits from changes in the type of emergency response (e.g., Advanced Life Support or Air Medical Services rather than Basic Life Support), which may result in more appropriate emergency personnel on scene sooner. Also, correctly identifying patients as being severely injured can shorten response time at the trauma center, since a trauma team may be activated in advance of the patient arrival. While the effect cannot be quantified at this time, it may be substantial, since unlike the benefits of change in destination, these factors can benefit patients who were already transported to a trauma center (74% of post-admission patients already went to trauma center).

Limitations of this research include that the benefits of AACN rely upon others, such as 9-1-1 dispatchers and EMS first responders, to "act differently." Upon receiving an automatic collision notification with a high probability of severe injury, these end users need to send different resources to the scene or make the

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[27] Schoell, S. L., Doud, A. N., Weaver, A. A., Talton, J. W., Barnard, R. T., Martin, R. S., Meredith, J. W. & Stitzel, J. D. (2015). Development of a time sensitivity score for frequently occurring motor vehicle crash injuries. *Journal of the American College of Surgeons*, *220*(3), pp.305-312.
[28] Staudenmayer, K., Weiser, T. G., Maggio, P. M., Spain, D. A. & Hsia, R. Y. (2015). Trauma center care is associated with reduced readmissions after injury. *The Journal of Trauma and Acute Care Surgery*.

decision to transport a patient to a trauma center who might otherwise be sent to a local hospital, in order for the benefits to be attained. Although the ACS Field Triage Decision Scheme was cited here, many states, counties and municipalities have their own triage protocols, and do not necessarily follow the ACS Decision Scheme. Pre-hospital care systems may not currently have EMS protocols in place that would dictate what first responders should do when receiving an AACN message with a high probability of severe injury. The estimates presented in this paper assume a 100% cooperation or compliance with AACN in step 3 of the triage protocol. It is hoped that the current research, along with prior research, will demonstrate the potential for benefits associated with AACN, leading others to adopt and implement protocols that would allow these benefits to be realized. This analysis also assumes universal cell coverage availability. Information is currently not available demonstrating the proportion of fatal crashes that occur outside of cell phone coverage areas and thus would not have access to an AACN call.

V. Cost

The complete cost of an AACN system may include the cost of the system hardware, cellular service, as well as societal costs to PSAP, pre-hospital care systems, and trauma systems that may need to implement new protocols in order to fully utilize the AACN information. System and cellular costs may be evaluated using methods such as a tear down study, and/or information voluntarily provided by manufacturers or TSPs. System costs are expected to be minimal because the equipment necessary is similar to that required for Event Data Recorders (EDR). Further work in these areas is ongoing and a comprehensive cost analysis is unavailable at this time.

Societal cost may be much more difficult to determine. As demonstrated above, at the CDC recommended 20% risk threshold, the prediction algorithm falls far short of the undertriage rates recommended by the ACS. However, reducing the risk threshold increases overtriage rates, which may result in more "false positives" (or persons with only minor injury) being transported to the higher level trauma center, which can increase cost of care. As a preliminary attempt to estimate societal costs, we have evaluated the potential cost saved due to mortality reduction and the potential cost spent on triaging minor-severity injured people to higher levels of care.

The benefits at a specific threshold is the number of lives saved by AACN multiplied by the dollar amount saved per fatality prevented. As noted above, the estimated number of lives saved by AACN was, at most, 721 per year (assuming the injury prediction algorithm correctly identifies 90% of the fatal occupants). As for the economic savings, Blincoe et al. (2015) estimate the comprehensive fatality injury cost to be $9,129,066.[29] Since a fatality prevented by AACN cannot be considered to be uninjured, it is assumed that the saved occupant will still have a maximum AIS (MAIS) 4 injury level with a comprehensive injury cost of $2,414,252. The cost-savings of preventing a fatality is the difference between these two injury costs which is $6,714,814. The cost benefit at a particular threshold, *t*, can now be expressed as Equation 4, where %FatalsPred is the percent of fatalities predicted at that risk threshold (again, 90% was used to estimate the 721 lives saved).

$$Benefit(t) = \frac{721}{0.90} \times \%FatalsPred(t) \times \$6{,}714{,}814 \qquad (4)$$

The cost at a specific threshold is the number of minorly injured occupants (ISS < 16) unnecessarily treated at a trauma center multiplied by the cost of overtriage per patient. The number of occupants with

[29] This equals comprehensive costs less congestion costs and property damage costs. Comprehensive costs consist of tangible losses (such as property damage, medical care, insurance costs, legal costs, etc.) plus costs associated with lost quality of life.

