ENHANCING POST-CRASH VEHICLE SAFETY THROUGH AN AUTOMATIC COLLISION NOTIFICATION SYSTEM

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ABSTRACT

In August of 2000, the National Highway Traffic Safety Administration (NHTSA) completed an Automated Collision Notification (ACN) Field Operational Test (FOT) in Erie County, New York that combined crash sensing, position location, and wireless communications technology in a system with the goal of saving lives and reducing disabilities from injuries by providing faster and more informed emergency medical responses to serious injury crashes. The ACN FOT Team designed and built an ACN system prior to the start of the test period in July 1997. ACN in-vehicle systems were then installed in 850 vehicles. The crash notification messages were delivered to emergency response and dispatch equipment installed at the Erie County Sheriff's Office, which served as the Public Safety Answering Point (PSAP) for this FOT. The data collected during the three-year test period and the crashes experienced by the test fleet demonstrated the feasibility of fielding an ACN system and the potential benefits of the system to the victims of motor vehicle crashes. An estimate of the potential benefits using a methodology based on the FOT data is also given.

INTRODUCTION

In 1999, there were 41,611 fatalities and an estimated 3,236,000 persons injured in police-reported motor vehicle traffic crashes. [1]. It is assumed that some of these casualties could be prevented if pre-hospital care could arrive at the crash scene to give early medical attention and stabilize the patients and transport them to emergency care facilities or trauma centers quickly. With the advances in technologies today, it is possible that the elapsed time from crash to arrival at an emergency care facility could be shortened.

Recent literature on traumatic deaths from all causes show that 50 to 90 percent of people who receive serious injuries die before arrival at an emergency care facility. [2]. Analysis of Fatality Analysis Reporting System (FARS) data indicate that 35-38 percent of light vehicle fatalities occur within ten minutes of the crash, 43-46 percent within one-half hour, and 56-61 percent within one hour after the crash. The National Automotive Sampling System's (NASS) Crashworthiness Data System (CDS) data agree with this time distribution. It has also been reported that of the approximately 41,500 crash deaths per year, nearly 20,000 die before receiving hospital care and that many of the remaining people die after reaching a hospital too late to be saved. In addition, it is estimated that 250,000 of the crash injuries are life threatening and that the economic costs of crash injuries each year amount to an estimated $100 billion dollars. [3].

The goal of ACN systems is to use technology to provide faster and smarter emergency medical responses in an attempt to save lives and reduce disabilities from injuries. This can be accomplished by both reducing the response time for providing emergency medical assistance to victims of motor vehicle crashes and increasing the information available for appropriate triage, transport, and treatment decisions. To attain this goal, an ACN system should automatically determine that a motor vehicle has been in a collision, notify emergency response personnel of the collision and the vehicle location, provide information concerning the crash, and establish a voice link between the vehicle and emergency response personnel.

Information that might be provided about the crash includes estimates of crash severity and the probability of serious injury. Crash severity estimates may be based on crash data, such as the change in velocity during the crash, the principal direction of force, or whether the vehicle was in a rollover. Estimates of the probability of serious injury may be based on the crash severity information along with vehicle data (e.g., vehicle weight, presence or absence of fire, and air bag deployment) and occupant-related information (e.g., age, gender, and safety belt use). The operation of an example ACN system is shown in Figure 1.
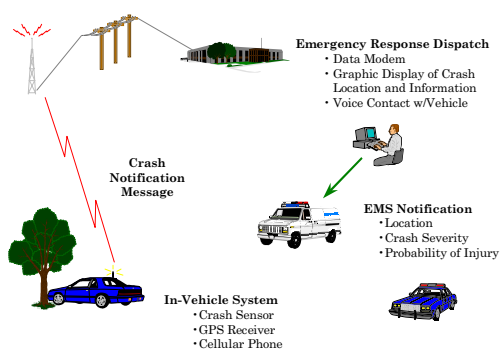
Figure 1. Example ACN System using crash sensing, position location, and wireless communications technology.

FIELD OPERATIONAL TEST DESCRIPTION

The ACN FOT program was initiated in October of 1995 with the selection by NHTSA of an ACN FOT team led by Veridian Engineering to design, build, install, and conduct the operational testing in Erie County, New York. The objective of the FOT was to demonstrate the feasibility of fielding an ACN system and investigate the potential benefits of the system. In addition to Veridian, the ACN FOT team included the Erie County Sheriff's Office, the Erie County Department of Emergency Services, Erie County Medical Center (ECMC) Department of Emergency Medicine, Rural Metro Medical Services of Western New York, State University of New York at Buffalo-Department of Industrial Engineering, and Cellular One. Veridian documented the results of the FOT. [4]. In addition, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) served as the independent evaluator for the FOT and produced an evaluation report addressing the performance of the ACN system. [5].

