

Emergency Medical Services and Congestion: A Research Proposal

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Synopsis

Traffic congestion, upon first consideration, would appear to be a problem primarily of interest to those in the fields of engineering and transportation. While it is true these disciplines are principally responsible for characterizing and mitigating traffic congestion, in the “real world” its impact extends well beyond these fields. For example, traffic congestion has important environmental and worker productivity implications. Similarly, congestion-related pollution has come to be associated with certain chronic medical conditions. Moreover, of no small consequence is the reality that traffic congestion may have an impact on acute health problems resulting from delays in the provision of emergency medical services (EMS). For example, ambulances are not always able to avoid traffic congestion chokepoints. It follows that when there are even short delays in the delivery of care to a patient or delays in transporting a patient to definitive care, such delays can have adverse implications on outcomes. Thus, when viewed from a public health perspective the relationship between congestion and EMS reveals several important opportunities for multi-disciplinary, translational research.

The first of these opportunities focuses on the issue of **primary prevention**; that is, opportunities to prevent congestion-related EMS delays and thereby prevent adverse patient outcomes associated with such delays. Research has suggested that suburban areas have longer average EMS response times than urban areas. However, the specific relationship between urban sprawl and EMS response times remains unclear. With the rapid growth of suburbs, shifts towards a more elderly population, and the ongoing need for improved emergency preparedness, there is an urgent need for systematic evaluation of sprawl’s impact on EMS delivery in the United States to identify opportunities for intervention. Towards this end, one component of the proposed study will quantify the association between urban sprawl and EMS response time in the United States using national EMS data linked to a widely used county-level sprawl index. This information may be useful to policy-makers considering land use alternatives in rapidly growing areas of the country.

In addition to *primary* prevention, the issue of congestion and EMS can also be viewed from a **secondary prevention** perspective; that is, identifying *early* opportunities for interventions to minimize congestion from impacting patient outcomes. In contrast to primary prevention, which in the present case would be focused on preventing congestion-related delays, secondary prevention assumes such delays will occur yet attempts to minimize their impact. To accomplish this task, so as to fully understand the impact of congestion on EMS, it is first necessary to understand EMS providers’ experience with it. Thus, a survey of EMS providers’ professional experience with congestion in terms of education / training, knowledge regarding role of congestion on patient outcomes, congestion-related driving behaviors, congestion-related decision making will be conducted. This will provide valuable information on the actual role of congestion on EMS provider behavior.

Another valuable *secondary* prevention initiative that will be addressed by the proposed study seeks to minimize the impact of congestion by evaluating a strategy to reduce the amount of time occupants of motor vehicle collisions (MVCs) must wait for the arrival of EMS. By providing EMS care in a more timely and informed manner, the potential impact of congestion may be mitigated. With respect to the strategy of interest, automatic collision notification (ACN)

systems utilize collision sensors and wireless technology to detect and transmit information regarding the occurrence of a MVC. ACN systems represent a unique opportunity to potentially extend the *Golden Hour* by reducing the time between MVC occurrence and EMS arrival. While debate exists regarding the association between pre-hospital times and subsequent survival, more rapid EMS arrival reduces time to definitive care and such care has been shown to reduce mortality. Thus, this study will also evaluate whether the integration of OnStar[®] technology into pre-hospital care systems may yield of time savings that (theoretically) improve patient outcomes. Evidence to support the integration of ACN technology into EMS / transportation systems may speed the provision of care and subsequent patient outcomes.

While *secondary* prevention is interested in the early detection of public health problems, ***tertiary prevention*** focuses on reducing longer term impacts. With respect to congestion and EMS, research suggests that rapid transport times matter for moderate- and high-risk patients. Thus, pre-transport information regarding injury severity may serve to help tailor pre-hospital / hospital care resources which may result in a more informed EMS response thereby improving patient outcomes. To address this need, the fourth component of the proposed study will build upon existing post-crash injury assessment techniques by using AACN-related occupant, collision, and vehicle information coupled with advanced regression analysis and multi-body modeling to estimate the regional and overall injury likelihood for MVC victims. The results of such research can be used to aid EMS personnel in the making the following decisions regarding the identification of: the most appropriate EMS unit(s) required to respond to specific MVC events (basic versus advanced life support); the most appropriate mode of transportation (e.g., ground versus air ambulance); the most appropriate medical facility (closest hospital or regional trauma center); and the most appropriate group of specialized medical/surgical professionals (neurosurgeons, orthopedists, etc.) needed.

The final component of this effort will be to translate the findings of the research tasks into practical congestion mitigation techniques for emergency responders, dispatchers, traffic managers, and planners. It is expected the research program will reveal opportunities to address the congestion problem from several different perspectives. The end product of this task will be a set of techniques to address congestion along with practical guidelines for implementation coupled with cost projections and cost-benefit specification.

This multidisciplinary, public-health approach will yield valuable information that can be subsequently used to address the congestion problem on multiple fronts.

Aim I: Urban Sprawl and Pre-hospital Emergency Care Time

Background

Decreasing pre-hospital emergency care times is a fundamental yet challenging goal of critical care providers and the focus of extensive study, including a recent Institute of Medicine report (Bailey et al., 2003; Committee on the Future of Emergency Care in the United States Health System, 2007). Pre-hospital care is comprised of several distinct intervals including: pre-alarm, response, on-scene, transport, and delivery (Carr, Caplan et al. 2006). Each of these intervals must be optimized in order to achieve the ultimate goal of minimizing time to definitive care following trauma or other medical emergencies outside of a clinical setting. Development of EMS resource allocation strategies such as systems status management are on-going in an effort to react to environmental factors that delay both the EMS response and transport intervals, such as traffic congestion, with varying degrees of success (Hough, 1986; Bledsoe, et al., 2003; Sayre et al., 2005; Hauswald et al, 1990; Stout et al, 2000). However, missing from the current policy and academic debate surrounding EMS planning is a consideration of more proximal causes of EMS delays that likely mediate their effects through phenomenon such as traffic congestion. A prominent example is the physical design (i.e., built environment) and land use mix of neighborhoods and regions. With this study, we plan to test how development patterns in suburban areas impact pre-hospital emergency care times. In particular, we will focus on the impact of urban sprawl and its component features on a) EMS response time, b) transport time, and c) overall time to definitive care following trauma or medical emergencies.

Sprawl is an increasingly prevalent development pattern in the United States typified by low-density construction, poor street connectivity, and single-use zoning that separates residential housing from civic and commercial districts (Frumkin et al., 2004). These built environment characteristics increase automobile reliance, trip distances, trip time variability and traffic congestion leading to a variety of negative health outcomes including increased risk of injury or death from motor vehicle crashes, obesity, and declines in social capital (Frumkin et al., 2004; Ewing et al., 2003; Ewing et al., 2006).