ISS < 16 is estimated to be around 4 million annually, using CDS 2006-2008. Since not all of these occupants will be sent to a trauma center as a direct result of AACN, the following reduction factors were applied:

1. % overtriage NOT identified by steps 1 and 2 of the triage protocol = 78%[30,31]
2. % of occupants with ISS < 16 that were in a crashed vehicle that met the conditions for the AACN system to make a call (i.e. delta-V ≥ 15 or airbag deployment) = 60%
3. % access to trauma center = 80%

Applying the reduction rates to the 4 million occupants produces 1,497,600, which is then applied the rate of false positives at a specific threshold. The rate of false positives is equal to one minus the specificity computed at the occupant level.

The cost of a minor injured occupant treated at a trauma center is approximately \$5,000 to \$10,000.[32,33] Using the midpoint of this range, the cost at a particular threshold is,

$$Cost(t) = 1{,}497{,}600 \times (1 - specificity(t)) \times \$7{,}500$$

Computed values for benefits, costs, and their difference are shown in Figure 6. Difference between benefits and costs by threshold levels. At the CDC recommended threshold of 20%, benefits exceed costs by about \$2.18 billion. As the threshold is lowered, benefits continue to be greater than costs. Around the 6% threshold, costs start to climb at a higher rate than benefits, and eventually the two become equal somewhere between the 0.8% and 0.7% thresholds. After this point costs exceed benefits.

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[30] Newgard, C. D., Zive, D., Holmes, J. F., Bulger, E. M., Staudenmayer, K., Liao, M., Rea, T., Hsia, R. Y., Wang, N. E., Fleischman, R. and Jui, J. (2011). A multi-site assessment of the ACSCOT field triage decision scheme for identifying seriously injured children and adults. *Journal of the American College of Surgeons, 213*(6), p.709.

[31] Brown, J. B., Stassen, N. A., Bankey, P. E., Sangosanya, A. T., Cheng, J. D. and Gestring, M. L. (2011). Mechanism of injury and special consideration criteria still matter: an evaluation of the National Trauma Triage Protocol. *Journal of Trauma and Acute Care Surgery, 70*(1), pp.38-45.

[32] Newgard C. D., Staudenmayer, K., Hsia, R. Y., Mann, N. C., Bulger, E. M., Holmes, J. F., et al. (2013). The cost of overtriage: more than one-third of low-risk injured patients were taken to major trauma centers. Health Aff (Millwood); 32: 1591–1599. doi: 10.1377/hlthaff.2012.1142

[33] Faul, M., Wald, M. M., Sullivent, E. E., Sasser, S. M., Kapil, V., Lerner, E. B., Hunt, R. C. (2012). Large cost savings realized from the 2006 Field Triage Guideline: reduction in overtriage in U.S. trauma centers. *Prehosp Emerg Care, 16*: 222-229.

