NEW TOOLS TO REDUCE DEATHS AND DISABILITIES BY IMPROVING EMERGENCY CARE: *URGENCY* SOFTWARE, OCCULT INJURY WARNINGS, AND AIR MEDICAL SERVICES DATABASE

Howard R. Champion, Research Professor of Surgery, Uniformed Services University of the Health Sciences, Principal Investigator,

Augenstein JS, Professor of Surgery, University of Miami; **Blatt AJ**, Senior Scientist, General Dynamics; **Cushing B**, Surgeon, Maine Medical Center; **Digges KH**, Professor of Engineering, George Washington University; **Flanigan MC**, Physical Scientist, General Dynamics; **Hunt RC**, Emergency Physician, CDC; **Lombardo LV**, Physical Scientist, NHTSA; **Siegel JH**, Professor of Surgery, University of Medicine and Dentistry of New Jersey. United States

Paper Number 05-0191

ABSTRACT

Research by the U.S. Department of Transportation, Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA) has developed technologies to improve transport and treatment of crash victims. Multidisciplinary (engineering, medical, and epidemiological) research has been initiated to improve the ability for: (a) identifying the approximately 250,000 crashed vehicles with occupants that probably have serious injuries each year, (b) alerting emergency medical care providers to the potential for serious (especially occult) injuries, and (c) enhancing the timeliness and quality of rescue and treatment through better utilization of air medical services. These improvements will lead to reducing the deaths and disabilities resulting from crash injuries.

This paper describes recent advances in tools to improve the rescue, transport, and treatment of seriously injured crash victims. Specifically, this paper reports on the development of *URGENCY* software for crash injury assessment, an Occult Injury Database (OID) for emergency medical warning flags, and the Atlas & Database of Air Medical Services (ADAMS). These tools provide for timely and appropriate rescue actions when needed.

Introduction - NHTSA Administrator Dr. Jeffrey W. Runge recently described the current motor vehicle crash problem and available safety advances as follows: *"Serious crashes happen every day, more than half of them in rural areas where the ability to rapidly contact 9-1-1 and the capability of responders to quickly reach the scene can mean the difference between life and death. New technologies such as wireless E9-1-1, automatic collision notification and emergency vehicle route navigation are available that will make emergency access more reliable and help deliver faster and better care."* [1]

This paper describes recent research and development activities that support the delivery of faster and better care.

Background -- In September 1966, the National Academy of Sciences (NAS) issued a report that found *"49,000 deaths in 1965 were due to motor-vehicle accidents."* That report, *Accidental Death and Disability: The Neglected Disease of Modern Society*, focused on emergency care noting that *"Data are lacking on which to determine the number of individuals whose lives are lost or injuries are compounded by misguided attempts at rescue or first aid."*[2] The title, the findings, and many of the recommendations in that 1966 report are applicable to this day 39 years, and more than 1,750,000 crash deaths and 10 million serious crash injuries, later in the U.S. [3-6].

The NAS report also pointed to the need for research to improve diagnosis and treatment of injuries, stating that *"findings are important to alert emergency department staffs to the incidence of covert injuries that might well dictate first priority care, as well as the care and prophylactic measures that must be observed during definitive care and rehabilitation."*

Dr. William Haddon, the first Administrator of NHTSA, directed NHTSA to perform research to improve the emergency treatment of crash victims. An early study funded by the agency, published in 1971, "Alcohol and Highway Safety: Behavioral and Medical Aspects" highlighted the need for improving emergency medical treatment of crash injuries, including early recognition of internal (covert, occult, or hidden) injuries. [7]

In 1973, Dr. Haddon wrote *"The ninth strategy in loss reduction is to move rapidly in detection and evaluation of damage that has occurred. The generation of a signal that response is required; the signal's transfer, receipt, and evaluation; the decision to follow-through, are all elements here—whether the issue is wounds on the battlefield or highway*." [8]

Methods - Members of the research team were brought together by NHTSA for their expertise in trauma care research, advanced technologies, emergency medicine, crash data analysis, and motor vehicle crashworthiness engineering. The team, in recent years, performed a series of statistical analyses of data on crashes, deaths, and injuries [11-18, 44]. The sources of the data included the Fatal Analysis Reporting System (FARS), the National Automotive Sampling System (NASS), and the Crash Injury Research and Engineering Network (CIREN).

Some of the multidisciplinary team members came from the NHTSA CIREN Centers. CIREN researchers study the most serious crash injuries – those that result in deaths, disabilities and loss of livelihoods. These injuries represent about 12 percent of all crash injuries, but account for about 77 percent of the economic costs of crash injuries. The costs associated with serious crash injuries amount to about $112 billion in economic costs (excluding value for pain and suffering) each year. [1]

Over the past ten years research and development was conducted to refine the analyses and develop tools that could be used to improve triage, transport, and treatment decision-making for future crash victims. The team has presented its findings and recommendations at various stages to the NHTSA and to other organizations concerned with reducing morbidity and mortality of crash victims. This paper provides further updates on these efforts. [11-18].

The Problem –Each year, along the 4 million miles of roads in the U.S., about 5 million Americans are injured in 17 million crashes involving 28 million vehicles. Among those 28 million crash-involved vehicles, approximately 250,000 Americans suffer seriously life-threatening Abbreviated Injury Scale (AIS 3+) injuries. Specifically where and when they will occur is not predictable. Thus, it is important to be able to rapidly distinguish the one crashed vehicle that has a seriously injured person from the 100 crashed vehicles that have no injury or simply minor injuries.

Historically, each year a growing number and percentage of all crash deaths were Not Taken to a medical facility for treatment. And many people currently Taken to a medical facility for treatment die from crash injuries without the benefit of timely definitive care.

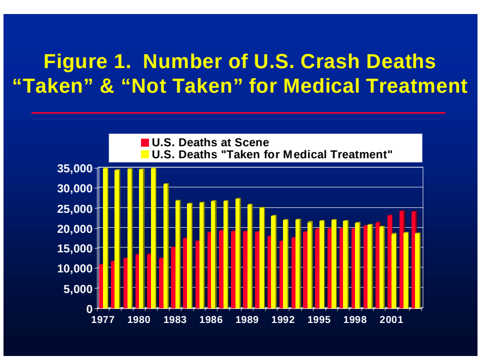


Figure 1. Number of U.S. Crash Deaths "Taken" & "Not Taken" for Medical Treatment

Figure 1 shows that in the year 2002, the number of people dying in crashes without being taken to a medical treatment facility amounted to 23,795 deaths, nearly 56 percent of crash deaths. The percentage of crash fatalities each year that are Not Taken to a medical treatment facility has increased over the past 15 years. The number of crash fatalities Taken for medical treatment has declined to 18,463, and this percentage has declined to 43 percent, in 2002. [18]

Both the fatalities Taken and those Not Taken suffered serious injuries. But limitations of FARS data on injury severity do not permit distinguishing survivable from non-survivable injuries. Thus, the number of these people that might have survived with timely, definitive medical care is unknown. While the number that might have survived is currently unknown, the research reported herein indicates that with new technologies, substantial benefits may be possible. Other researchers have estimated potential benefits ranging from hundreds to thousands of lives saved each year with improvements in post-crash care. [24, 30-32, 45]

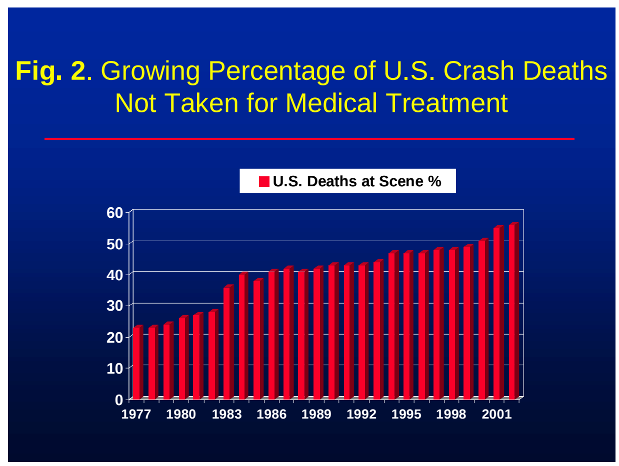


Fig. 2. Growing Percentage of U.S. Crash Deaths Not Taken for Medical Treatment

Figure 2 shows that in the year 2002, the percentage of people dying in crashes without being taken to a medical treatment facility amounted to nearly 56 percent of crash deaths. The percentage of crash fatalities each year that are Not Taken to a medical treatment facility has increased steadily over the years. The percentage of crash fatalities Taken for medical treatment, conversely, has steadily declined.