There is also a growing concern that the continued expansion of urban sprawl may further fracture the EMS system in the United States and threaten the goal of decreased pre-hospital emergency care times (Lambert et al., 2006; Millard, 2007). Residential development generally far outpaces the provision of medical infrastructure in sprawling suburbs, placing new homes distant from tertiary care centers that are most frequently located in downtown areas (Millard, 2007). Moreover, the high traffic congestion typical of sprawling areas, combined with features such as poor street connectivity, further threatens efficient and effective EMS operation.

Previous research suggests that suburbs may have longer average EMS response times than urban areas (Lambert et al., 2006). However, the specific relationship between urban sprawl and pre-hospital emergency care time remains unclear. This study will quantify the association between urban sprawl and pre-hospital emergency care time in the United States using multiple national EMS data sources linked to a county-level measure of sprawl widely used in urban planning and public health literature. This information will assist on-going efforts to optimize

pre-hospital emergency care in the United States by researchers and emergency personnel and inform debate regarding land use alternatives in rapidly growing suburban areas.

Methods

Study Design

A cross-sectional analysis of multiple national EMS data sources linked to a previously developed county-level sprawl index will be conducted to measure the association between sprawl and pre-hospital emergency care times.

Data

Pre-hospital Emergency Care Times: Pre-hospital emergency care data will be obtained from two sources: the Fatal Analysis Reporting System (FARS) and the National Emergency Medical Services Information System (NEMSIS).

FARS is a national census of all motor vehicle crashes in the United States in which there is at least one fatality within 30 days of the crash. Included in the dataset are time recordings for notification time of EMS, arrival time of EMS at the crash scene, and arrival time EMS at hospital (i.e. definitive care). Global position coordinates for the crash are also available allowing linkage of cases to other spatial data. Emergencies other than motor vehicle crashes involving a fatality are not included in FARS. Specific information regarding the on-scene interval are also not included. Multiple years of FARS data are publicly available for download from the National Center for Statistics and Analysis at the National Highway Traffic Safety Administration website (<http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/NASS.html>).

NEMSIS is a national EMS database in final development stages that will collect state and territorial pre-hospital care data in a standard XML format allowing analysis at local, state, and national levels. NEMSIS will provide highly specific EMS data for each pre-hospital care time interval. It will also include information about all types of emergency response (i.e. trauma and medical emergencies) potentially allowing a truly comprehensive analysis of sprawl's impact on pre-hospital care times. Ten states are currently submitting statewide data into NEMSIS. These data are expected to be publicly available in June 2008. Availability of data from other states will be forthcoming over the next few months.

County-sprawl Index: County-level sprawl will be measured using index scores previously developed by Ewing et al. This widely used index is a composite of factors incorporating measures of residential density, segregation of land use, strength of metropolitan centers, and accessibility of the street network (Ewing et al., 2003; Ewing et al., 2006; Ewing et al., 2003; Trowbridge et al., 2008). Higher index values indicate counties with more compact development (i.e., less sprawl). Sprawl indices are available for most counties or county equivalents (n=954) in the United States.

Analysis

Our analysis will primarily focus on the EMS response interval from notification until arrival at the scene. This interval represents the transport time of the ambulance and is impacted by the environment through which the EMS team must navigate. Total time to definitive care (i.e. time from EMS notification to arrival at hospital) will also be explored. If NEMSIS data become available, we will include specific sub-analyses of transport times as well as a comparison of sprawl’s impact on pre-hospital care times for a) emergencies in different contexts (e.g. home vs. public road) and b) different emergency situations (e.g., trauma vs. medical).

We anticipate using hierarchical linear modeling to test the association between prehospital care times and county-level sprawl due to the nested nature of our environmental variables of interest (Ewing et al., 2006). However, other analytic strategies including propensity scoring will also be evaluated and considered. Numerous other variables available in FARS and NEMSIS that could potentially impact pre-hospital care times will be evaluated for inclusion as potential confounders. Examples of available variables include: weather conditions, light condition, time of day, day of the week, as well as other contextual conditions.

Expected Outcomes

At the completion of this study, our results will be assembled in a final report and submitted for publication in a peer-reviewed academic journal. The complete content of the final report and manuscript will be dictated by the nature of the analysis results. However, we anticipate including information regarding: a) county-level variation in prehospital care times in the United States, b) the relationship between degree of county-level sprawl and pre-hospital care times and c) identification of sprawl components that are most predictive of pre-hospital care times.

Translation and Implementation

One possible result of this aim is the identification of an association between sprawl and longer pre-hospital care times. While it may not be reasonable, as a result, to recommend that communities be reconfigured to address this problem, such information may be useful in terms of the physical re-organization of pre-hospital and hospital resources. As with the other aims, the nature and scope of the recommendation emanating from this aim will rest upon the observed results which cannot be predicted at the present time. Nonetheless, the research team, led in this regard by Mr. Sullivan, will be charged with translating the observed into action-oriented public safety recommendations.

Timeline

	Months 1-3	Months 4-6	Months 6-9	Months 9-12
Data collection, cleaning, validation	x			
Statistical analysis		x		
Manuscript preparation			x	
Translate/implement findings			x	x

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Aim II: Characterize EMS providers' perspectives and experiences with congestion

Background

Attempts to quantify the impact of traffic congestion on patient outcomes and its determinants are important objectives that should be pursued. However, translating such research into strategies to overcome any documented impact of congestion also requires input from those faced with the problem on a daily basis. Gaining insight from EMS providers, specifically ambulance drivers, regarding their perceptions as to the impact of congestion on how they deliver and provide care will provide an important context for proposed interventions emanating from this proposal. Evaluating health care providers' experiences and perspectives on health care delivery is a technique that has been used successfully to enhance the provision of care among patients with specific health problems. It also highlights the fact that, like most health concerns, the etiology of congestion-related EMS delays is multi-factorial and thus so too should be the solutions. Acquiring an understanding of the importance of this problem and techniques needed to overcome it, from EMS providers themselves, will enhance recommendations emanating from this project.

Methods

Phase 1: Survey Development

A working group of 10-12 EMS providers and dispatchers from the Birmingham Regional Emergency Medical Services System (BREMSS) region will be convened to discuss the issue of EMS and traffic congestion. The objective of this working group is to identify salient issues and topics that will be used to form the basis for a survey instrument to be distributed to a random sample of EMS providers from across Alabama. The working group will meet three times. During the initial meeting, the charge to the group will be explained and an informal, though guided, discussion of the topic will be initiated. The working group meeting will be guided by two EMS educators in collaboration with Dr. McGwin. During the second meeting, the working groups will review all of the issues raised during the initial meetings and refine them. It is anticipated that relevant topics will include: education/training, knowledge regarding role of congestion on patient outcomes, congestion-related driving behaviors, congestion-related decision making. During the third meeting the survey instrument will be distributed to the working group members who will critique it for both form and content. Finally, the working group will also assist in the identification of the most efficient and effective manner for distributing the survey.