An ACN system may be viewed as consisting of an in-vehicle system that determines that a crash has occurred and initiates a request for assistance. The response network delivers the crash notification information and generates an emergency medical response. The in-vehicle system contains a crash sensor to determine that a collision has taken place, a location system to determine the position of the vehicle, and a wireless communications system to send the crash notification information to the appropriate PSAP for emergency response dispatch.

Figure 2 shows the in-vehicle system used by Veridian for the ACN FOT.

Figure 2. Veridian in-vehicle system used in the ACN FOT included a cellular phone, backup battery, cellular and GPS antennas, and an in-vehicle module with crash sensors and GPS board.

This system determined location using a Global Positioning System (GPS) receiver, sensed a crash with accelerometers dedicated to the ACN function, and communicated automatically with the PSAP via a cellular phone. The in-vehicle system applied the output of its accelerometers to an algorithm that computed a measure of the severity of a possible crash based on the vehicle acceleration history. This severity measure was compared to a threshold based on an estimate of injury risk being exceeded to determine the occurrence of a crash. The threshold varied depending on the change in velocity and principal direction of force for the crash. Once a crash was detected, a data message containing the vehicle location, information characterizing the crash (i.e., change in velocity, principal direction of force, and rollover occurrence), and the vehicle cellular phone number was sent to the Erie County Sheriff's Office, the PSAP for the FOT. Once the data message was delivered, the system automatically switched to voice mode providing the vehicle occupants with a hands-free voice line with the PSAP.

The crash notification calls were made via a 1-800 number to a single regional message center. This ACN FOT response network architecture was based on what was technologically feasible and financially affordable for the FOT and a desire to avoid changes to the emergency response system during this technology demonstration. It was not meant to be the architecture of choice for future deployed ACN systems.

Upon receipt of an ACN call at the Sheriff's Office 9-1-1 Dispatch Center, a computer console displayed a detailed road map with the vehicle's last location, a series of past locations, and data characterizing the crash. The displayed data included the change in velocity experienced by the vehicle; whether the crash was a frontal, side, or rear-impact crash; whether a rollover occurred, the make, model, and year of the vehicle; and the probable number of occupants in the vehicle. An example of the PSAP display screen for a single vehicle crash is shown in Figure 3. It is noted that the vehicle location shown in Figure 3 do not appear exactly on the road because of the slight error in plotting the GPS specified location. Once the data message was received, the system automatically converted to a voice line to the vehicle occupants, providing the 9-1-1 dispatcher with the opportunity to confirm the nature of the emergency and obtain additional information (e.g., number of cars and occupants involved in the crash and confirmation of the crash location).

In addition, a computer software developed for relating crash severity parameters to potential injuries was installed in the dispatch facility ACN equipment to produce an easily understood probability of serious injury estimate. The software used the information provided in the crash notification message (i.e., change in velocity, principal direction of force, whether the vehicle was in a rollover) along with supplemental information obtained from vehicle databases or from the vehicle occupants (e.g., occupant age and gender, use of seatbelts, vehicle weight and damage) to automatically calculate the probability of serious injury for the crash. [3]. Figure 4 shows rating of an 89% probability of the presence of at least one serious injury (Abbreviated Injury Scale (AIS) 3 or greater rating). In this example, the 89% rating was triggered by a side impact crash with a 38-mph change in velocity involving a rollover with a 30-year old female occupant.
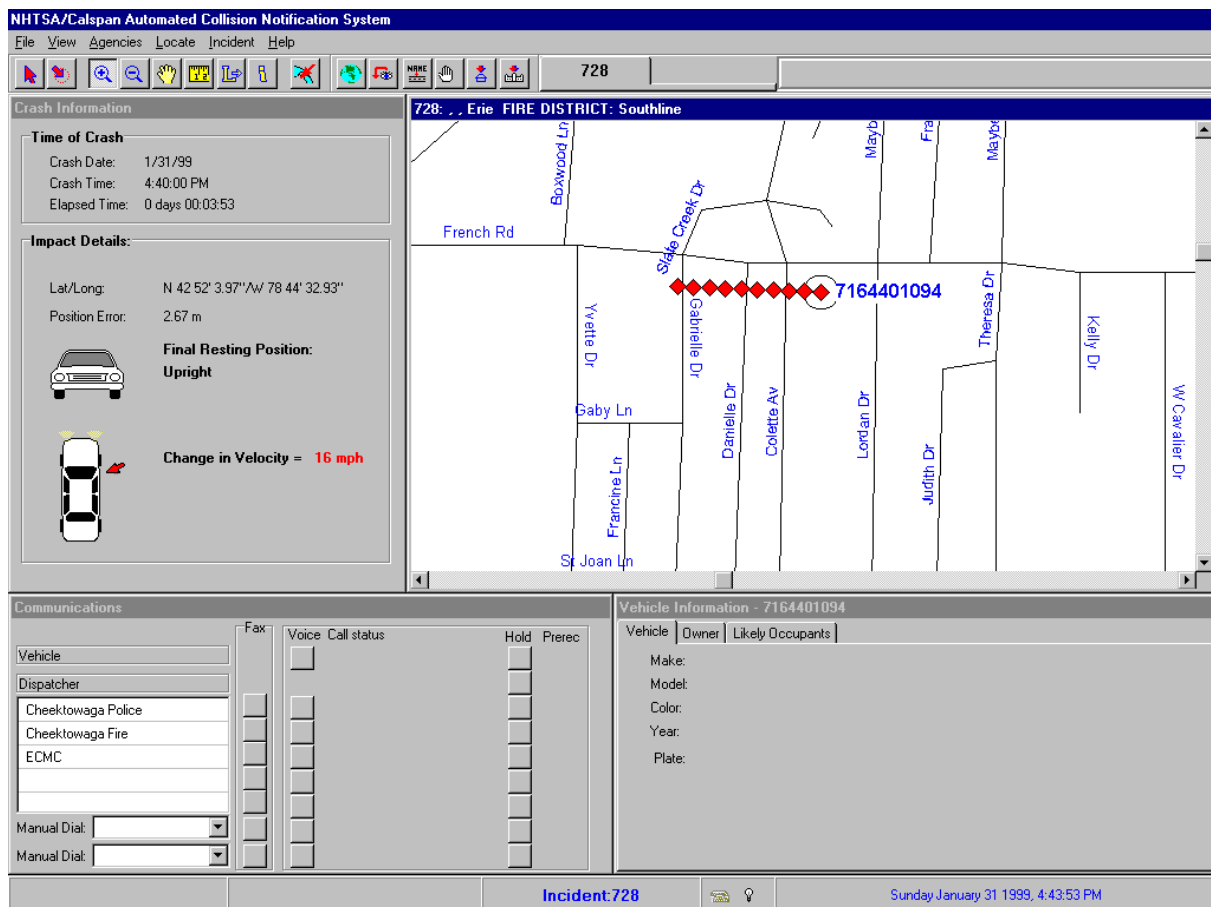