The increase in the number and percent of deaths at the scene may be due to a number of factors. More research is needed to understand the cause(s) of the increase in the number and percentage of "dead at the scene" and the possible remedies.

Reducing Time from Crash to Trauma Center --

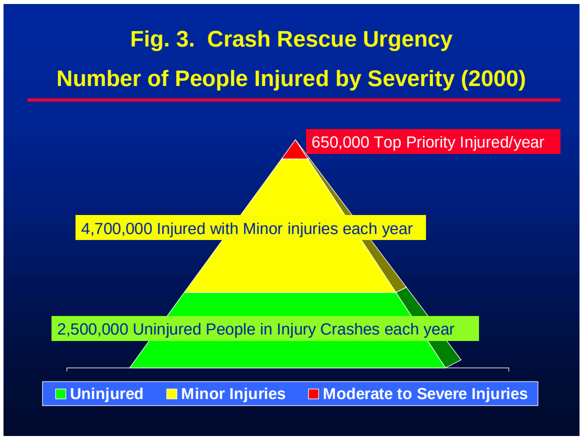


Figure 3 categorizes crash injuries in terms of their severity and urgency of treatment in all crashes involving injuries. The most important (life, or livelihood, threatening) injuries need to be treated differently from the more numerous cases of minor and uninjured people in crashes. Those with serious injuries require advanced emergency care while those with minor or no injury do not. The challenge is to distinguish and treat appropriately and rapidly the urgent injuries from the minor injuries.

In Figure 3, the top category shows that about 650,000 people suffer moderate to severe threat-to-life (AIS 2+), high priority, injuries each year. Currently some, but an unknown portion, of these people are under-triaged, i.e., receive less than optimal care in terms of timeliness, quality, and/or place of treatment (e.g., seriously injured not taken directly to a trauma center). Under-triage can result in needless deaths and disabilities.

The lower two categories show that there are about 7 million people who suffer minor or no injuries in crashes each year. Currently some, but an unknown portion, of these people are over-triaged to hospitals and trauma centers and found not to need the highest level of medical treatment. Over-triage can result in needless added health care costs.

Thus, tools are needed to better allocate emergency medical resources according to need, both for providing life saving care to those who need it, and for economic savings for those without serious injuries.

Note that the injury severity level often is not known at the time and scene of the crash. Thus, it is important to develop information systems and protocols that help to distinguish those who are likely to have serious injuries from those who are unlikely to have serious injuries – and to do so both faster and more accurately than we do today.

Since 1977, more than 1 million people have died from crash injuries along U.S. roads. Nearly 500,000 of these people died from crash injuries without having been taken to a medical treatment facility. Each year 43,000 people die and 650,000 suffer disabling injuries. Many of these people could benefit from faster, more informed, transport and treatment [4].

The morbidity of serious injuries is described by the trauma maxim "Time is tissue." As an injury results in bleeding or edema, the longer tissue is deprived of oxygen and normal function, the greater the deterioration. And the longer the deterioration is allowed to progress, the greater the complexity of treatment, and the greater the long-term consequences. Long-term consequences include decreased physical function, pain, suffering, psychological and sociological problems, and economic harm.

Timely, optimal treatment is necessary to reduce morbidity resulting from many crash injuries occurring each year. Nearly 66,000 serious brain injuries occur to light vehicle occupants each year. About 3,500 serious spinal cord injuries occur each year that often result in life-long disabilities including quadriplegia and paraplegia. Nearly 140,000 lower limb injuries (hip, leg, knee, ankle and foot) of moderate to serious threat to life are sustained in crashes each year. Another 20,000 upper limb injuries occur each year. [10] Many injuries involve critical joints that result in long-term disabilities, psychological and sociological problems, economic harm, and pain and suffering – especially when timely, optimal care is not received.

The literature of emergency medical care has long documented that for many serious injuries, time is critical. In a description by R Adams Cowley of the origin of the Maryland Shock Trauma Center (now a base for research by the Maryland CIREN team) completed in 1969:

"During these years of initial organization, it was learned that the first 60 minutes, "the golden hour," after a life-threatening injury incident dictates whether a patient will live or die. Another factor influencing survival is access to an emergency medical system providing on-site resuscitation, evaluation, triage, and communication and transportation with care en route to a definitive care facility." [60]

As described by RD Stewart:

"Trauma is a time-dependent disease. 'The Golden Hour' of trauma care is a concept that emphasizes this time dependency. That is in polytrauma (typically, serious crash victims suffer multiple injuries) patients, the first hour of

care is crucial, and the patient must come under restorative care during that first hour.... Pre-hospital immediate care seeks to apply supportive measures, and it must do so quickly, within what has been called the 'Golden Ten Minutes.'" [34]

Dr. John R. Border described the problems of polytrauma in a classic textbook "Blunt Multiple Trauma":

"Major errors in care are made when the principles that appear largely valid for a single injury are extrapolated to the blunt multiple trauma patient." [47, 57, 61-62]

Both the internal (difficult to detect) nature and extent of blunt trauma, and the compounding effects of multiple injuries combine to complicate the emergency medical treatment of crash victims. This need for rapid diagnoses and treatments for the optimal care of crash injuries makes them time critical.

The authors of this paper compared the available data on fatal crashes in FARS with the goal of trauma care to get seriously injured patients into a trauma center for diagnosis, critical care and appropriate surgical treatment within the "Golden Hour" [14, 17, 18]. The team used the time benchmarks in Fig. 4 for data available in FARS on the delivery of patients to medical facility care within the "Golden Hour."[9]

[Note that the FARS currently does not contain data on the capability level of medical facilities to which victims in fatal crashes have been transported for treatment, nor does FARS currently contain data on methods of transport (air, ground, or ground and air)].

Fig. 4. "Golden Hour" Benchmarks

Time from Crash to:

- **EMS Notification: <1 Minute**
- **EMS Scene Arrival: <10 Minutes**
- **Hospital Arrival: <45 Minutes**
- **Definitive Care: <60 minutes**

Figure 4 shows the medical benchmarks of the "Golden Hour" to provide optimal care for seriously injured crash victims.

Fig. 5. Fatalities in Crashes Meeting Benchmarks 2002

Times	Benchmarks	Reported*
EMS Notification	<1 minute	9,013 (21%)
Scene Arrival	<10 minutes	11,279 (26%)
Hospital Arrival	<45 minutes	6,004 (14%) (Taken + Not Taken)

* Only in Crashes with Reported Times

Figure 5 shows the number of fatalities in FARS 2002 that reportedly met medical benchmarks of the "Golden Hour" to provide optimal care for seriously injured crash victims.

Fig. 6. Average 2002 Performance Recorded in U.S. Rural Fatal Crashes

Times	Benchmarks	Average*
EMS Notification	<1 minute	**7 minutes**
Scene Arrival	<10 minutes	**18 minutes**
Hospital Arrival	<45 minutes	**53 minutes**
Definitive Care	<60 minutes	**68 minutes**

* Average Times for Crashes with Times <=120 minutes

Figure 6 shows the EMS average time performance in U.S. rural fatal crashes as recorded in FARS 2002. Note, only crashes with times less than 120 minutes were used to calculate average times to minimize effects of questionable and very long times on the averages. Average times to trauma center greater than 120 minutes have just been documented in the State of Maine. [66] Average EMS Notification times have declined nationally with the growing availability of cell phones over the past decade from 9 minutes to 7 minutes in fatal rural crashes [5].

Fig. 7 Needed Reductions in **Average** Times in Recorded U.S. Rural Fatal Crashes 2002

Times	Benchmarks	Needed
EMS Notification	<1 minute	**- 6 minutes**
Scene Arrival	<10 minutes	**- 8 minutes**
Hospital Arrival	<45 minutes	**- 8 minutes**
Definitive Care	<60 minutes	**- 8 minutes**

Figure 7 shows the needed reductions in *average* times in U.S. rural crashes. Methods by which these reductions can be achieved are indicated in Figure 8.

Fig. 8 Feasibility of Reductions in Average Times in Recorded U.S. Rural Fatal Crashes 2002

Times	Reductions Needed	Feasible with
EMS Notification	- 6 minutes	ACN
Scene Arrival	- 8 minutes	ACN + URGENCY
Hospital Arrival	- 8 minutes	Air Medical Services
Definitive Care	- 8 minutes	Trauma Systems (AACN+URGENCY+Air Med)

Figure 8 shows technologies that could be employed to reduce average times: Automatic Crash Notification (ACN) equipment, *URGENCY* software, Air Medical Services, and Trauma systems linked together via wireless communications systems. [23, 50-52]

The Need for Timely Intervention – In FARS 2002, there were 42,815 fatalities along U.S. roads; 23,795 fatalities (56%) were Not Taken for Medical Treatment and the rest died later.