Phase 2: Survey Distribution

The EMS Division of the Alabama Department of Public Health maintains a database of all currently licensed EMS providers in Alabama. Using this information as a resource, a random sample of approximately 250 EMS providers will be selected and invited to participate in the study. Because EMS providers are likely to be concentrated in urban areas where traffic congestion is a more significant problem than in rural areas, over-sampling of rural EMS providers is likely not necessary. Pending feedback from the working groups, EMS providers

may be contacted for participation via a number of methods including mail, telephone or email. Similarly, the survey itself can be completed via these same methods.

Phase 3: Statistical Analysis and Interpretation

Descriptive statistics (e.g., means, proportions) will be used to summarize the survey results. Whether these responses differ according to geographic (e.g., urban vs. rural) and provider (e.g., age, experience) characteristics will be investigated. The survey results will be presented to the working groups and insight regarding their interpretation will be sought.

Phase 4: Translation and Implementation

An important component of this research proposal is the translation of the observed research results into practicable recommendations that serve to improve public health. Mr. Andrew Sullivan will lead this effort working with each project from the outset to understand its objectives and methodology. His experience in the field of traffic engineering makes him an outstanding resource and ideally suited to evaluate how the results from each aim can serve to address congestion as it relates to the delivery of EMS care.

With respect to Aim I, at the present time it is difficult to surmise what the results will say regarding EMS providers experience with congestion. However, to move the observed results as rapidly as possible into practice recommendations Mr. Sullivan will actively participate in all phases of this project. He will also conduct background research during the first year investigating the training of EMS providers with respect to traffic and congestion. Once the survey results are available and with the assistance of the working group, he will focus his efforts on the identification of training programs that allow drivers, dispatchers, and traffic managers to better respond to congestion situations.

Project Timeline

	Month 1	Months 2-5	Months 6-12	Months 13-15	Months 16-24
Identify working group members	x				
Obtain EMS provider information	x				
Conduct working group meetings		x			
Design survey instrument		x			
Select survey sample		x			
Distribute/conduct survey			x		
Statistical analysis				x	
Translate/implement findings				x	x
Manuscript preparation					x

Aim III: The Role of Within-Vehicle Technology for Improving EMS Response Time

Background

ACN technology represents an opportunity to enhance trauma care and thereby patient survival, particularly in the pre-hospital setting. ACN systems use collision sensors and wireless technology to detect and transmit information regarding the occurrence of a MVC (Butler, 2000; Berube, 2000; Starosielec, Funke, Blatt, 1999; Kianianthra, Carter, Preziotti, 2000 and Akella, et al., 2003). All currently available ACN systems provide the geographic location of the MVC; some of the newer systems also provide information on the nature and severity of the collision. Future systems, using available technology and sensors could also provide information on the number and seating position of vehicle occupants, occupant restraint and protection system use, post-collision vehicle orientation (e.g., final resting position on roof, side, or upright), and occupant ejection.

At the present time, ACN systems are not integrated with EMS. When an ACN equipped vehicle is involved in a collision, the vehicle automatically transmits a message to a national call center operated by the ACN telematics service provider (TSP) (e.g., OnStar[®]). The TSP call center attempts to talk to occupants of the vehicle and when necessary, contacts the public safety dispatch organization (i.e., the 9-1-1 call center) serving the region in which the collision has occurred, and provides them with collision information including location. Until recently, the collision information was relayed to the Public Safety Answering Point (PSAP) verbally. While this continues to be the case in a majority of PSAPs recent advances are beginning to allow PSAPs to receive selected data via their 9-1-1 system.

ACN systems provide an opportunity for reducing the time between injury and EMS arrival, which may be especially important in rural areas where MVCs may go unobserved for protracted periods and result, therefore, in delayed notification of EMS. Moreover, the information available from newer systems (e.g., collision severity) can be used to estimate occupant injuries and aid in the delivery of pre-hospital care and thereby improve patient outcomes (Talmor, Thompson, Legedza, Nirula, 2006; Champion, et al., 2004; Champion, et al., 2005). Quantitative estimates of the potential benefit of ACN systems have been described; for example, Evanco (1999) estimated the relationship between fatalities and collision notification time and reported that depending on level of ACN market penetration (i.e., the number of vehicles on the road with ACN equipment), 6.7% to 11.9% reduction in rural fatalities could be achieved. More recently, Clark and Cushing (2002) estimated that an ideal ACN system would result in a 1.5% to 6% reduction in MVC deaths in the U.S. annually. Given that the average number of MVC-related fatalities per year is over 40,000 (for example NHTSA reported 43,443 MVC-related deaths in 2005; NHTSA, 2005), Clarke and Cushing's more conservative estimate of potential lives saved with ACN technology translates into 640 to 2,560 lives *per year*. However, these studies are largely theoretical and not based upon data from actual ACN-related MVCs.

The Alabama ACN Project

Commercial ACN Systems

At the present time the two largest commercial providers of ACN services in the United States are OnStar[®] and ATX Group. Together they will have more than 6 million subscriber vehicles by the end of 2008. OnStar[®] systems with one year of service are standard equipment on virtually all retail 2008 GM models. The ATX Group ACN telematics service is available as 'Tele Aid' on selected Mercedes models and, 'Assist' on BMW vehicles. Selected Lexus models offer an ACN system under the brand Lexus Link[®]. Although the total number of subscribers represents a relatively small percentage of the registered vehicles on the road (i.e., ~2 %), subscriber vehicles have been increasing steadily since the service became commercially available. Both commercial services utilize systems that are integrated with the vehicle electrical architecture. The systems are activated by in-vehicle collision sensors and the resultant messages are transmitted by cellular technology to the telematics service provider call center. In both cases, the collision location (i.e., vehicle latitude and longitude at the time of the collision) is determined using GPS and reported as part of the message. Of the two providers, OnStar[®] collects a richer set of collision data from the vehicle and they have a larger subscriber base (approximately 5 million). For these reasons, OnStar[®] was asked to participate in the current program. However, while the current integration is with OnStar[®], the software to communicate, display and integrate collision messages is generally applicable to any telematics service provider that can send a collision message using a standard format.

In the first generation OnStar[®] ACN system an automatic call is initiated by a telematics equipped vehicle to the OnStar[®] call center upon the deployment of any airbag in the vehicle (Butler, 2004). The call provides a collision message with the location of the vehicle along with an alert that a collision has occurred. Second generation AACN systems generate an automatic collision call for a larger number of collision types including collisions due to qualified rear, side and frontal impacts regardless of airbag deployment. In addition, rollover sensing is being phased in on selected vehicle types (e.g., sport utility vehicles), and will be more broadly available when rollover airbags become available. Furthermore, AACN systems provide information on the direction of impact (side, frontal or rear end collisions) and the severity of the collision (i.e., ΔV). Finally, the AACN in-vehicle system can sense multiple impact collisions and report collision data for up to two impacts.

Birmingham Regional Emergency Medical Services System (BREMSS)

The BREMSS serves the counties of Blount, Chilton, Jefferson, St. Clair, Shelby, and Walker. This region is home to approximately 1,100,000 people, and encompasses approximately 4,000 square miles. The BREMSS region includes approximately 180 Emergency Medical Service agencies, over 2,000 emergency medical technicians, and over 21 9-1-1 agencies. The BREMSS, established in October, 1996, provides regional trauma coordination services. The BREMSS region includes ten trauma centers; two are designated as Level I trauma centers and eight as Level III.