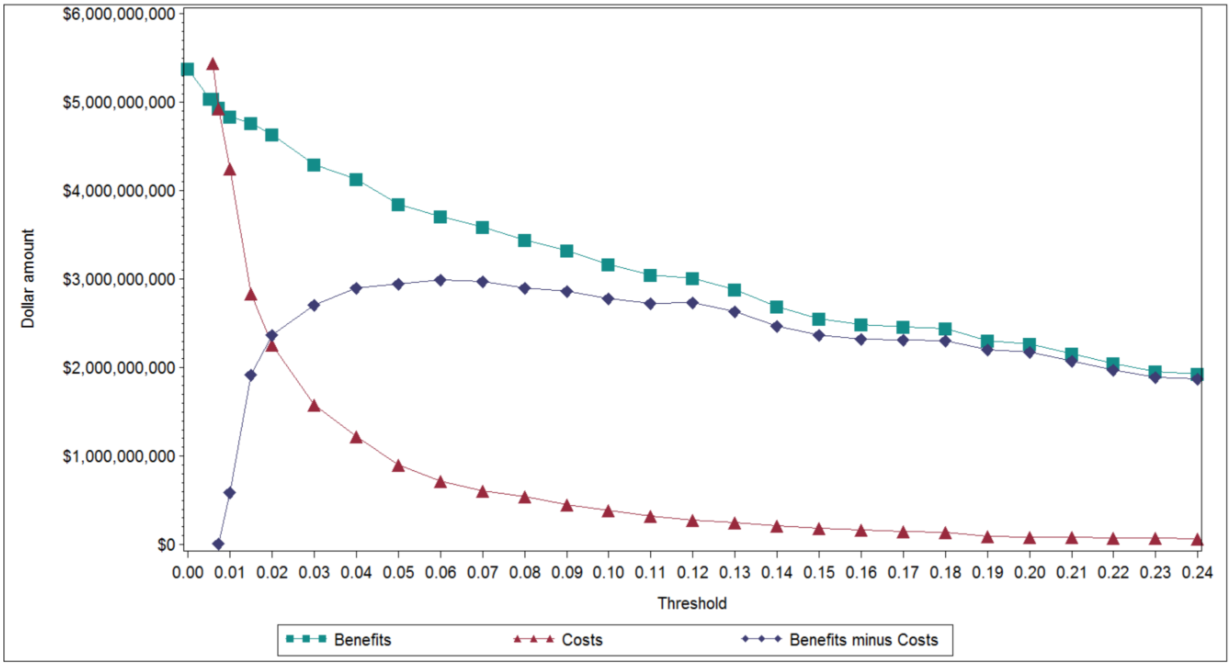

Figure 6. Difference between benefits and costs by threshold levels.

This analysis is only a preliminary look at societal costs of AACN. However, it demonstrates that it may be more cost-beneficial to take more occupants to trauma centers (based on the AACN injury prediction), even though this entails more minimally injured people being overtriaged. Although an *increase* in overtriage is being noted here, that is in comparison with the overtriage rate resulting from the 20% risk threshold recommended by CDC. In practice, actual overtriage may be already be much higher than predicted here using the injury prediction algorithm. Stitzel et al. (2016) compared ISS and the occupant's actual triage status (trauma center or hospital) using NASS-CDS and found that actual overtriage rate was around 60%.[34] Thus, following the recommendation of an injury prediction algorithm may actually help reduce overtriage and result in cost savings.

VI. Test Procedures

Because it is believed that AACN may be beneficial, the agency has also conducted research on how AACN system performance might be objectively evaluated. With this goal in mind, NHTSA has embarked on research to establish a test procedure that could be used for this purpose. ACN/AACN systems establish voice communications and transmit information about a vehicle collision to a telematics service provider (TSP) or a PSAP. Obtaining ACN/AACN data requires the cooperation of the TSP or PSAP. Independently obtaining the contents of this data is not possible, assuming secure, proprietary communication between the vehicle and the TSP or between the vehicle and the PSAP. Therefore, the agency's test procedure research has focused on the equipment and methods for detecting the presence of communication with the TSP or PSAP without obtaining the communication's contents.

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[34] Stitzel, J. D., Weaver, A. A., Talton, J. W., Barnard, R. T., Schoell, S. L., Doud, A. N., Martin, R. S. & Meredith, J. W. (2016). An injury severity-, time sensitivity-, and predictability-based advanced automatic crash notification algorithm improves motor vehicle crash occupant triage. *Journal of the American College of Surgeons, 222*(6), pp. 1211-1219

To objectively evaluate an AACN system, the performance requirements were defined as follows:

- A post-crash notification system must demonstrate the capability to properly function (turn on, enable voice, data transmission) in current regulated crash tests and under current NCAP full-scale crash conditions.
- The system must remain functional post-crash for some minimum length of time to allow the TSP or PSAP operator to remain on the line with the occupant while waiting for EMS arrival.