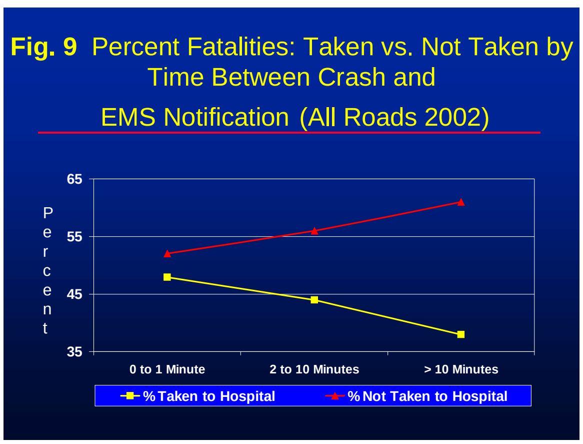


Figure 9 using FARS 2002 data, shows that the percent of fatalities Not Taken for medical treatment increases as the time between crash and EMS Notification increases while the percent Taken for medical treatment declines.

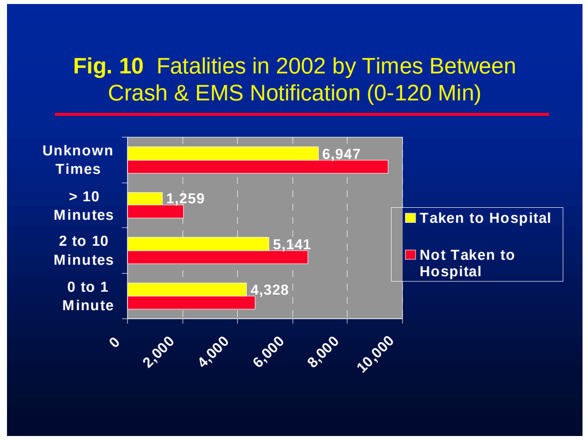


Figure 10 shows the numbers of fatalities in each time interval are not based on small numbers of cases. The percentages Taken versus Not Taken in Figure 9 are based on substantial numbers of cases in each time interval.

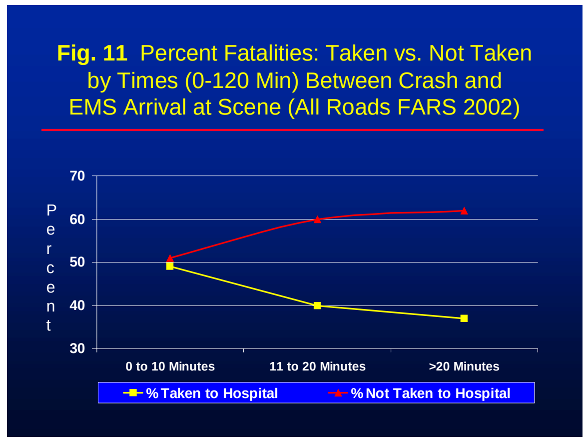


Figure 11 shows that the percent of fatalities Not Taken for medical treatment increases as the time between crash and EMS Arrival increases, while the percent Taken for treatment declines.

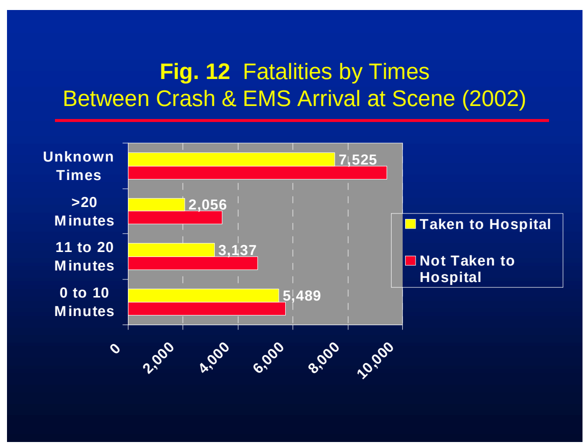


Figure 12 shows the numbers of fatalities in each time interval and indicates that the percentages Taken versus Not Taken in Figure 11 are based on substantial numbers of cases in each time interval. The later the arrival, the greater the percentage of people Not Taken for treatment in that time interval. These data support the "Golden Ten Minutes" rule.

Finding Serious Injury Crashes – Run-off-the-road (ROR) crashes are an important safety problem resulting in 17,927 fatalities in the year 2002. Vehicles that run off the road and crash may be difficult to see. In ROR crashes in 2002, there were 11,068 fatalities that were Not Taken for medical treatment and 6,686 fatalities that were "Taken." [9]

Decreased visibility also is often present complicating location of the crash. Decreased visibility is defined as times between dusk and dawn and/or weather conditions involving snow, rain, and/or fog. In 2002, of the 17,927 fatalities in ROR crashes there were 11,120 fatalities with decreased visibility conditions and 6,807 fatalities without decreased visibility. [9]

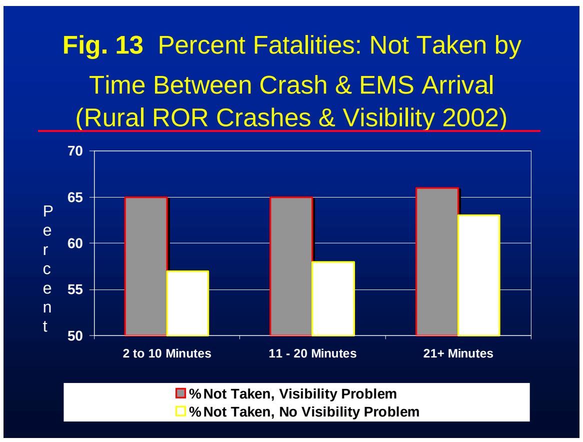


Figure 13 shows that in rural run-off-the-road crashes, with decreased visibility, the percent of fatalities Not Taken for medical treatment is greater in each time interval when visibility is impaired.

In many such crashes, ACN technologies can help locate the crash and speed the delivery of emergency services because accurate GPS locations are provided even if the crashed vehicle is out of sight from the road or not easily seen because of poor visibility conditions.

Urban/Rural -- A recent report published by NHTSA described the problem of preventable mortality in rural areas as follows: *"Typically, rural areas have a higher preventable mortality rate than urban regions. This may be due to a number of factors, such as the time elapsed from the emergency call to the arrival of the ambulance at the scene of the incident, the time for the ambulance to reach the trauma center, insufficient experience with certain trauma procedures due to infrequent occurrences, and inadequate training for EMS personnel in rural areas."* [39]

Using Crash Scene Information to Improve Care –

Meeting the Safety Need with Information Technology: *URGENCY* Software - To advance, in Dr. Haddon's words, *"the detection and evaluation of damage….and the generation of a signal that response is required"*, the research team has developed the nation's first prototype software called *URGENCY* and worked on subsequent versions. This tool is designed to help detect and evaluate crashes to distinguish serious injury crashes from non-serious injury crashes. A research version of the latest *URGENCY* software prepared by Drs. Bahouth and Digges is available for academic review at:

http://surgery.med.miami.edu/williamlehman/

Research on *URGENCY* software continues through development of two software packages *SCENE URGENCY* software and Automatic Crash Notification (ACN) *URGENCY* software. [16] *SCENE URGENCY* addresses current needs of responders to crashes to better assess the probability of serious injury presence. *ACN URGENCY* addresses the future need to assess injury probabilities in crashes of new vehicles equipped with ACN systems. The goal is to save crash victims from death and disability through the application of engineering knowledge of crash injury mechanisms and probabilities of serious injuries.

Future research also is expected to help us better estimate the potential benefits in mortality and morbidity reductions possible with faster and better emergency medical decision-making. Hopefully, in the future, improvements in triage, transport, and treatment, with ACN, *URGENCY*, and earlier and better utilization of Air Medical Services will reduce the number of deaths of people -- both those "Taken for Treatment" and those "Not Taken for Treatment."

ACN with *URGENCY* information on crash severity can help dispatchers, instantly and automatically, decide to send appropriate resources such as extrication equipment in severe crashes, thereby, saving additional precious minutes.