All hospitals in the region are linked to the BREMSS Trauma Communications Center (TCC) which monitors hospital resource availability via secure dedicated connections. If a patient meets ACS trauma triage criteria, pre-hospital personnel contact the BREMSS TCC and are directed to transport the patient to the most appropriate hospital, defined according to availability

of trauma care resources (e.g., ICU beds). These resources are monitored in a real-time environment using the LifeTrac[®] software system with trauma centers changing the status of specific resources as they become unavailable and vice versa. The LifeTrac[®] system also supports the collection of scene data and the delivery of these data to receiving hospitals. The BREMSS TCC also dispatches aero-medical resources when needed.

The LifeTrac[®] system is built around a wide area computer network that connects multiple Birmingham region hospital emergency departments with the BREMSS TCC. The system supports a number of functions including: trauma and stroke patient routing decision support assistance to EMS providers in the field and region-wide monitoring and reporting of hospital diversion information.

BREMSS/OnStar[®] Integration

Since 2005, ACN and AACN messages emanating from OnStar[®] equipped vehicles involved in MVCs in Alabama have been sent electronically to the BREMSS TCC and integrated with the BREMSS trauma management software called LifeTrac. As is the case in the rest of the country, when an OnStar[®] equipped vehicle is involved in a collision, data are first sent over the voice channel to the OnStar[®] customer service center and a voice communication is subsequently established with the vehicle occupants. OnStar[®] verifies that emergency services are needed and places a call to the appropriate 9-1-1 Public Safety Answering Point (PSAP). Changes in technology are now permitting the call to arrive at the PSAP on a 9-1-1 trunk line. For those OnStar[®] collisions that occur in Alabama, a collision data message is forwarded to the BREMSS TCC using a data routing infrastructure developed under a joint Federal Highway Administration (FHWA) / Minnesota Department of Transportation (MnDOT) field operational test (FOT) (Battelle et al., 2006). One focus of the FHWA / MnDOT FOT was to evaluate standards-based communication infrastructure and protocols for forwarding telematics data to secondary emergency response agencies such as EMS agencies. The ComCARE Vehicle Emergency Data Set (VEDS) (ComCARE Alliance, 2004), adopted during the FHWA / MnDOT FOT, is used for all data messages in the Alabama ACN Program.

Collision message data are received at the TCC by a data integration broker. The data integration broker is a software component called the Intelligent Information Integration Broker (I3B) that securely receives the collision message data from the data routing infrastructure. The I3B determines if the collision has occurred in the BREMSS region and if so, uses the open standard communication protocols to push the collision message data to the BREMSS / LifeTrac[®] system. When LifeTrac[®] receives a collision message it presents an alert to TCC operators and displays the ACN / AACN data. Then using the LifeTrac[®] system, the TCC operators manually associate the received collision message with relevant patient records. A patient record is created for every patient meeting the trauma triage guidelines. Once the patients are associated with the OnStar[®] message, the collision data are automatically integrated with the patient record and made available to receiving hospitals.

A web server associated with the I3B makes the collision message data available for viewing by authorized PSAPs in the BREMSS region via a web browser over secure internet connections. This web server does not currently provide the PSAP with a crash alert message; the crash alert

and related information is provided via a phone conversation between the OnStar[®] Communication Center and the PSAP. The browser software presents the collision location on a map display along with the street address calculated from the latitude and longitude received from OnStar[®].

Once the OnStar[®] collision message data are pushed to the BREMSS LifeTrac[®] system it is manually associated with patient records by the TCC Communicators and then electronically forwarded to receiving hospitals with the patient data. The association of collision data with the patient record is made based on TCC Communicator discussions with EMTs on the scene. The patient data with the OnStar[®]-derived collision data are also sent back to the I3B for storage in a research database. These data include the EMS event timeline recorded by BREMSS TCC communicators. BREMSS communicators also contact the appropriate PSAP (after the patient is transported) to obtain time associated with the receipt by the PSAP of the first voice call reporting the collision, other than that received from OnStar[®]. These times are also added to the research database.

It is important to note that during the current phase of the Alabama ACN Project, the intent was to develop a research database and demonstrate the feasibility and begin to assess the benefits of electronically routing ACN and AACN messages to relevant pre-hospital EMS and public safety agencies. Neither the TCC nor the 9-1-1 agencies depend upon the ACN messages for primary alerting or dispatching purposes. In accordance with the agreement with their subscribers, OnStar[®] continues to contact the appropriate 9-1-1 agency by administrative telephone to initiate the emergency collision response. However, immediately upon receipt of the OnStar[®] ACN or AACN message at the I3B, the process of linking ACN data with the associated dispatch, pre-hospital and, ultimately, clinical patient information is begun.

Methods

This objective of this aspect of the proposal is to quantify the potential time savings associated with using ACN systems to dispatch EMS resources. Using the research database described above, this study will compare the time difference between the receipt of the ACN message and the associated PSAP call received for that same incident. This difference theoretically represents, on average, how much more rapidly EMS resources would have arrived on the scene had they been dispatched upon receipt of the crash message from OnStar[®]. The repercussion of this time savings should then translate into more rapid hospital arrival. As shown graphically in Figure 1 below, the area in red represents the hypothetical amount of time savings that an ACN system could provide and what we will attempt to quantify as part of this Aim. The practical implication of reducing the red component of the timeline is a more rapid hospital arrival for the patient, which may subsequently translate into improved outcomes.

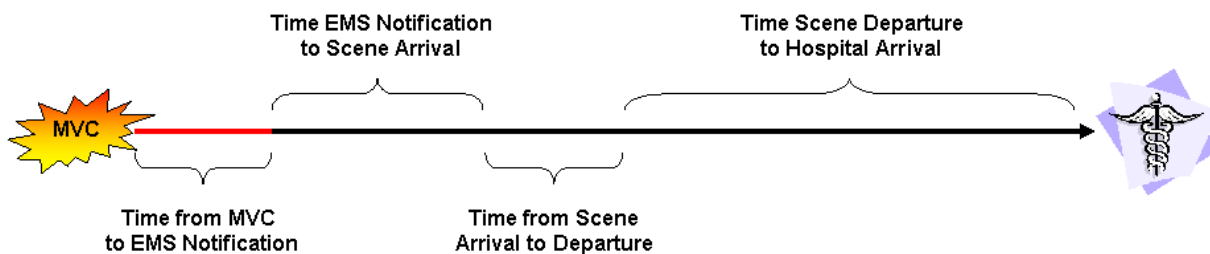


Figure 1. Hypothetical timeline for EMS response to MVC.

Descriptive statistics (e.g., mean, median, etc.) will be calculated across all available ACN MVCs in the research database (described above) and stratified by specific characteristics of interest. For example, it will be important to evaluate whether the potential time savings is greater in rural versus urban areas.