Figure 3. ACN FOT PSAP Display Screen showing vehicle position, time of crash, and crash details.
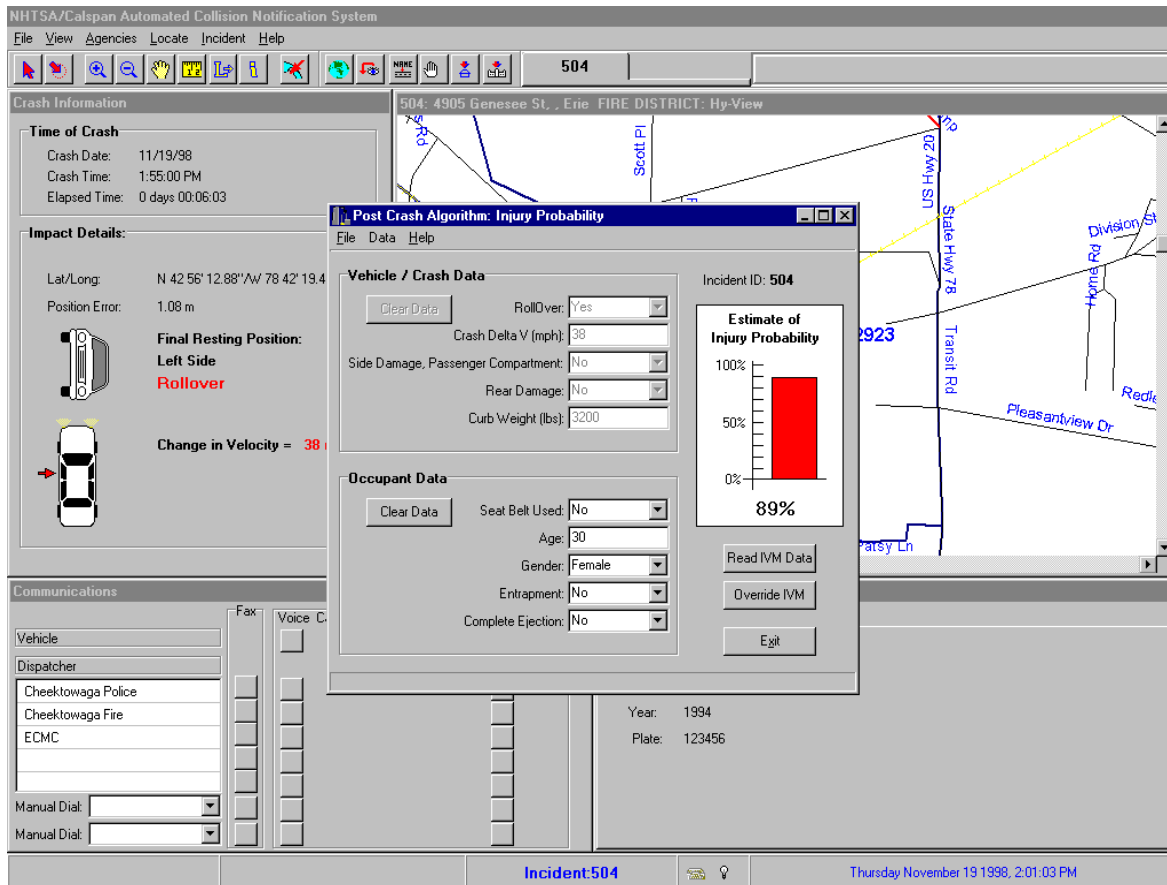
Figure 4. Dispatch Center Injury Probability Display Screen.