The purpose of the procedure is to assess the capability of an ACN/AACN equipped vehicle to establish communication with either the TSP or the PSAP after a crash test. The test will monitor the presence of cellular communications. The test equipment consists of a radio frequency (RF) power detector, detector antenna and data acquisition system. The detector antenna receives RF energy from the vehicle's cellular antenna. Most antennas have a published set of frequencies to which they are tuned to respond. The detector antenna should be designed to respond to the frequencies in question. The antenna should be placed sufficiently close to the cellular wireless antenna such that the biggest RF signal received by the antenna comes from the vehicle's cellular antenna.

The detection process is as follows:

- The detector antenna intercepts the ACN/AACN signal.
- After amplification and filtering, the signal is fed to the RF power detector.
- The RF power detector circuitry converts the RF energy to a slowly varying voltage proportional to the input signal power, which is monitored for changes that indicate a phone call occurring.

Data Acquisition System

Crash tests performed for occupant protection assessment have substantial native data acquisition capabilities for recording the streams of data coming from crash test dummies, vehicle instrumentation and the like. However, this data acquisition capability may not be able to be used for RF detection because the sampling rates for the RF detector are much slower than the native data acquisition system. Also, the RF detector for ACN/AACN assessment must run for a much longer time than the native crash test data acquisition systems are usually expected to run. We believe a small, physically robust data acquisition system is required for this application.

Pre-Test Requirements

This section outlines what NHTSA would envision as the potential general pre-test procedures necessary for testing an ACN/AACN system during a full-scale crash test.

1. Activate an account with the TSP. Prior agency testing demonstrated that the TSP service account for the TSP should be active prior to the test. In systems which directly contact the PSAP, such as Ford Sync's "9-1-1 Assist," the ACN feature should be activated before the crash test.
2. Equipment Installation. Taking into account the high accelerations that the system experiences during a crash test, care should be taken to securely fasten the system and its components. With the system securely fastened, the antenna is mounted as close as possible to the vehicle's cellular antenna to ensure maximum reception from the vehicle's antenna.
3. Test the data recording trigger. A trigger input to the RF detector's data acquisition system should cause the RF detector system to take data. This trigger input should be the same as the input provided by the crash trigger.
4. Identify frequencies of interest. In general, the frequencies used by a particular system may be obtained from the FCC website once the FCC identifier for the device is known. Since the goal is to detect transmissions from the cellular wireless system, frequencies which are in the ISM band intended for WiFi use should be rejected by the detection circuit. The RF detector circuit should

employ band pass filters which reject WiFi, Bluetooth or any other non-cellular frequencies while accepting the others listed on the FCC website.

5. Make a test call. A phone call should be placed on the ACN/AACN device prior to the crash test, and the RF detector output voltage level should be measured. In most cases, the call is placed by manually pushing a button inside the vehicle. During the test call, the TSP or PSAP can be alerted that this is a test call made by a crash test laboratory, and that a crash test will be run shortly, and an automatic call is expected to be placed. The data acquisition system should be able to record RF power data while the test call is made to the TSP or PSAP. There should be a measurable difference in the RF detector's output when a phone call is occurring. Specifically, if the RF detector can show greater than 10dB of change when the test call is present then the detector is operating nominally. If the 10 dB change is detected, proceed with the crash test. If it is not, make any necessary corrections to the detection system.
6. Perform the crash test. A similar difference in RF power should appear when the ACN/AACN system places a call after the crash has occurred.

Post-Test Performance Assessment and Documentation

The RF detector should reveal transmissions from the vehicle's wireless cellular system for some minimum length of time after impact, to verify its functionality post-crash. A transmission should be assumed when the RF power increases from background by more than 10dB. In the case of a TSP system, the vehicle's OEM will provide the data which the crash vehicle sent to the TSP. The data provided by the OEM should be consistent with the parameters of the crash test.

Actual Crash Test Data

Figure 6 shows RF detector data from an actual crash test.The crash occurred on the rising edge of the green trigger plot at 29.89 seconds. The low band of the RF detector shows a response indicating a phone call to the TSP at 35.15 seconds, about 5 seconds after the crash. In this case, the TSP's operator was on the line until crash test personnel provided assurance that everything was OK at 86.38 seconds. The difference in dBm from transmitting versus not transmitting was 26 dB. This represents a factor change of 398.1 (10^2.6) from 0.00001 milliwatts to 0.003981 milliwatts.