Extrication -- Extrication is an increasingly important factor in fatal crashes [17]. In 1990, extrication was involved in crashes resulting in 4,426 fatalities. In 2002, nearly 10,000 fatalities occurred in crashes involving extrication. [9] Extrication requires specialized equipment and trained rescue teams to remove occupants rapidly and safely. First responders to the scene may have to wait for heavy rescue teams to extricate the crash victim.

Once heavy rescue teams arrive at the scene of serious injury crashes, extrication can take many precious minutes. CIREN researchers have found that in serious injury crashes extrication often takes more than 20 minutes. [65] The NHTSA/CIREN database, as of Nov. 2004, has 123 cases with extrication times equal to or less than 20 minutes and 102 cases of extrication times equal to or greater than 21 minutes.

In future implementations, ACN and *URGENCY* information could save valuable time by alerting dispatchers that the crash severity information, e.g., rollover, near side impact, high Delta V, indicates heavy rescue teams might well be needed. In addition, since the ACN crash message includes the make and model of the crashed car, it is now technically possible for heavy rescue teams to receive extrication information on the number of air bags, their location, and vehicle cut points specifically for the crashed vehicle – before arriving at the scene.

Alternatively, for all vehicles currently on the road, crash evaluation services could be provided by a third party, either via call center, wireless internet, or software carried by rescue personnel on PDA's or laptop computers. Such systems could provide rescue teams with extrication information specifically for the crashed vehicle using the Vehicle Identification Number (VIN) – shortly after arriving at the crash scene.

More advanced versions of *URGENCY* software will employ additional sensor data to create a more robust and sophisticated triage, transport, and treatment decision-making tool. Future *URGENCY* ratings may calculate the probabilities of the presence of minor as well as major injuries. Information will be included such as the number, size, and seating positions of occupants, seat track location (closeness to air bag), crash pulse, air bag time of deployment, level of air bag deployment, deployment of seat belt emergency tensioning retractors, seat belt forces, door openings, presence or absence of fire, pre-crash speed, and braking deceleration.

Occult Injuries – Occult injuries cause problems in providing timely optimal care. This section of the paper describes work by NHTSA and CIREN researchers to improve detection and treatment of serious occult injuries.

Brain injuries, especially the so-called "talk and die" injuries, are a constant concern to emergency medical care providers. As described in *Advanced Trauma Life Support Program for Doctors (ATLSPD):*

"Despite proper attention to all aspects of managing the patient with a closed head injury, neurologic deterioration can occur, often rapidly. The lucid interval commonly associated with acute epidural hematoma is an example of a situation where the patient will 'talk and die'." Diagnosis can be made more difficult by other circumstances, e.g., *"Alcohol and/or other drugs also may alter the patient's level of consciousness."* [56]

Thoracic injuries including lung, heart, and aortic injuries, without initial bleeding, can be fatal later. To overcome difficulties in diagnosis, the ATLSPD advises *"Contusions and hematomas of the chest wall should alert the doctor to the possibility of occult injury."* It also warns of the pitfalls to be avoided regarding elderly and pediatric patients:

"A. Elderly patients are not tolerant of even relatively minor chest injuries. Progression to acute respiratory insufficiency must be anticipated and support instituted before collapse occurs."

"B. Children often sustain significant injury to the intrathoracic structures without evidence of thoracic skeletal trauma. A high index of suspicion is essential." [56]

Internal bleeding injuries in the abdomen without external symptoms e.g., liver, spleen, and bowel injuries have long been a concern in emergency medical care of crash victims. As the ATLSPD describes the problem: *"Abdominal injuries must be identified and treated aggressively….A normal initial examination of the abdomen does not exclude a significant intra-abdominal injury…Knowledge of injury mechanism, associated injuries that can be identified, and a high index of suspicion are required."* [56]

Occult Injury Warnings - To advance *"the detection and evaluation of damage*", the nation's first Occult Injury Database (OID) was developed by researchers at the CenTIR, NHTSA, and CIREN [19]. The OID is a new tool for studying the problem of occult crash-related injuries that often can be fatal. Occult injuries can be fatal because of their severity, time sensitivity, and treatment criticality.

For the purposes of this database, occult injuries are defined as injuries that are not easily recognized and are life-threatening. They require timely treatment at the scene, in transport, and at medical facilities and 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. Crash victims may decline medical treatment, despite needing care, because they "look and feel OK." Many factors complicate diagnoses of crash injuries. In multiple injury cases, common in crashes, the pain of one injury may distract the patient from pain of another more serious injury. Or the presence of alcohol may impair the ability of the patient to provide proper responses during medical examination. Occult injuries also are often characterized by deterioration at differing rates. Initially, such injuries may not be apparent. However, if not properly treated, victims can deteriorate, sometimes rapidly, and too often suffer fatal consequences.

The OID was used to estimate, also for the first time, the potential number of fatalities occurring each year from occult injuries to occupants in motor vehicle crashes. The estimates indicate that in an average recent year, 1,186 crash-related fatalities were recorded with a potentially occult injury as the "Only Cause of Death." In addition, based on data from 1997-2001, the estimates are that, in an average year, of 29,118 injuries recorded as a "Cause of Death," 18,888 were potentially occult injuries.

Thus, nearly 65 percent of all the fatal injuries recorded as a cause of death to occupants in crashes each year were due to potentially occult injuries. The approximately 18,888 potentially occult injuries recorded as a Cause of Death each year were distributed by body region as follows: 10,376 head, 6,001 thoracic, and 2,511 abdominal and pelvic injuries. Of the 1,186 single Cause of Death cases, 441 were head, 658 thoracic, and 87 abdominal/pelvic. [19] See

http://www.cubrc.org/centir/occult_injury.html

Crash information may be used to improve triage and treatment decision-making by helping in the identification of occult injuries. [54-55] Researchers at the CIREN centers and NHTSA have found that use of information from the crash has the potential of providing more sensitive triage and faster diagnosis of injuries for motor vehicle crash victims.

One of the first contributions on occult injuries by current NHTSA/CIREN researchers occurred after the advent of air bags. While air bags protect the head and face in serious crashes, internal injuries are being missed. This happens because the previously common "tell tale" signs of bleeding from facial lacerations and decreased levels of consciousness are now often not present to alert emergency medical care providers to the severity of the crash.

This new injury pattern led NHTSA to issue a *Research Note* "Detection of Internal Injuries in Drivers Protected by Air Bags" to help emergency medical care providers better recognize occult internal injuries. That *Research Note* recommended that rescue workers "lift the deployed air bag to look for steering wheel deformation." [21]

This "Lift and Look" tip to make a quick visual check was made to reduce the likelihood that potentially fatal internal injuries would be missed because motorists protected by air bags "may look fine and feel fine, but not be fine." Occult internal injuries from blunt trauma often are survivable if detected and treated appropriately in time.

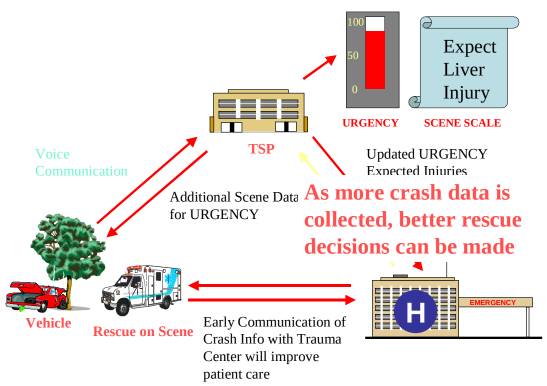
Consequently, NHTSA published and widely distributed the poster "Look Beyond the Obvious" based on continued research at the Miami CIREN Center [22]. This research found additional occult injury patterns that could be recognized using information from the crash. The "Look Beyond the Obvious" poster listed five indicators based on crash scene information to help emergency care providers detect internal injuries. These were organized into a checklist in an easy to remember mnemonic SCENE:

- **S - Steering Wheel Deformation –** Lift the air bag and look. A bent steering wheel could provide an alert that internal injuries are present.
- **C - Close Proximity of Driver to Steering Wheel** – Occupants of small stature or large girth sitting close the steering wheel are at greater risk of internal injuries.
- **E - Energy of the Crash** – Twenty (20) or more inches of vehicle crush, or twelve (12) inches of intrusion, indicate high-energy crash forces.
- **N - Non-use of Seat Belts** – Non-use of lap or lap shoulder belts by any of the occupants can result in multiple impacts of the occupants (including occupant to occupant loading) and greater probability of internal injuries. Note the non-use of lap belts continues to be of concern. The estimated number of vehicles on the roads today equipped with manual 2-point belts exceeds 10 million vehicles.
- **E - Eyewitness Report of Crash Scene –** Verbal reports, photos, and tele-video images of the crash vehicle convey some idea of the severity of the crash, and may indicate the possibility of occult injuries.