During the ACN FOT the display in Figure 4 was available, but not automatically shown to the dispatcher; instead the operation of the algorithm was investigated after the crash. It is envisioned that future versions of the software could include other sensor data, such as crash pulse, airbag deployment time and whether the airbag deployment was staged and if so which stages deployed, seat belt forces, door openings, presence or absence of fire, and the number, size, and seating positions of occupants to further improve emergency medical response.

ACN FOT EVALUATION

The primary goal of the ACN FOT was to evaluate system benefits and performance. While the ultimate measure of benefit of an ACN system is the reduction in mortality to crash victims, the focus of the ACN FOT was in determining the possible reduction in emergency medical response times with an ACN system. Since only a limited number of crashes were expected to occur during the FOT, it would have been difficult to use the data from the FOT to develop a precise estimate of the system benefits in terms of

reduction of fatalities. The evaluation of system performance measured the notification time, notification success rate, and false notification rate for the ACN system. In addition, those institutional issues that were encountered during the ACN FOT were documented, along with their resolution and recommendations concerning them. The complete evaluation plan for the FOT is provided in Reference 6.

The FOT collected data on crash notification and emergency medical response times both for vehicles equipped with ACN systems and for those without ACN systems. The collection of data for vehicles without ACN systems was undertaken by using a Crash Event Timer (CET) to provide a baseline against which to judge the performance of the ACN system. This allowed a comparison of currently reported emergency medical response times in FARS derived from police reports, emergency medical service reports and hospital medical reports against those derived from the data recorded by CET's. A major concern with the accuracy of the reported response times is that the precise time of crash is often

unknown and therefore is based on an estimate in the police accident report. In addition, when times are reported, they are often rounded to the nearest multiple of five minutes. [5].

This portion of the ACN FOT involved designing, building, and installing CET's in the vehicles of volunteers from the test area. The CET, shown in Figure 5, was a relatively simple and inexpensive device that used an inertial switch to sense the occurrence of a crash and start a processor counting elapsed time from the start of the event. Veridian, when notified of the crash, sent a team to read the elapsed time counter and convert it to time of the crash. This information was used with data collected from PSAPs and emergency medical service providers to accurately determine the crash notification and emergency medical response times. CET's were installed in about 2,700 vehicles during the CET test period (August 1996 through August 2000) with most installations occurring between August of 1996 and December of 1997.
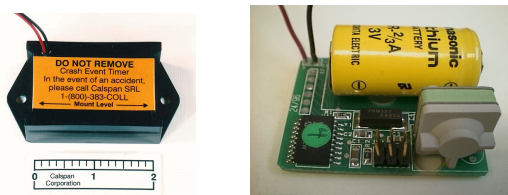

Figure 5. Collision Event Timers.

ACN in-vehicle systems were installed in 850 vehicles during the ACN test period (July 1997 through August 2000). About 500 systems were installed during the first year of the test period, and an additional 350 were operational by April 1, 2000 accounting for 1300 vehicle years of testing. Data supporting the evaluation of ACN system performance was collected automatically from the ACN in-vehicle system and the Sheriff's Office Dispatch Center and manually from the PSAPs and EMS service providers. In addition, experienced crash investigation teams from Veridian reviewed all crashes involving ACN-equipped vehicles, inspected all involved vehicles and the crash scene; interviewed police, EMS dispatchers, and fire/rescue personnel; collected notification and response times of emergency services; analyzed dispatcher emergency message records; and obtained injured victim medical records.