Translation and Implementation

As noted above, the research team is fortunate to have the expertise of Mr. Andrew Sullivan, an engineer with ample experience in the area of traffic management. His role on the project is to assist in the translation of the research findings into practicable public safety recommendations and, if possible, actually implement these recommendations. And as with Aim I it is difficult to elucidate these recommendations or methods of implementation *a priori*. However, given the nature of this aim the likely recommendation would be to formally integrate the Alabama ACN Project into the existing public safety infrastructure. This would perhaps include the recommendation that ACN/AACN messages be sent directly to PSAPs as well as exploiting these messages for use in larger traffic and incident management systems. Mr. Sullivan’s experience in the area of traffic operations and safety, with a specific focus on traffic control systems and traffic simulation, makes him the ideal resource for translating the objective results of this aim and developing relevant recommendations that are both evidence-based and feasible within the existing infrastructure.

Timeline

	Months 1-3	Months 4-6	Months 6-12	Months 13-24
Data collection, cleaning, and validation	x			
Statistical analysis		x		
Manuscript preparation			x	
Translate/implement findings			x	x

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Aim IV: Potential Improvements in Medical Treatment and EMS through Real-time Injury Assessment of Occupants Involved in Crashes (Post-Crash Injury Prediction using Multi-Body Modeling and Advanced Region-Specific Regression Equations)

Background

According to NHTSA, 650,000 people suffer moderate to severe threat-to life (AIS 2+), high priority, injuries each year in the United States. An unknown portion of these people receive less than optimal care (i.e., under-triaged) in terms of timeliness, quality, or place of treatment (e.g., seriously injured not taken directly to a trauma center) (Champion et al., 2005). The failure to correctly assess the severity of these injuries can result in needless deaths and disabilities. Conversely, about 7 million people in the U.S. suffer minor or no injuries in crashes each year (Champion et al., 2005). An unknown portion of these people are over-triaged to hospitals and trauma centers when, in fact, they may not need the highest level of medical treatment. Over-triage can result in needless added health care costs, unnecessary burdens on resources, and may compromise the availability of specialized care for those who actually need it. Thus, a more timely and accurate assessment of injury severity is needed to better allocate emergency and medical resources to provide life saving care for those who need it.

Fortunately, the fundamental framework from which to create improved triage of injured occupants already exists. AACN systems automatically transmit data regarding details on the location and, to some extent, the severity of a crash. One of the best known AACN systems is the OnStar[®] technology that will be incorporated into more than 10 million General Motors vehicles by 2010. The OnStar[®] system uses front and side sensors as well as the sensing capabilities of the Sensing and Diagnostic Module (SDM) to measure the crash severity. In the event of a moderate to severe frontal or side-impact crash, data are transmitted from the affected sensors to the SDM which in turn transmits the crash information to the vehicle's OnStar[®] module. Within seconds, the OnStar[®] module will send a message to the OnStar[®] Call Center (OCC) through a cellular connection, informing the advisor that a crash has occurred. A voice connection between the advisor and the vehicle occupants is established. The advisor can then conference in 911 dispatch or a PSAP, which determines if emergency services are necessary. If there is no response from the occupants, the advisor can provide the emergency dispatcher with the basic crash information from the SDM that reveals the severity of the crash and the dispatcher can identify what emergency services may be appropriate. Using the Global Positioning System (GPS) satellite, OnStar[®] advisors are able to tell emergency workers the location of the vehicle.

The most advanced OnStar[®] system provides two essential parameters for general assessment of crash severity - the principle direction of force (PDOF) and the change in vehicle velocity (ΔV). While these two factors are necessary for assessing the potential injury of occupants involved in the crash, they are not sufficient. Specifically, a much larger number of crash-specific (e.g., offset vs. full-frontal), vehicle-specific (e.g., restraint availability) and occupant-specific (e.g., age, gender) parameters must be concurrently evaluated in order to accurately assess the severity of injury. The URGENCY Algorithm was first proposed in 1997 by Malliaris and Digges and subsequently developed through a collaboration of researchers at the University of Miami School of Medicine, George Washington University, and NHTSA. The algorithm developed a logistic

regression equation with weighting factors using National Automotive Sampling System (NASS) data from 1997-2003. The regression equation incorporates crash characteristics (e.g., ΔV , belt use, airbag deployment, intrusion, steering wheel deformation, gender, multiple impacts, rollover, ejection, narrow object impact), occupant characteristics (e.g., age, height, weight), as well as vehicle factors useful for crash severity prediction and predicts the likelihood of serious (AIS 3+) injury. While the algorithm has been generally validated against data sets different than those used to develop the algorithm, there is relatively little discussions of the error bounds and confidence intervals associated with different parameters or the regression equation itself. While the indication of a generalized severity (i.e., AIS 3+ injury) is unquestionably a crucial piece of information for EMS and medical personnel, the lack of specificity regarding the injured body region could increase the time and optimality of treatment.

With respect to specific injuries, developers of the URGENCY algorithm have identified a subset of trauma, the so-called Occult Injuries (Champion et al., 2005; Augenstein et al., 1995; Augenstein et al., 2003). Occult injuries are injuries which are not easily recognized and/or difficult to diagnose but which can be life-threatening because of their severity, time sensitivity, and treatment criticality. They require timely treatment at medical facilities/trauma centers that are equipped and staffed to provide optimal care. Occult injuries present difficulties at all stages of care: triage, transport, and treatment decision-making. A partial listing of occult injuries resulting in automobile crashes was generated by NHTSA and Crash Injury Research Engineering Network (CIREN) researchers and summarized by Champion et al. (2005). The injuries include the so-called “talk and die” brain injuries (e.g., the lucid interval commonly associated with acute epidural hematoma); lung, heart, and aortic injuries of the thorax that may lack initial bleeding but may later become fatal; and abdominal injuries to the liver, spleen, and bowel in which internal bleeding may be present without initial external symptoms. According to Champion et al., (2005) the diagnosis of crash injuries is complicated in cases where the pain of one injury may distract the patient from pain of another more serious injury or where the presence of alcohol may impair the ability of the patient to provide proper responses during medical examination. While researchers have developed Occult warning flags (OCCULT Software) to aid in the identification of occult injuries in certain impact scenarios, the relationships are general correlations based on a few occupant and crash details and, similar to the URGENCY algorithm, may not account for many of the detailed occupant factors required for a refined assessment of the injury risk.