These recommendations on occult injury indicators are increasingly relevant. Today, the need to detect occult injuries is growing each year as more Americans are riding with their belts buckled (now 79%) and protected by air bags (air bags are now in more than 133 million vehicles, or 60% of the fleet). While air bags and seat belts are now estimated to save nearly 17,000 lives each year, these post-crash tips can increase the number of lives saved. [20]

NHTSA/CIREN researchers have continued this work and identified a series of crash characteristics associated with occult injuries. [44] These researchers have developed the following "Warning Flags," or tips, to alert first responders to crash conditions that result in increased risk of occult injuries and compelling injuries. Figure 14 schematically describes the information flow possible from the scene of serious crashes to EMS, hospitals, and telematics service providers (TSP) such as ATX, Cross Country Group, and OnStar. [18, 29]

Figure 14. Schematic of Improved Communications with Occult Injury Warning Flags



NHTSA CIREN researchers have worked for years to identify the characteristics of motor vehicle crashes that increase the risk of serious injury. This research resulted in the development of a mathematical algorithm (discussed above) to estimate the probability of the presence of serious injury in a car crash based on crash severity measures. The NHTSA CIREN research team incorporated the algorithm into computer software named *URGENCY* to relate crash severity measures to the probability of serious injuries. [11-18]

In addition to developing improvements in *URGENCY* for use with Automatic Crash Notification (ACN) systems, work has proceeded to develop *SCENE URGENCY* for use with handheld computers for use in all current crashes since most vehicles currently are not equipped with ACN systems. Field-testing of this software is planned.

Occult injuries comprise a fraction of all crash injuries and result in an unknown number of preventable deaths. In many cases the deaths might have been prevented had the injuries been recognized and treated in time. Independent studies funded by NHTSA found a range of preventable deaths from 17% in rural Montana in a 1992 report [36], 12.9% in a rural Michigan study [37], and 7-21% in North Carolina in a 1995 report [38]. Occult injury warning flags, had they been available, may have helped improve system effectiveness.

Note that the preventable death studies just cited were performed before air bags were present in a large proportion of the fleet and at times when safety belt use was lower. In addition, these studies examined the problem of preventable deaths "as is." They did not address how many additional deaths might have been preventable using new technologies providing information from the crash. Use of such crash information is expected to improve quality of care by alerting medical care providers to the potential for occult injury presence and reduce the risk of missed injuries.

CIREN researchers have identified potentially useful indicators of the presence of occult injuries. [44, 48] Several occupant and crash characteristics have been associated with an increased risk of serious injury. Each factor is being incorporated into developmental software as an "Occult Injury Warning Flag." The following Warning Flags have been organized into a mnemonic OCCULT:

- **O -- Occupant Age & Sex –** Older adults have a higher risk of suffering serious injuries than younger adults in a crash of the same crash severity (in all crash directions combined). [15, 44, 63]

  For example, in a 35 mph frontal impact crash, a 25 year-old male has about a 41 percent probability of suffering a serious injury. In a crash of the same type and severity, a male age 75 faces a 74 percent probability of being seriously injured. Thus, independent of the vehicle damage, occupant age should be taken into account in assessing the probability of serious injury. [16]

  Females in a crash of a given severity also face a greater risk of suffering serious injuries than do males. For example, if the occupant in a 35 mph frontal crash is a female, instead of a male as in the above crash; at age 25 her risk of serious injury is about 45 percent.

  The overall risk of serious injury in a crash of a given severity increases at a rate of nearly 1 percent per year of age through the adult years.

  Figure 15 below provides data indicating the growing importance of age in the nation's crash problem. As the U.S. population ages, the average age of crash fatalities has increased steadily over the past 20 years. Note, however, that while the nation's average age of the population has increased from 34 to 36 since 1980, the average age of crash fatalities has increased at a greater rate from 33 to 40.

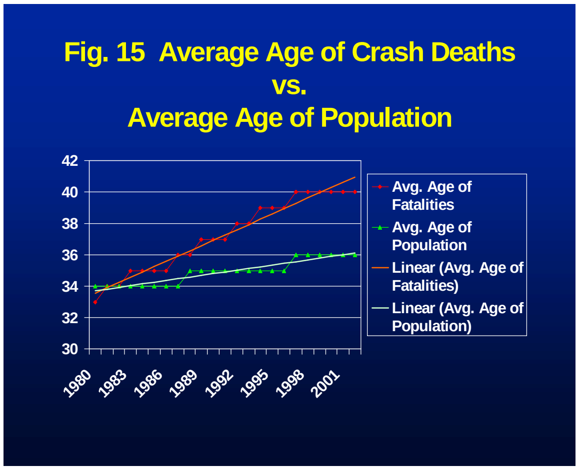


Fig. 15 Average Age of Crash Deaths vs. Average Age of Population

Currently, more than 10,000 people, age 55 and older, are killed in crashes each year. In the near future, demographics indicate that the importance of age in crashes will grow rapidly. The U.S. population age 65 and older is projected to increase from 35 million in 2000 to 63 million by the year 2025. [40]

Researchers at the Alabama CIREN Center recently published a paper concluding that "Older adults have the highest rate of motor vehicle collision-related blunt aortic injury (BAI), and their injuries tend to occur in less severe collisions. A high level of suspicion for BAI among older adults should not be reserved for high-energy collisions only." This underscores the importance of faster and more informed transport and treatment decision-making that takes into account the age of the crash victims. [41-43]

- **C – Caught or Entrapped** – As is shown in Figure 16, if an occupant is entrapped in the vehicle, the risk of serious injuries nearly triples to close to 75 percent from an assumed baseline crash with a 25 percent probability of a serious injury. Thus, entrapment is a warning flag that serious injuries are likely in that crash. [15, 44]

- **C – Complete or Partial Ejection** – Also as can be seen from Figure 16, if ejection is involved in a crash, the probability of serious injury approximately doubles to more than 50 percent probability of serious injury. [15]

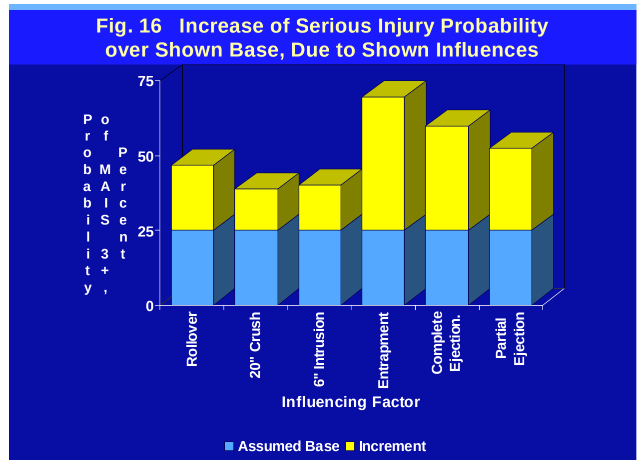
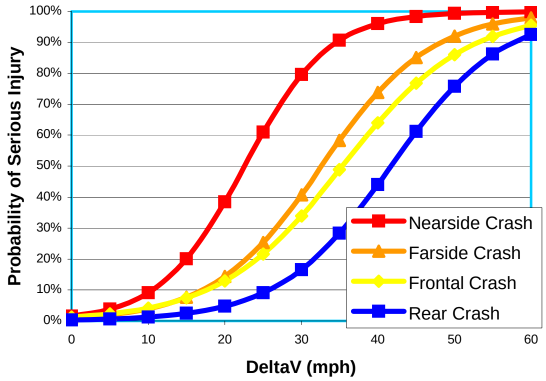


Fig. 16 Increase of Serious Injury Probability over Shown Base, Due to Shown Influences

- **U – Under-ride and Narrow Object Crashes** – Crashes that involve under-ride of another vehicle or impacts with poles, trees, and other narrow objects increase the likelihood of internal and other serious injuries. These crashes may involve increased belt loads and late deployment of air bags that result in less than optimal crash protection. Part of the physical crash problem here is that vehicle crash sensors may sense crash forces late (milliseconds later) in these crashes. Thus, the occupant may be less optimally positioned to obtain maximal protection from the restraint systems and suffer internal injuries. [44]

- **L - Lateral Crashes, Near Side, Far Side and Off-Side Crashes –** As Figure 17 indicates, the risk of serious injury is very dependent on crash type. Note that side impacts, of a given crash severity, have the highest risks, with near side impacts having the highest risk of serious injury. For instance, in crashes with a 30 mph Delta V, occupants struck on the near side have an estimated 80% risk of suffering serious injury. Far-side occupants have nearly a 50% risk. Occupants in 30 mph frontal crashes have nearly a 40% risk. And occupants experiencing a rear impact crash with a 30 mph Delta V have about a 20% risk. Note that crash force direction can result in four-fold to six-fold differences in probability of serious injury. [44]

Figure 17 - Probability of Serious Injury by Crash Direction and Severity



Crashes in which the vehicle is struck from the side, or off-side at one of the wheels, may result in rapid rotation of the vehicle and cause occupants to suffer internal injuries that are asymptomatic and not apparent e.g., aortic, abdominal, and spinal injuries.