ACN SYSTEM PERFORMANCE

The data sample available for analysis from this FOT was considered to be too small to enable significant statistically valid conclusions to be drawn. Of the 70 ACN crashes, 48 were below the threshold levels established for notification. Of the remaining, one was outside the test area and thus not investigated and crash event time was not available for another. There were system failures in another 5 cases and therefore, there were only 15 ACN crashes available for analysis of PSAP notification times. The sample size for the baseline response time data collection effort was also small. There were only 25 CET notification times available for analysis. Nevertheless, it can be stated that the ACN system worked as expected. The PSAP at the Erie County Sheriff's Office was successfully notified in 16 of the 21 ACN crashes for a success rate of 0.76. The five failures were due to: (1) insufficient cellular phone coverage at the crash location, (2) damage inflicted to the ACN in-vehicle system during the crash, (3) low vehicle battery voltage when the backup battery was not available due to corroded terminals, (4) a disconnected telephone line to the modem in the ACN dispatch center equipment at the Erie County Sheriff's Office, and (5) unknown cause. The ACN system success rate could be further improved by careful installations to avoid some of these anomalies.

The ACN system notified the PSAP at the Erie County Sheriff's Office within 2 minutes of each of the 15 ACN crashes analyzed (crash event times were not available for a crash which occurred outside of the FOT area in Rochester, New York although the Erie County Sheriff's Office was successfully notified of the crash) and it was noted that after the ACN dispatch equipment computer was synchronized to a standard time source partway through the FOT, all notifications were within 1 minute. This performance was consistent with what was expected for the system. The average baseline notification time determined from the CET evaluation data was 5.6 minutes. While the majority of the CET based notifications would have been within 3 minutes, the distribution of CET based notification times included a number of larger time periods (9, 12, 30, and 46 minute times were included in the limited test sample).

The cumulative distributions of ACN and CET notification times based on the collected data are shown in Figure 6 as continuous curves. Based on the discrete data, all notifications for the ACN systems were received within 2 minutes, while 20% of those

for vehicles without ACN systems required greater than 5 minutes.

There were 31 false notifications made to the Erie County Sheriff's Office for a non-crash event during the FOT. Considering the vehicle years of operation, this false notification rate is considered rather small. Veridian Engineering attributed these false alarms to faulty accelerometer mounting in the in-vehicle system or unstable or intermittent power supplied to the in-vehicle system. This number of false alarms would most certainly result in a rate considered unacceptable in a widely deployed system. However, it is likely that improvements in the production process and hardware design could allow significant reduction in the false alarm rate from that experienced in the developmental prototype equipment used in this FOT.

In summary, the data collected and evaluated for the ACN FOT supports the following statements:

a. The ACN in-vehicle system worked as expected. It was able to sense that a crash had occurred, determine the vehicle's position, and deliver a crash notification message to the FOT 9-1-1 dispatch center via a cellular telephone call that was then switched to a voice line.

b. The crash detection algorithm detected all but one minor injury crash (AIS-1) during the FOT and reduced the notification of property damage-only crashes by more than 85%.

c. Based on the FOT data, the ACN system produced an average PSAP notification time of less than 1 minute. This average notification time was significantly less than the observed times for a number of the CET crashes.

d. The ACN system success rate was 0.76. Failure mechanisms included expected cases of insufficient cellular phone coverage at the crash location and damage inflicted to the ACN in-vehicle system during the crash. It should be noted that the small sample size of the data from the FOT limits the statistical significance of this result.

e. The ACN in-vehicle system produced a number of false alarms during the FOT. Improvement in the production process and hardware design could reduce the false alarm rate from that experienced in the developmental equipment used in this FOT. A need for improving the reliability of the developmental ACN dispatch center equipment was also noted during the FOT.
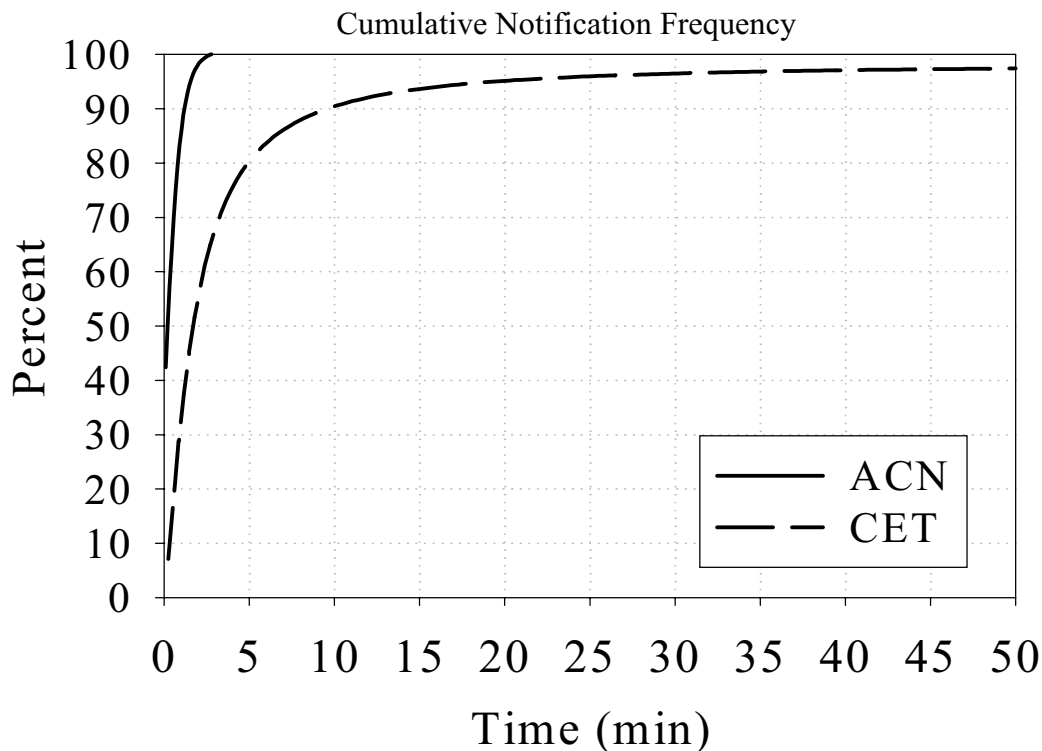