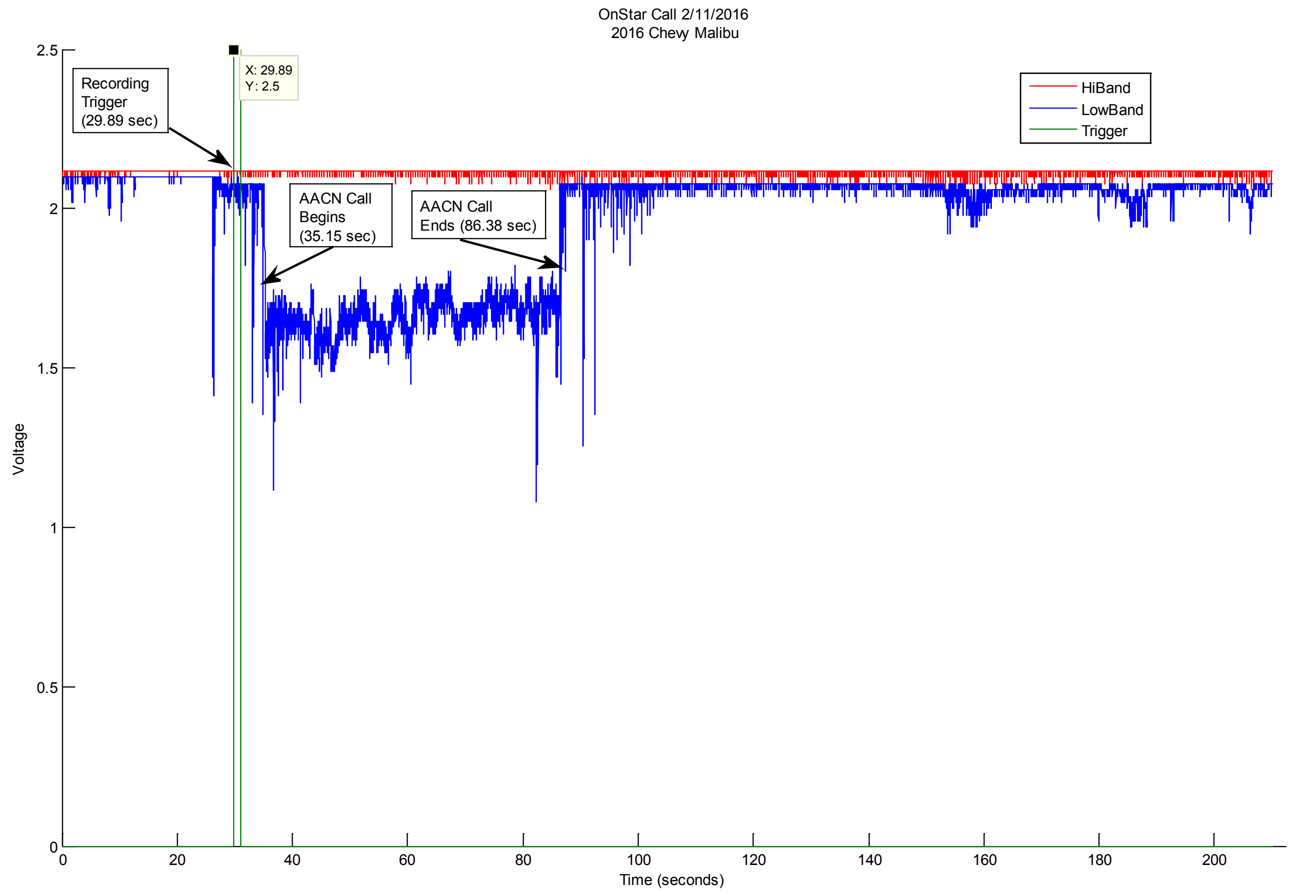

Figure 7. Example data from a crash test.