- **T – Two or More Impacts** – Crashes that involve multiple impacts such as vehicle-to-vehicle followed by an impact with another vehicle or structure increase the risk of serious injuries. Crashes involving multiple impacts may induce complex loading of the chest, abdomen, and spine. [44]

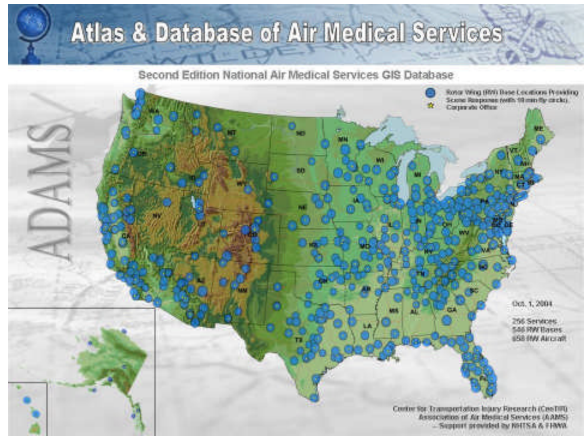
With ACN and *SCENE URGENCY* software and Occult Injury Warning Flags, the outcomes of many serious crash injuries are expected to improve. These new tools will enable better outcomes with improvements in the timeliness, appropriateness, and efficacy of the medical care received by the crash victim. In too many cases, especially in rural areas, people die without having obtained definitive care at a trauma center within the "Golden Hour." Definitive care for seriously injured crash victims includes expert care at the scene and en route, thorough, timely, and accurate diagnoses, intensive critical care facilities, and readily available trauma teams with surgeons specializing in brain, spinal cord, internal organ, and orthopedic injuries.

ADAMS for More Timely Rescues – To advance the ability to provide timely, quality, emergency medical care, the researchers have developed the nation's first Atlas and Database of Air Medical Services (ADAMS). See

http://www.adamsairmed.org/

ADAMS was developed to facilitate, in Dr. Haddon's words "*the decision to follow-through,*" the deployment of air medical services to rescue people in serious injury crashes.

Fig. 18 Atlas & Database of Air Medical Services (ADAMS)



The national view of ADAMS is shown in Figure 18. ADAMS is designed to improve the timeliness and quality of emergency response and care. Research that led to ADAMS is at [18, 23, 25-29, 46, 49, 58-60].

Currently in virtually all 42,000 deaths and 250,000 serious injuries every year, helicopter rescue operations do not begin unless, and until, someone in authority (usually police, fire or EMS) travels over land to the crash scene to make a judgment to call for air medical rescue. Consequently today, too often, the deployment of appropriate rescue resources results in the dispatch of too little, too late, to save lives and prevent disabilities. Without the tools described in this paper there also is a substantial amount of over-triage currently occurring.

Current national data on air medical rescues is too scarce to quantify how many seriously injured people in crashes might have benefited from the more-timely and often higher level care provided by air medical rescue teams both at the scene and en route to the trauma center.

Better utilization of air medical services can produce reductions in mortality and morbidity of crashes. Such benefits can be achieved with faster response and transport times, higher quality care at the scene and in transport, and at the highest-level trauma center. The goal is to facilitate air medical care when needed, and avoid over utilization when not needed.

To fully reap the safety benefits of ACN technology for seriously injured crash victims, information on the crash must be provided to the appropriate emergency responders as soon as possible. By coupling advanced ACN technology with the smart use of air medical transport, it is anticipated that many seriously injured crash victims will benefit.

A detailed survey of air medical services was conducted including the specific location of all air medical bases and Rotor Wing (RW) aircraft in the country. This detailed assessment of air medical rotor wing service coverage areas across the nation was used to produce ADAMS [29].

ADAMS is implemented in a Geographic Information System (GIS) on the web. It displays, in a map context, the locations of all known air medical base helipads and their coverage areas, as well as the locations of their communication centers and receiving hospitals / trauma centers. Summary information on rotor wing aircraft (e.g., N#, make & model, cruise speed, etc.) is also included. Figure 18 provides a map showing national coverage by air medical RW services.

Using ADAMS in concert with ACN and *URGENCY*, the researchers believe that the nation is now better equipped for processing *"the signal's transfer, receipt, and evaluation,"* and making *"the decision to follow-through"* for seriously injured crash victims. In the near future, using crash-specific information from the ACN signal and using *URGENCY* to interpret the injury implications of the signal, dispatchers will be able to rapidly assess the need for an air medical response. With ADAMS, air medical services will have the ability to be on early alert, as will the nearest trauma centers. It is expected that the near-parallel (rather than serial) response which ensues, will enable appropriate responders to reach the scene sooner after the crash than is currently possible.

In addition, the data-driven inputs provided by ACN, *URGENCY*, and ADAMS will enable *smarter* triage so that those who are most seriously injured in a crash get to the right place – a Trauma Center. It is anticipated that when the ACN-*URGENCY*-ADAMS components start to function together as part of a trauma system response, lives will be saved and disabilities reduced [18, 25-29, 58-60].

In addition to being designed as a tool to improve operations; ADAMS is designed to be a research tool to find ways to continuously improve emergency care. ADAMS is contributing to research by the Association of Air Medical Services (AAMS). The AAMS Research Committee currently is examining the potential of using Auto Launch/Early Activation policies to improve emergency medical care to seriously injured people. [64]

ADAMS data and software tools will soon be made available to analysts collecting data for national crash databases. In the near future, mode of transport (ground, air, or some combination) as well as the air medical service utilized will be easily recorded in the crash data record along with the location and type of hospital or trauma center to which the patient was transported. ADAMS will therefore enable national crash databases to document *how* crash victims were transported as well as *where* they were transported to. In addition, accurate crash times (from ACN crashes) can be coupled with the time data already collected in the national databases (time of EMS notification, scene arrival, hospital arrival, etc.).

Accurate crash data will improve emergency response timeline information and further strengthen and expand the utility of the nation's crash research databases. ACN-*URGENCY*-ADAMS will help provide a better picture of *how*, *where*, and *when* crash victims received emergency care and will support research efforts aimed at improving access to such care throughout the country.

Air Medical Coverage Relative to Fatal Crash Locations

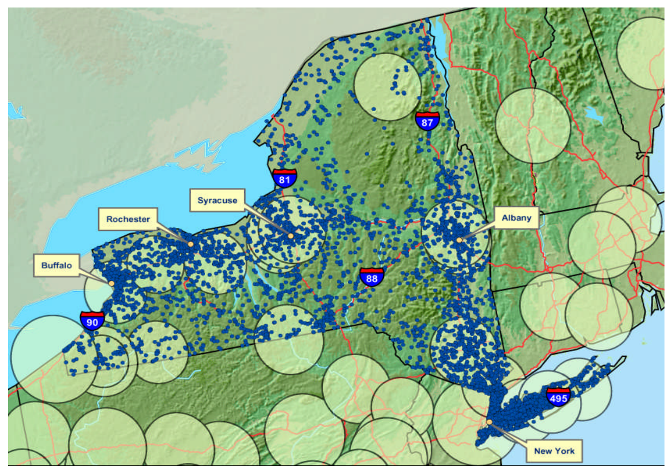


Figure 19. NY FARS Data for 1996 – 2001 in a GIS Map with Air Medical Fly Zones

Figure 19 shows a map of NY with the locations of all fatal crashes between 1996 and 2001 indicated by a blue dot. This data was geo-coded using specialized software developed by Drs. Hwang and Thill at the Department of Geography at the State University of NY at Buffalo. [67]

http://www.adamsairmed.org/pubs/ITS_SSC.pdf

Also overlaid on the map are the interstate highways and major cities. [18]

Analyzing fatality data in a geographic context enables researchers to easily view where crashes are occurring and aids in characterizing the nature of these events in each region (e.g., are they predominantly in urban, suburban, or rural areas, are they on or off the major highways, are they overly concentrated in specific locales that could benefit from better use of air medical services, etc.?)