Figure 6. Comparison of Cumulative distribution of ACN and CET PSAP Notification Times

POTENTIAL BENEFITS

Several attempts to quantify the safety benefits of ACN systems have been attempted both by NHTSA staff [2] and others. As mentioned previously, slightly under 40 percent of the deaths generally occur within ten minutes of injury in motor vehicle crashes and around 60 percent of the deaths occur within an hour. It is well known that any serious airway obstruction or severe bleeding can result in deaths within ten minutes of receiving the injury. Pre-hospital care providers are generally at the scene after 10 minutes after the crash and any resulting injury. Thus the NHTSA analysis assumed that deaths that occur within ten minutes and those who die after ninety minutes may not be helped by ACN. These two assumptions limit the target population. It is further assumed that because of the large number of head, thoracic and burn injuries at the AIS 5 and 6 levels that occur in crashes, only about 10 - 11 percent of the fatal cases could be helped by pre-hospital intervention. Based on the 2,400 fatalities that result within thirty minutes of injury and the 5,250 fatalities that occur between thirty minutes and one hour, Reference 2 estimated that a total of 240 to 765 lives could be saved by an ACN-type system.

Other approaches have used analytical models by calculating transition probabilities for each possible change of state of victims over short intervals of time. Equating incapacitating injuries to be equal to NHTSA's General Estimate System (GES) injury data and setting total deaths as equal to that in FARS, and assuming transition to deaths is proportional to FARS rates, the model is used to predict the fatalities prior to notification, after notification and during the interval between EMS arrival and a chosen time period after the crash. Using such methods, estimates of the reduction in deaths from fully functional ACN systems have been attempted. However, the authors are not aware of published estimates of safety benefits using this methodology. ERTICO, the European ITS organization, estimates that ACN has the potential to be 15 percent effective. However, the methodologies used in those effectiveness estimates are not known.

A possible approach is to use the available data from ACN FOT on percent notification frequency and notification times presented in Figure 6. Even though the available number of data points are small, they have been used to approximate the cumulative percent notification frequency which is plotted against notification time for baseline CET systems and ACN systems. The methodology for calculating the effectiveness of ACN systems presented below is based on several assumptions.

- It is assumed that the crash outcomes in terms of fatalities are directly proportional to improvement in crash notification times.
- Victims of crashes who die at various time intervals after the crash are uniformly helped in the same manner as crash notification times are shortened.
- Changing conditions of victims transitioning from one level to another in crashes over any specific time intervals are ignored in this analysis.
- It is assumed that the number of fatalities that occur instantaneously at the time of crash are not helped by the improvement in crash notification times.
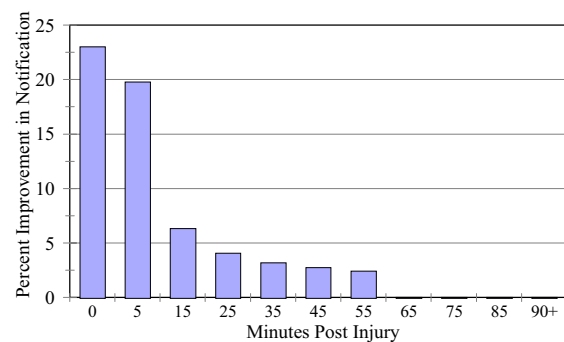

Figure 7   Percent improvement in notification frequency vs. time.

Based on the above assumptions, a method has been used in calculating the effectiveness of ACN systems which is described below:

The difference between the two cumulative distributions in Figure 6 is the percent improvement in notification frequency which has been calculated at time zero and at 5 minute intervals thereafter. If it is assumed that injury occurs instantaneously after crash, the time scale in Figure 6 can be treated as the elapsed time in minutes, post crash injury. Thus, the calculated improvement in notification frequency is plotted against time intervals of 10 minutes post injury, the calculated values being the approximate mid-point values for the intervals selected for the calculation. The percent improvement in notification frequency is shown in Figure 7. As evident, the percent improvement in notification frequency drops from 23 percent at time zero 20 percent at 5 minutes and to almost no improvement beyond 60 minutes, post injury.