VII. Technical Considerations

There are currently two types of post-crash notification systems available: embedded and Bluetooth-enabled. Hardware requirements vary depending on system type. For embedded systems, the vehicle must be capable of recording and storing the necessary data (e.g., delta-V, belt use), and transmitting that data out of the vehicle. This requires the same vehicle sensors as the restraint control module or an EDR. Also required are antennas (external mobile network antenna, GNSS antenna), cellular equipment (telematics module) and connectivity to transmit voice and data, and a dedicated battery so that the ACN/AACN system may still function post-crash. Bluetooth-enabled systems differ in that the embedded antenna and telematics are not present; the emergency call is made automatically through the user's linked cell phone, rather than through vehicle's cellular connection.

Bluetooth-enabled systems offer some advantages such as the fact that most consumers already have a personal cell phone and the cost is already borne by the consumer. Even so, a fundamental flaw in a Bluetooth-enabled system is that it requires a user to act (i.e., to link their cell phone to their vehicle, and have it turned on at all times in the vehicle). In addition, this system option is expected to have poor crashworthiness compared with an embedded system because there is no reliable method of ensuring that a personal phone is functional post-crash.

Many current post-crash notification systems in the U.S. operate through a third party TSP. In this type of system, a voice call is initiated between the vehicle and the TSP and data elements are also transmitted electronically to the TSP. The data elements are used in an algorithm at the TSP level to determine likelihood or probability of severe injury. The TSP operator initiates contact with the PSAP; data (including calculated injury severity probability) can be relayed to the PSAP via voice communication with the TSP operator, or electronically. Currently, voice transmission is the norm, since, as noted above, not all PSAPs are capable of accepting electronic data. These TSP systems are owned and operated by motor vehicle manufacturers who offer these services to customers who subscribe for a monthly fee. Alternately, a direct-to-PSAP call may be made by the vehicle. In this type of system, the injury severity prediction algorithm is computed by software within the vehicle. Direct-to-PSAP call may offer some advantages over third party systems in terms of reduced data transmission.

Ideally, data would be transmitted electronically to the PSAP. However, currently not all PSAPs are capable of accepting electronic data. Thus, in current direct-to-PSAP systems, "data" is transmitted to the PSAP via a voice recording. Next Generation 911 (NG911) is an Internet Protocol (IP)-based system that allows digital information (e.g., voice, photos, videos, text messages) to flow seamlessly from the public, through the 9-1-1 network, and on to emergency responders. This is the system PSAPs need to have in place in order to receive electronic data. According to 2015 state data from the National 911 Program,[35] about 14% of States have fully operational NG911 systems, 19% have some NG911 capabilities and 50% have no NG911 capabilities to-date (17% of state capabilities are currently unknown). Data from preceding years demonstrates that States' capabilities are expanding each year.

Data elements required for third party and direct-to-PSAP systems differ. In order for AACN systems to function optimally, it is believed that a minimum set of data needs to be identified. These data should be useful to end users, such as dispatchers and EMS. Transmission of extraneous data should be avoided for practicality (i.e., too much information could actually be detrimental to making timely dispatch and triage decisions) and privacy considerations. End users will need vehicle information (e.g., make, model, color) and location information (e.g., GPS, vehicle heading) to locate the vehicle, and injury severity prediction (e.g., severe/not severe) to determine appropriate resources and destination decision, but may not need other crash information such as delta-V. Since in a direct-to-PSAP system the injury severity prediction is computed at the vehicle level, fewer data elements are required to be transmitted out of the vehicle (Table 7). Third party systems transmit (to the TSP) all the data elements required in the direct-to-PSAP system, plus additional data elements (e.g., delta-V, belt status, multi-event; see Table 8) because the injury severity prediction is computed by an algorithm at the TSP level. In this case, the TSP operator can act as a filter, relaying only the necessary information to the PSAP. The agency has therefore attempted to identify what could reasonably be considered a minimum set of data elements to be transmitted to the TSP for use in injury prediction (Table 5, Table 6). These are based on the recommendations of the 2008 CDC expert panel, the EU eCall regulation, along with other literature demonstrating what attributes are helpful in predicting injury risk. As additional information is gathered and research performed, additions and/or deletions from this list are possible.