An additional overlay on the map in Figure 19 shows the air medical base locations with 10 minute fly circles. With ADAMS it is possible to perform even more detailed analyses of air medical coverage patterns. The number of crashes that occurred within 10- minute fly-circles in NY State between 1996 and 2001 were calculated. The data indicates that 75-78% of the fatal crashes occurred in areas that were within a 10-minute fly-circle.

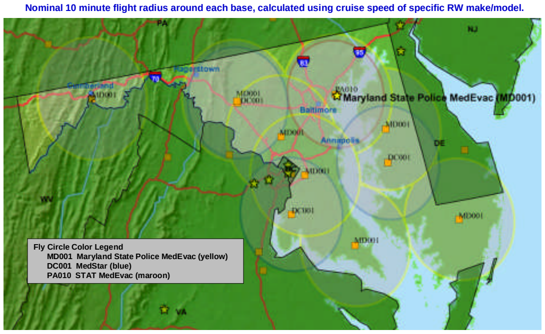
Nationwide, about 70 percent of the population is located within 10-minute fly circles in the U.S. and about 97 percent within 30-minute fly circles. In contrast, about 33 percent of the interstate and U.S. highway system is located within 10-minute fly circles in the U.S.; and about 82 percent of these roads are within 30-minute fly circles. [29]

Figure 20 shows an ADAMS map of Maryland's air medical system with 10-minute fly zones. This illustrates the possibility of rescues within the "Golden Hour" in the future with ACN, *URGENCY*, and ADAMS. An ACN signal is translated into a high URGENCY rating alerting the statewide trauma care system. EMS and heavy rescue teams arrive within the "Golden 10 minutes". Air medical arrives. Patient(s) extricated by 30 minutes after the crash. Within 45 minutes post-crash, patient(s) arrive at trauma center. Patient receives definitive care in the Operating Room within "Golden Hour" post-crash. The result will be lives saved and disabilities prevented.

CenTIR Center for Transportation Injury Research

Fig. 20 Air Medical Base Location & Coverage Areas in State of Maryland

Nominal 10 minute flight radius around each base, calculated using cruise speed of specific RW make/model.



Conclusions -- New technologies are available to:

(a) rapidly detect and evaluate damage with ACN,

(b) alert emergency medical care providers with *URGENCY* software and Occult Injury Warning Flags,

(c) enable earlier and more informed dispatch decisions, including air medical services,

to rescue people seriously injured in crashes - in time to save lives and prevent disabilities. The lifesaving and disability-reducing capabilities of these new technologies will help build a safer America.

References

1. NHTSA, *CIREN Program Report, 2002*, DOT HS 809 564, September 2003, pp. 5, 37-45. Available at:

   http://www-nrd.nhtsa.dot.gov/departments/nrd-50/ciren/networkreport/

2. National Committee on Trauma and Committee on Shock, *Accidental Death and Disability: The Neglected Disease of Modern Society*, National Academy of Sciences, Washington, DC, September, 1966.

3. National Safety Council, *Accident Facts*, 1994, p. 70, Itasca, IL

4. NHTSA, *The Economic Impact of Motor Vehicle Crashes 2000*, DOT HS 809 446, May 2002, pp. 8, 9, 62.

5. NHTSA, *Traffic Safety Facts 2002*, DOT HS 809 620, January 2004, pp. 15, 170-173.

6. 106th Congress, Congress of the United States, Public Law 106-81, October 26, 1999, *Wireless Communications and Public Safety Act of 1999*, 113 STAT. 1286, 47 USC 609.

7. Perrine MW, Waller JA, Harris LS, "Alcohol and Highway Safety; Behavioral and Medical Aspects," Final Report to Department of Transportation, NHTSA, (DOT HS 800 599), 1971.

8. Haddon W, "Energy Damage and the Ten Countermeasures Strategies," *Proceedings, International Conference on the Biokinetics of Impacts*, Amsterdam, 1973, 490-504.

9. NHTSA, Fatality Analysis Reporting System (FARS), Automated Data Files.

10. NHTSA, National Automotive Sampling System (NASS-CDS), Automated Data Files 2000-2002.

11. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, Lombardo LV, *Post-Crash Injury Control*, Briefing for NHTSA Administrator, R Martinez, Washington, DC, March 27, 1997.

12. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Automatic Crash Notification," *AirMed*, March/April 1998, p. 36.

13. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "*Urgency* for a Safer America," *AirMed*, March/April 1999, pp.18-23.

14. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Reducing

Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Services Providers," *Proceedings of the National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders*, May 3-5, 1999, pp. 67- 84.

15. Malliaris AC, Digges KH, DeBlois JH, "Relationships Between Crash Casualties and Crash Attributes," Society of Automotive Engineers SAE 970393, February 1997. The development of the *URGENCY* triage algorithm reported in this paper was part of a multidisciplinary team's effort and was presented to the NHTSA Administrator in a briefing March 27, 1997. The multi-disciplinary team was led by Champion HR, and included Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Lombardo LV, Malliaris AC, Sacco WJ, and Siegel JH.

16. NHTSA, *CIREN Program Report, 2001*, DOT HS 809 377, December 2001, available at:

    http://www-nrd.nhtsa.dot.gov/departments/nrd-50/ciren/networkreport2001

17. Champion HR, Augenstein JS, Blatt AJ, Cushing B, Digges KH, Hunt RC, Lombardo LV, Siegel JH, "Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Vehicles in Crashes to EMS," *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles*, May 19-22, 2003, available at

    http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv18/cd/files/18ESV-000406.pdf

18. Champion HR, Augenstein J, Blatt AJ, Cushing B, Digges KH, Siegel JH, Flanigan MC, "Automatic Crash Notification and the *URGENCY* Algorithm: Its History and Use" *Topics in Emergency Medicine*, April-June, 2004, Vol. 26, No. 2, pp.143-156.

19. Blatt AJ, Jehle D, "Occult Injury Database," available at http://www.cubrc.org/centir/occult_injury.html

20. National Highway Traffic Safety Administration (NHTSA), "Traffic Safety Facts 2002, Occupant Protection," DOT HS 809 610.

21. Lombardo LV, Ryan SD, "Detection of Internal Injuries in Drivers Protected by Air Bags," *NHTSA Research Note*, August 1993.

22. National Highway Traffic Safety Administration (NHTSA), "Look Beyond the Obvious" Poster, a.k.a. "The SCENE Poster" provides tips to recognize crash conditions warranting an increased index of suspicion for occult injuries, 1994.

23. Funke D, Bellis E, Donnelly B, Blatt A, McClellan R, Wilson G, "Automated Collision Notification (ACN) Field Operational Test Final Report," National Highway Traffic Safety Administration, U.S. DOT HS 809 303, October 31, 2000.

24. Bachman LR, Preziotti GR, "Automated Collision Notification (ACN) Field Operational Test (FOT) Evaluation Report," National Highway Traffic Safety Administration, U.S. DOT HS 809 304, February 2001, page 6-7.

25. Sampalis JS, Denis R, Frechette P, Brown R, Fleiszer D, Mulder D, "Direct Transport to Tertiary Trauma Centers versus Transfer from Lower level Facilities: Impact on Mortality and Morbidity among Patients with Major Trauma," *Journal of Trauma*, Vol. 43, No. 2, August 1997, p. 288.

26. Falcone RE, Herron H, Werman H, Bonta M, "Air Medical Transport of the Injured Patient: Scene versus Referring Hospital," *Air Medical Journal*, Vol. 17, No. 4, October-December 1998, p 161.

27. Oppe S, De Charro FT, "The effect of medical care by a helicopter trauma team on the probability of survival and the quality of life of hospitalized victims," *Accident Analysis and Prevention*, 33 (2001) pp. 129-138.

28. Thomas SH, Harrison TH, Reenstra Buras W, Ahmed W, Cheema F, Wedel SK, "Helicopter Transport and Blunt Trauma Mortality: A Multicenter Trial," *Journal of Trauma*, Vol. 52, Number 1, January 2002, pp. 136-145.