Data on elapsed time from injury to death are generally available in an appreciable number of cases in the FARS data. The distribution of light vehicle

occupant deaths from the cases in 1999 FARS database with times of death are plotted at 10 minute time intervals, post injury which is presented in Figure 8. If it is assumed that this distribution is the same for the cases for which the time of death is not known, then the percent distribution presented in Figure 9 could be used in conjunction with the percent improvement of notification frequency presented in Figure 7 to determine the effectiveness of ACN systems for various scenarios of EMS delivery from instantaneous delivery post injury to several minutes of delayed delivery of services. It is reasonable to assume that the percent improvement in notification frequency is proportional to the percent of lives saved using the ACN system. Therefore, the product of the percent improvement of notification frequency at each time interval presented in Figure 7 and the percent deaths at the same time intervals presented in Figure 9 assumed over the entire time period gives an estimate of the effectiveness of the ACN system at each of the given time intervals.
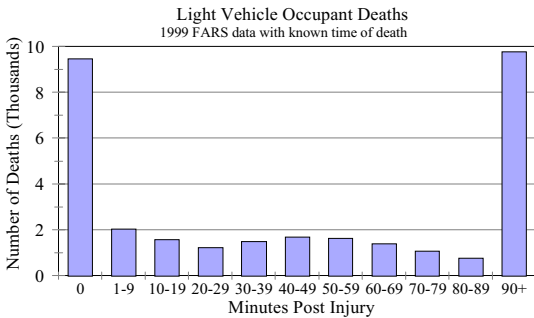

Light Vehicle Occupant Deaths
1999 FARS data with known time of death

Figure 8   Frequency distribution of deaths of occupants in light vehicle crashes
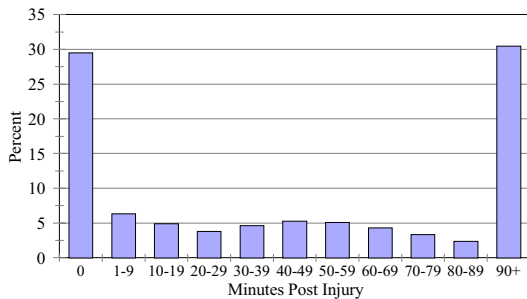

Figure 9   Frequency distribution of deaths as a percent of total deaths

The sum of those products gives an estimate of the total effectiveness since it is assumed that improvement in notification time can be equated to improvement in EMS delivery. However, since instantaneous delivery

of emergency services is unrealistic, more reasonable estimates of effectiveness can be obtained by shifting the time line in Figure 7 by the desired amount in minutes to the right, recalculating the products of percent improvement in notification at the shifted time intervals and the percent deaths in Figure 9 and summing up those products. Figures 10 through 13 give the percent effectiveness of ACN systems at various time intervals in minutes for various scenarios of EMS delivery, post injury. Figure 10 assumes instantaneous delivery of EMS services. Figures 11 through 13 assume delayed EMS delivery at 5 minutes, 10 minutes, and 20 minutes respectively.
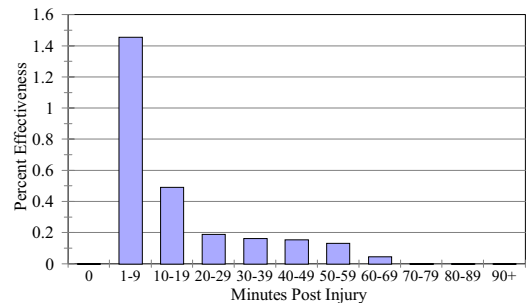

Figure 10   Percent effectiveness for various time intervals with no delay
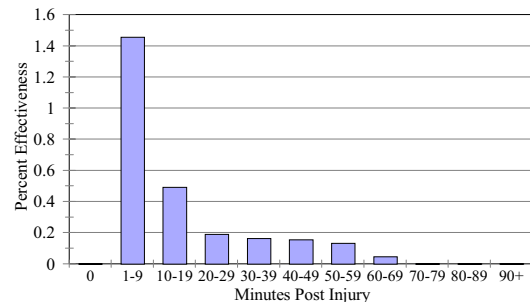

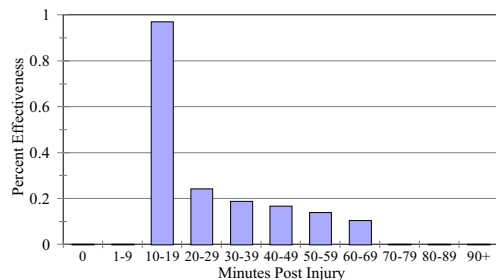**Figure 11**   Percent effectiveness for various time intervals when EMS delivery is delayed by 5 minutes.