Data format recommendations are based on the Title 49 Code of Federal Regulations (CFR) Part 563, "Event data recorders" and the Vehicle Emergency Data Set (VEDS) Recommendations. The VEDS Recommendations reflect the useful and critical data elements and schema needed to provide an efficient emergency response to vehicular emergency incidents, as determined by the AACN Joint APCO/NENA Data Standardization Working Group. This working group was formed specifically to address the need for an open standard format to be used for all providers and consumers of vehicle telematics information. The group consisted of the Association of Public Safety Communications officials (APCO) and National Emergency Number Association (NENA) staff, 9-1-1 PSAP practitioners, NHTSA's Office of EMS, and staff representing multiple TSPs.

[35] 2015 National 911 Progress Report. National Highway Traffic Safety Administration. Washington, DC. February 2016. Available at **http://www.911.gov/national911statistics.html**

Table 7. Minimum set of data elements required for transmission in direct-to-PSAP AACN systems:

Data elements required	Format
Time stamp	Date and time that the incident occurred in GMT. ISO8601 format: YYYY-MM-DDTHH:MM:SSZ
GPS location – Latitude	Latitudinal coordinate of the incident site in decimal degrees (-90° to +90°).
GPS location – Longitude	Longitudinal coordinate of the incident site in decimal degrees (-180° to +180°).
Vehicle type	Values: Car Pickup Utility (i.e., SUV) Van Motorcycle Bus Heavy/medium vehicles (>10,000 lb GVWR) Other
Make	Vehicle make
Model	Vehicle model
Primary color	Primary exterior color
Automatic or manual call	Values: Automatic Airbag Deployment Automatic Seatbelt Pretensioner Deployment Automatic Vehicle Accelerometers AACN Injury Severity Threshold Exceeded Manual
Injury severity prediction (high/low)	Yes or No

Table 8. Vehicle-to-TSP systems will require all elements in Table 7, plus these additional elements, to be transmitted from the vehicle to the TSP:

Additional data elements	Format
Driver belt status	On or Off
Passenger present*	Yes or No
Passenger belt status*	On or Off
Rollover	Yes or No
Multi-event	Yes or No
Delta-V (maximum resultant)	Units of 0-999 Km/hr or MPH
Delta-V (maximum longitudinal)	Units of 0-999 Km/hr or MPH
Delta-V (maximum lateral)	Units of 0-999 Km/hr or MPH

**Depending on availability of vehicle sensors, this may be limited to the right front passenger, or could include rear seats as well.*

VIII. Conclusions

This report details our findings with respect to ACN and AACN and summarizes our observations to date about these technologies. The key potential benefits of AACN identified in this research are faster notification time of the crash, which can lead to emergency medical services (EMS) responding to the scene faster, and the prediction of severe injury, which can be used to influence the decision to take an occupant to a trauma center rather than a local hospital. Agency research conducted for this report demonstrated that severely injured occupants have significantly higher survival rates when taken to a trauma center compared with being transported to a lower level hospital.

The agency evaluated the target population, or the group of motor vehicle occupant fatalities that could receive benefit from an AACN system. This target population shares certain necessary characteristics in order for these potential benefits to be realized, such as being in a light vehicle, having proximity to trauma center, and likelihood of the occupant surviving long enough to reach the trauma center. The agency also conducted research on injury prediction algorithms used by AACN systems to correctly identify an occupant as being severely injured. This is another key factor necessary for benefits to be realized. A preliminary cost-benefit analysis compared the cost associated with increasing the number of minor injured occupants to trauma centers to the cost “savings” achieved by increasing the survival of severely injured occupants by bring them to trauma centers. This analysis demonstrated that currently recommended thresholds for injury prediction (e.g., 20% risk of severe injury) may not be sufficiently sensitive to identifying severely injured or fatal occupants, and that it would be more beneficial to reduce these thresholds.

Finally, research was conducted on development of a procedure to test AACN systems. Because AACN systems establish voice communications and transmit information from the vehicle, it was possible to detect the presence of these communications without actually obtaining the communications contents, which are typically proprietary. Evaluation criteria were developed and a proof-of-concept test was performed.

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