The question now arises whether sufficient information is included in the URGENCY OCCULT algorithms to provide discriminatory assessment of the level required for accurate triage. For example, ΔV is an essential measure of crash severity but, for a given ΔV , a range of injury outcomes can occur depending on the particular type of crash. Figure 1 demonstrates this point by showing that many fatalities occur at relatively low speeds where conventional regulatory and compliance tests show four and five star ratings for vehicles. Even when age is taken into consideration to eliminate the influence of elderly occupants on the outcome, a large number of young occupants are killed in low speed crashes. While a number of individuals have developed hypotheses for why these fatalities are occurring (Lindquist et al., 2004), the fact remains that ΔV alone is not a sufficient discriminator of fatality risk (and by extension not a sufficient indicator of AIS 3+ injury risk). Figure 2 shows three different frontal crash scenarios all with the same ΔV . It is obvious that the magnitude and duration of the acceleration time histories are

different among the different types of crashes of the same ΔV and would contribute to differing levels of injury potential for the occupants. More subtle differences would be observed when considering the different components of the acceleration time history (i.e., longitudinal and lateral) even if the crash were nominally a frontal or side impact. Depending on the relative phasing and magnitude of the lateral and longitudinal pulses, the kinematics of the occupant could lead to differing interactions with the vehicle interior and, ultimately, to different injury risk and patterns.

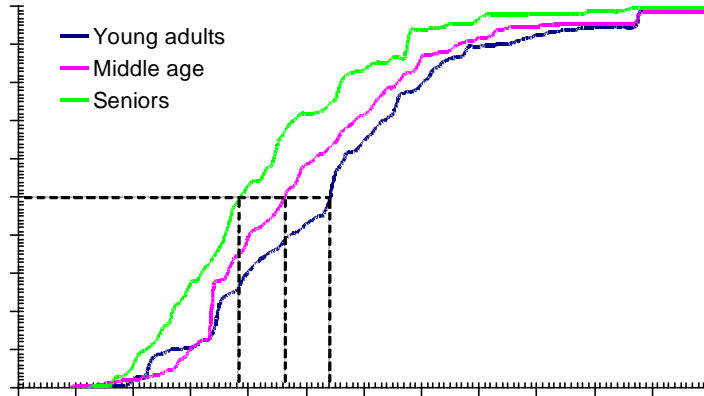


Figure 1. Distribution of crash fatalities as a function of Delta-V.

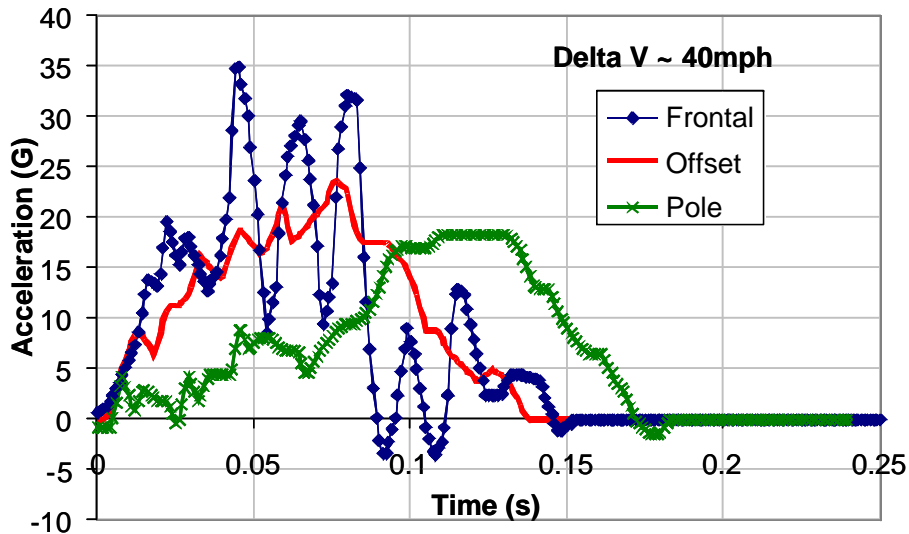


Figure 2. Variation in acceleration time history for three 64 km/h pulses.

Summary

Based on our literature review, present technical capacity, and opportunities, the following conclusions can be used as a basis for continued research:

1. AACN systems provide opportunities for reductions in morbidity and mortality reduction by extending safety to the post-crash phase.
2. The union of crash information and emergency medical services can improve overall quality of care of injured occupants through improvements in the timeliness, appropriateness, and efficacy of the medical care received by the crash victim.
3. Current post-crash analysis systems, such as the URGENCY algorithm, provide a good baseline assessment of injury severity of the crash-involved occupants although they lack specificity in terms of detailed crash and occupant characteristics that are likely necessary to identify accurate, body-region specific injury information for a particular occupant in a particular crash.

Objective

The objective of the proposed research is to build upon existing post-crash injury assessment techniques by using telematic transfer of occupant, crash, and vehicle information coupled with advanced regression analysis and multi-body modeling to estimate the regional and overall injury likelihood for the crash victim. This research is intended to aid EMS and medical personnel in the making the following decisions:

1. Identifying the most appropriate EMS unit(s) required to respond to specific MVC events (basic versus advanced life support)
2. Identifying the most appropriate mode of transportation (e.g., ground versus air ambulance)
3. Identifying the most appropriate medical facility (closest hospital or regional trauma center)
4. Identifying and mobilizing the most appropriate group of specialized medical/surgical professionals (neurosurgeons, orthopedists, etc.) needed to respond to injured occupants.
5. Providing pre-transport / pre-arrival information to awaiting medical resources (emergency room, operating room, etc.) so personnel and facilities are prepared to provide the injured with a level of care consistent with predicted injury severity.

Tasks

The proposed research will evaluate the ability of post-crash analysis techniques to provide the information on injury severity and location in sufficient detail to meet the aforementioned objectives. A multi-faceted approach is proposed that will use the existing software, the URGENCY algorithm, as the gold standard. An expanded regression equation will be developed that includes more detailed information on both the crash and occupant with a focus on developing region-specific injury prediction. With regards to occult and other injuries, region-specific information should aid in focusing EMS and medical efforts to areas that may have

sustained injury for a particular occupant and crash. In addition, the expanded algorithm will not be limited to AIS 3+ injuries but will provide probabilistic levels of injury to each body region. This could enable more accurate assessments of overall injury such as the Injury Severity Score or other measures which have an improved estimation of overall severity (as represented by threat to life). Both the URGENCY and REGION-SPECIFIC algorithms rely on regression analysis of existing crash data into which new crash and occupant data can be input. We propose developing a complementary tool that should increase the predictive capability for specific crashes, occupants, and vehicles (Figure 3).

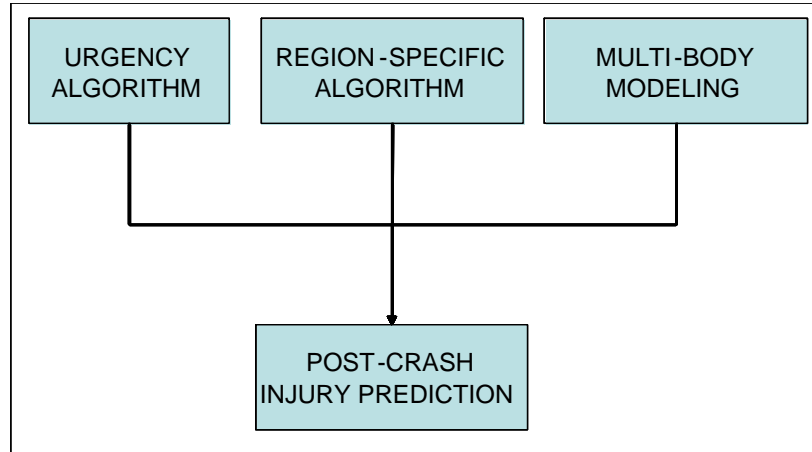


Figure 3. Proposed methods for evaluating post-crash injury severity.