29. Flanigan MC, Blatt AJ, Miller MA, Pirson HB, Lombardo LV, Mancuso D, "The Atlas and Database of Air Medical Services (ADAMS): A Timely Safety and Security Link." Available at http://www.adamsairmed.org/pubs/ITS_SSC.pdf

30. Clark DE, Cushing BM, "Predicted effect of automatic crash notification on traffic mortality," *Accident Analysis and Prevention*, 34 (2002) 507-513.

31. Evanco WM, "The Potential impact of rural mayday systems on vehicular crash fatalities," *Accident Analysis & Prevention*, 1999, 31:455-462

32. Kanianthra J, Carter A, Preziotti G, "Field Operational Test Results of an Automated Collision Notification System," SAE Proceedings, Convergence 2000, Oct. 1, 2000, Detroit, 2000-01-C041.

33. NHTSA, National Automotive Sampling System (NASS), Crashworthiness Data System, 1995-1997, DOT HS 809 203, 2001.

34. Stewart RD, "Pre-hospital Care of Trauma," in McMurtry RY and McLellan BA, *Management of Blunt Trauma*, Baltimore, MD: Williams and Wilkins; 1990: 23-29.

35. NHTSA, *1998 Strategic Plan of the NHTSA*, *Promoting Safe Passage into the 21st Century*, September 1998, DOT HS 808 785, p. 30.

36. Esposito TJ, Reynolds SA, Sanddal ND, Hansen JD, Rinker CF, Dale G, Maningas PJ, O'Reilly PJ, Bleicher J, Petrashek B, Rural Preventable Mortality Study, NHTSA Report DOT HS 807 973, Washington, DC, Dec. 7, 1992.

37. Maio RF, Burney RE, Gregor MA, Baranski M, Welch KB, Rothman ED, Michigan Rural Preventable Mortality Study, NHTSA Report DOT HS 808 341, Washington, DC, June 1995.

38. Cunningham PRG, North Carolina Preventable Mortality Study with Inter-Rater Reliability Modifications, NHTSA Report DOT HS 808 345, Washington, DC, July 31, 1995.

39. Garrison HG, Gough SB, Swanson MS, Cunningham PRG, *The React Project: Rural Enhancement on Access and Care for Trauma*, National Highway Traffic Safety Administration, U.S. DOT HS 809 521, October 2002.

40. U.S. Census Bureau, Projections of the Total Resident Population by 5-Year Age Groups, and Sex with Special Age Categories. Washington, DC: U.S. Department of Commerce, 2000.

41. Melton SM, McGwin G, Abernathy JH, MacLennan P, Cross JM, Rue LW, "Motor Vehicle Crash-Related Mortality Is Associated with Prehospital and Hospital-Based Resource Availability", *Journal of Trauma*, 2003; 54: 273-279.

42. McGwin G, Reiff DA, Rue LW. "Differences in the incidence and etiology of blunt thoracic aortic injury in motor vehicle collisions by age." *Journal of Trauma*, 2002; 52: 859-66.

43. McGwin G, Reiff DA, Moran SG, Rue LW, "Incidence and Characteristics of Motor Vehicle Collision-Related Blunt Thoracic Aortic Injury According to Age," JOT 52: 859-866.

44. Augenstein J, Perdeck E, Stratton J, Digges K, Bahouth G, "Characteristics of Crashes that Increase the Risk of Serious Injuries," 47th Annual Proceedings, Association for the Advancement of Automotive Medicine, September 2003, pp.561-576.

45. Lob GC, Pieske O, Messner G, Bauer P, "Automatic Collision Notification: Reduction of Rescue Time for Seriously Injured Occupants," Orthopedic Trauma Association; 2003, Polytrauma Scientific Poster 46. Available at: http://hwbf.org/ota/am/ota03/otapo/OTP03046.htm

46. Prasad P, "Role of Electronics in Automotive Safety," 2000-01-C086, SAE Proceedings, Convergence 2000, Detroit, Oct. 1, 2000.

47. Foley RW, Harris LS, Pilcher DB, "Abdominal Injuries in Automobile Accidents: review of care of fatally injured patients" *Journal of Trauma*, 1977, August 17 (8): 611-5.

48. Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Malliaris AC, Quigley CV, Craythorne AK, Young PE, "Occult Abdominal Injuries to Airbag Protected Crash Victims: A Challenge to Trauma Systems," *Journal of Trauma*, Vol. 38, No. 4, 1995. See also Augenstein JS, et al, "Heart Injuries Among Restrained Occupants in Frontal Crashes," SAE 970392.

49. American College of Emergency Physicians, "Automatic Crash Notification and Intelligent Transportation Systems," ACEP Policy Statements, Approved February 2002, available at http://www.acep.org/1,5069,0.html, accessed 12/9/02.

50. GM, "GM Advanced Automatic Crash Notification Announcement," Press Release July 31, 2002, available at http://www.gm.com/company/gmability/safety/news_issues/releases/onstar_072902_lang.html, accessed 12/0/02.

51. Greater Harris County 9-1-1 Emergency Network, "Ford Telematics Delivers Crash Information in Less Than 60 Seconds," Press Release, Houston, Texas, August 28, 2002, available at http://www.911.org/news/release13.asp, accessed 12/9/02.

52. ITS America, "Recommendations for ITS Technology in Emergency Medical Services" Press Release, Seattle, WA, October 7, 2002. Available at http://www.itsa.org/ITSNEWS.NSF/4e0650bef6193b3e852562350056a3a7/bd4fc63176d6989385256c4b000c0d15?OpenDocument.

53. NHTSA, "Safety Belt and Helmet Use in 2002 – Overall Results", DOT HS 809 500, September 2002, available at http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2002/809-500.pdf.

54. Jones IS, Champion HR, "Trauma Triage: Vehicle Damage as an Estimate of Injury Severity," *Journal of Trauma*, Vol. 29, No. 5, May 1989, p. 646.

55. Hunt RC, Brown RL, Cline KA, Krohmer JR, McCabe JB, Whitley TW, "Comparison of Motor Vehicle Damage Documentation in Emergency Medical Services Run Reports Compared with Photographic Documentation," *Annals of Emergency Medicine*, 1993, 22:651-656.

56. American College of Surgeons, *Advanced Trauma Life Support Program for Doctors*, Sixth Edition, 1997, pp. 30-39.

57. Fakhry SM, Watts DD, Luchette FA, "Current Diagnostic Approaches Lack Sensitivity in the Diagnosis of Perforated Blunt Small Bowel Injury: Analysis from 275,557 Trauma Admissions from the EAST Multi-Institutional HVI Trial," *Journal of Trauma*, 2003; 54: 295-305.

58. Trunkey DD, "Trauma," *Scientific American,"* August 1983, Vol. 249, No. 2, pp. 28-35. This paper was the original inspiration for the ADAMS project. Subsequently, other researchers reinforced the life-saving value of air medical services. [25-28] And after 20 years, ADAMS was born.

59. Trunkey DD, "History and Development of Trauma Care: The U.S. Experience," *Clin Orthop*, 2000; 374:36-46.

60. Cowley RA, Dunham CM, *Shock Trauma/Critical Care Manual, Initial Assessment and Management*, Maryland Institute for Emergency Medical Services Systems, Baltimore, MD, University Park Press, 1982.

61. Border JR, Allgower M, Hansen ST, Ruedi TP, *Blunt Multiple Trauma, Comprehensive Pathophysiology and Care*, Marcel Dekker, Inc., 1990.

62. Border JR, "Death from Severe trauma: Open Fractures to Multiple Organ Dysfunction," *Journal of Trauma*, Vol. 39(1), July 1995, pp.12-22.

63. Champion HR, "Major Trauma in Geriatric Patients", *AJPH* 79(9), 1989.

64. Wish JR, Davis DP, "Auto Launch/Early Activation: A Survey of AAMS Members and Literature Review," *Air Medical Journal*, in press.

65. Pintar FA, Yoganandan N, Gennarelli TA, Olshanski J, "Evaluation of Extrication After Motor Vehicle Crash," CIREN Presentation, 4 Nov. 2004, Baltimore, MD.

66. Clark DE, Anderson KL, Hahn DR, "Evaluating an Inclusive Trauma System Using Linked Population-Based Data," *Journal of Trauma*, Vol. 57, No. 3, September 2004, pp.501-509.

67. Hwang J, Thill J, "Applying Artificial Intelligence Methodology to Geo-referencing with Imperfect Information", 99th Annual Meeting of the Association of American Geographers, New Orleans, LA, March 6, 2003.