Using multi-body models of a specific vehicle and occupant, crash data obtained from the AACN systems will be used as input to the models. The objective would be injury prediction for a given crash event with customized estimates developed within seconds after a crash had occurred. Using established injury risk functions for each body region, probabilistic injury predictions will be made for the head, neck, chest, abdomen, thigh, and leg (Figure 4). Once the injury metric has been determined, it will be substituted into a risk function to estimate AIS 2+, AIS 3+, AIS4+, and AIS 5+ injury risk. One downside of this approach is that relatively few of the injury metrics currently incorporate age as a specific variable in the injury risk function. While these data exist for the distal leg/ankle and to some degree the chest, the other body regions will not include age as a specific factor. The project team will develop a graphical depiction of how best to represent the relative risks associated with each body region. As a starting point, we are proposing green-yellow-red coding similar to that employed in European New Car Assessment Program (Euro NCAP) and Insurance Institute for Highway Safety (IIHS) evaluations (Figure 6).

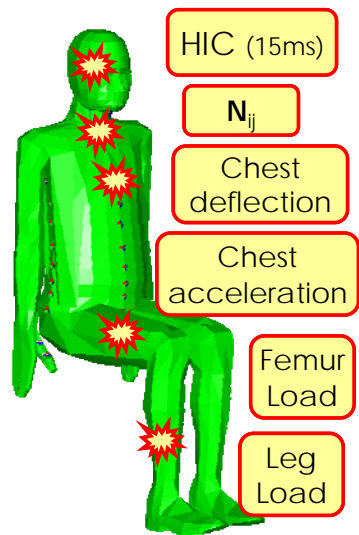


Figure 4. Injury Metrics to be used in assessment of region specific trauma.

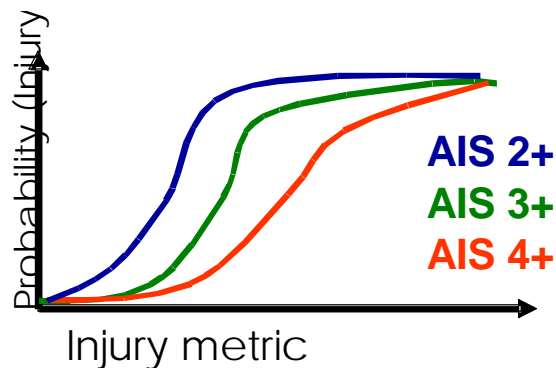


Figure 5. Probabilistic assessment of injury potential from injury metric.

The benefit of increased information on the injury predictive capabilities of the REGION SPECIFIC algorithm and the MULTI-BODY modeling will be weighed against the relative increase in complexity. Given the effort required to develop the region-specific and multi-body models as well as the need to validate them, this proposal focuses on only adult occupants in single impact frontal crashes for the initial development and validation with the assumption that the techniques could be expanded to include lateral, rear, rollover, and multiple impact crashes in subsequent phases.

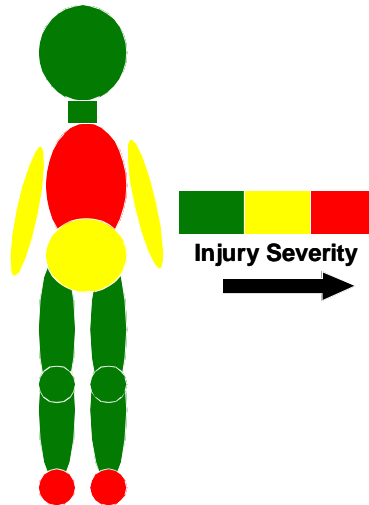


Figure 6. Illustration of potential region-specific ranking by multi-body simulations.

Task 1. Development of a REGION-SPECIFIC Algorithm.

Weighted cases from the National Automotive Sampling System Crashworthiness Data System for years 1998-2006 will be used to develop an expanded version of the urgency algorithm that includes body-region and AIS-level specific estimates. Information will be combined to create occupant-level records with up to 10 injuries which will then be categorized into AIS values by body region, demographic, vehicle and crash information. Ordinal multivariate regression models will be developed to predict maximum AIS by body region. For the initial phase of the study, inclusion criteria will be belted drivers or front seat occupants 18 years old or older, in single vehicle frontal (defined as 11-1) crashes against fixed objects while traveling in passenger cars model year 1990 or newer with no rollover, ejection or fire. Explanatory variables will include age, gender, weight and height of the occupant, curbweight, wheelbase, airbag availability and model year of the vehicle, general area of damage, direction of the impact, and whether the frontal airbag deployed. Half of the data meeting inclusion criteria will be used to develop the predictive models and the other half was used in the validation of this predictions. Predictive values will be presented with their 95% CIs.

Task 2. Development of MULTI-BODY Models.

Given the prevalence of the OnStar[®] AACN systems, the ability to produce real time estimates of crash injury severity will likely involve GM vehicles. To have a representative sample and to ensure sufficient number of cases for both development and evaluation, we propose to develop three baseline GM vehicle models – a small sedan, a mid-sized sedan, and a pickup truck. A variety of sources will be used to generate the geometric and material information including commercial databases for geometry (e.g., Viewpoint), NHTSA finite element (FE) and multi-body models developed for compatibility research, as well as from surface digitization and material testing performed specifically for this project.

The MADYMO Software, maintained by TASS, is the worldwide standard for occupant safety analysis because of its fast simulations and relatively accurate restraint modeling techniques. Through a combination of multi-body, facet, and FE techniques, MADYMO balances efficiency, accuracy, and reliability. The multi-body technique is particularly suited for the post-crash injury prediction because of its computational efficiency. A multi-body framework with deformable bodies and non-linear contact definitions has been chosen to represent the occupant-vehicle system such that the system has a realistic non-linear response with sufficiently low computational time in order to perform statistical analysis of the system parameters. The MADYMO™ database also contains a FE facet surface occupant model representative of the average adult male population described in the RAMSIS™ database (Ramsis, 1997). The facet surface model, or simply the facet model, is more accurate in terms of surface geometry and local deformation, at the cost of slightly higher computational run-time. As shown in Figure 7 the facet model, comprises of 92 bodies including rigid and deformable bodies. The use of deformable bodies in the thorax and abdomen region allows for biofidelic kinematics of the occupant model compared with the previous version of the rigid-body model. The outer geometry of the facet model is comprised of a FE skin mesh, which includes 2000 elements and 1000 nodes (Figure 7). The connectivity of the different rigid and deformable bodies in both of the models is represented through non-linear joints with multiple degrees of freedom. The orientation, stiffness characteristics, and range of motion of the different joints are determined from a range of post mortem human subject (PMHS) and volunteers tests (further details included in the MADYMO Model manual [TNO, 2006(a)]). The components of the model have been developed and validated against impact loading using experimental procedures described in de Lange et al., (2005).

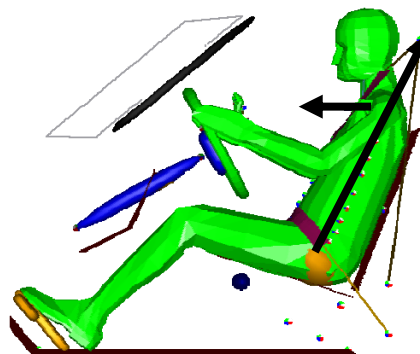


Figure 7. Illustration of MADYMO facet model.

As previously noted, specific vehicle models will have to be developed for each vehicle of interest (Figure 8). The exact GM vehicles to be modeled will be decided by the project team in consultation with UAB subsequent to discussions about the availability of real world crash data for validation and evaluation. Once three models (small sedan, mid-sized sedan, pickup truck) have been identified, the geometry will be developed based on the commercial data base data (i.e., Viewpoint), NCAP interior measurements, and/or digitization of exemplar vehicles at the UVA Center for Applied Biomechanics. Material properties will be obtained from existing FE models or from tests to be conducted on the instrument panel and seat. While belt properties can likely be obtained, the project team will have to inquire about the availability of pressure tank

tests and/or airbag inflation properties. If these are not readily available, we will try to avoid selecting cases where the airbag is not fully inflated prior to occupant contact.

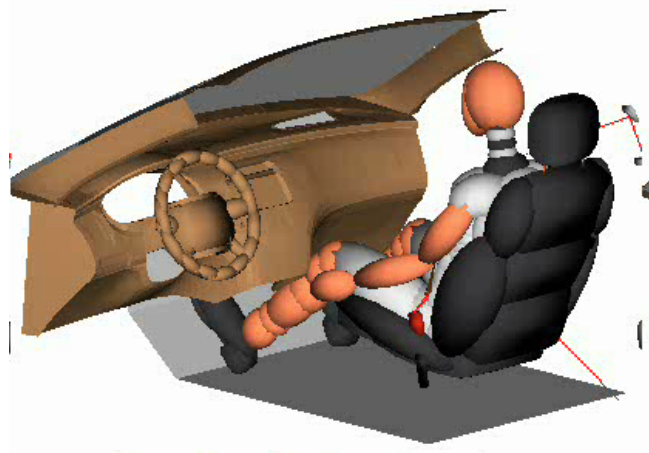


Figure 8. Illustration of a sample interior to be developed.

Task 3. Validation of MULTI-BODY Models.

Validation of the vehicle models is most easily performed independent of the human body model. For this reason, the vehicle models will be validated against published crash tests from NHTSA (FMVSS 208-type), NCAP (belted full frontal), IIHS (frontal-offset), and other publicly available sources. A MADYMO version of the Hybrid III dummy will be used for comparison with the physical dummy results. Standard measures such as head accelerations, neck forces/moments (where available), femur forces, and leg forces/moments (where available) will be used for validation.

Task 4. Evaluation of the Predictive Capability of URGENCY Algorithm, BODY REGION SPECIFIC Algorithm, and the MULTI-BODY Models.

To demonstrate utility of the BODY REGION Specific algorithm and the MULTI-BODY models, six to twelve cases will be selected from either the existing OnStar[®] database at UAB or from CIREN cases. To account for differences in stature and mass among the occupants, scaling of the models will be performed based on dimensional analysis (Figure 9).



Figure 9. Illustration showing scaling of models to account for occupant size and mass.

In addition to the variation among the three vehicle types modeled, the objective will be to identify cases that have variation in occupant parameters (e.g., size) as well as collision severity or direction (Figure 10).

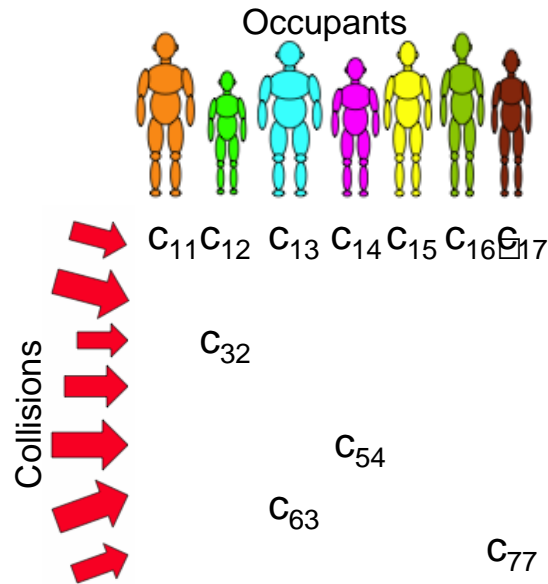


Figure 10. Illustration of variation in crash and occupant conditions to be used in evaluation of regression equations and multi-body models.

After selecting the cases, the AACN data as well as supplemental case data (e.g., occupant data, EDR acceleration data, etc.) will be input into the URGENCY algorithm, the BODY REGION SPECIFIC Algorithm, and the MADYMO model. Other than the input information, the statisticians and modelers will be performing their analysis “blind”, without any information on the injury outcome. For the URGENCY algorithm, the output will be the likelihood of AIS 3+ injury for each case. For the BODY REGION SPECIFIC Algorithm and the MULTI-BODY modeling, the injury probability in each body region will be provided. After the respective injury risks have been calculated, the results will be compared with the actual injuries sustained by the occupants. As a basic assessment of specificity of the models, Receiver Operator Curves will be generated for the AIS 3+ levels for the overall body as well as for the specific body regions (BODY REGION SPECIFIC and MULTI-BODY MODEL only). The project team will work with UAB to identify other methods of evaluating the relative sensitivity and specificity of the models in a more robust fashion that accounts for the probabilistic nature of the injury risk output at multiple severity levels.

Translation and Implementation

Given the existing infrastructure of the Alabama ACN Project and the UAB UTC the translation of the results from the above described research into realistic public safety recommendations is anticipated. Though there are likely to be many technological and other hurdles to the integration of injury prediction algorithms into the process of dispatching EMS resources the anticipated results from this research will go a long way towards demonstrating their potential. In developing recommendations associated with this aim specific effort will be directed towards identifying these technological and other hurdles and proposing ways to overcome them.

Project Timeline

	1-3	4-6	7-9	10-12	13-15	16-18	19-24
Identification of Frontal Crash Cases	x						
Vehicle Model Development	x	x					
Urgency Algorithm Predictions		x					
Improved Statistical Model Predictions		x	x				
Preliminary Simulation Results			x				
Injury Predictions from Models				x			
Model Refinement					x		
Comparison of Urgency Algorithm, Statistical Model, Simulations						x	
Manuscript Preparation							x

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