Figure 12   Percent effectiveness for various time intervals when EMS delivery is delayed by 10 minutes.
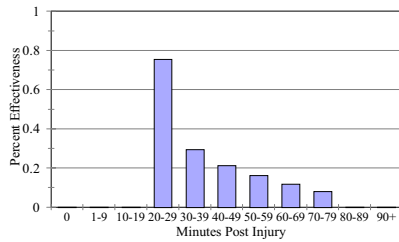
Figure 13 Percent effectiveness for various time intervals when EMS delivery is delayed by 20 minutes.

Using this method, it was estimated that the total effectiveness ranges from 1.81 percent for a 10 minute lag to 2.62 percent, assuming a 5 minute delay post injury in delivery of EMS. The same for a 20 minute delay is estimated as 1.62 percent. It is recognized that these values are being calculated at discrete points on the time line because the paucity of data does not permit the development of continuous curves for the percentage of deaths that occur at various times, post injury. Therefore, the effectiveness estimates developed could change, if the discrete points selected are different. However, it must be noted that these numbers could not be drastically different and the estimates arrived at are reasonable. Thus, based on an annual light vehicle fatalities of 32,000, it is estimated that the number of lives saved when all vehicles in the fleet are equipped with ACN systems could be in the rage of 580 to 840 for a delay of 10 minutes and 5 minutes in EMS delivery, respectively. However, with a 20 minute delay in EMS delivery, the benefits could be as low as 520. These benefit estimates are based on the assumption that EMS arrival at the crash scene automatically results in preventing deaths. In other words, the calculations are based on the assumption that EMS services are 100 percent effective. For this reason, the benefit estimates provided in this paper are likely to be too optimistic.

It is clear that a significant reduction in emergency response times is possible with automatic collision notification. It is, therefore, reasonable to conclude that fully functional ACN systems when implemented will have the potential to save a significant number of lives irrespective of the assumptions and methodologies used in estimating the safety benefits. Precise estimates and methodologies can only evolve after an appreciable number of crashes of vehicles having these systems occur in the real world.

OPERATIONAL ISSUES

It was noted during the ACN FOT that some owners of ACN-equipped vehicles had difficulty under-standing how the system operated and the types of crashes for which an ACN response would be generated. It is suggested that future ACN deployments generate improved operating instructions and attempt to better educate the public about the capabilities of ACN systems. In addition, other possible methods for resolution of this issue include adding an indicator to the in-vehicle ACN equipment to indicate that a crash has been sensed but that no emergency call is being placed due to the low likelihood of injury. Providing a single-button for adding manual crash-reporting capability to the ACN system would also be helpful.

Since the ACN FOT was initiated in 1995, commercial crash notification services have entered the marketplace. The first were offered in 1996 and based notification on air bag deployment or manual activation, thus limiting the types of crashes for which automatic notification is possible. The crash notification message in these systems is delivered to a private response center via cellular telephone. The response center then establishes a voice connection to the appropriate PSAP for EMS dispatch based on the vehicle's location and relays the information in the data message. Future versions of these systems could use accelerometers (or other sensors) dedicated to the ACN function similar to those used in the FOT, allowing a greater variety of crashes to be automatically detected and potentially providing estimates of crash severity and the probability of serious injury.

It is anticipated that several automobile manufacturers will offer "ONSTAR" type systems in at least certain models in the near future. For example, in addition to General Motors and Ford Motor Company, Nissan, Honda and Mercedes-Benz will be introducing collision notification systems in certain selected models of their product lines. Some will have the notification tied to air bag deployment while others will only have the capability of manually notifying the nearest private service provider. However, none are expected to be the full-fledged safety systems with the capability of relating crash severity parameters to potential injuries and predicting physical conditions of victims. Along with basic crash parameters such as velocity of impact, crash forces, status of restraint use, intrusion profile of vehicle interior compartment, demographic data of occupants, and special medical conditions of crash victims if any could be valuable information in predicting severity of injuries, in making appropriate triage decisions and in optimizing the medical response in crashes. The opportunity for developing such a system is already here. The needed technologies are available. For example, imagine if

you will, the possibility of using appropriate sensors and equipment to automatically determine the condition of a crash victim and assess the extent of injuries through onboard diagnostic technologies. This could dramatically change emergency medical services agenda for the future in dealing with crash victims. The possibilities are limitless. What is needed to make it a reality is a shared commitment and cooperative efforts between medical personnel, law enforcement and fire and rescue staff, public safety groups and partnership between the government and the private sector.

These commercial crash notification systems utilize private response networks, as the 9-1-1 system does not currently allow ACN calls to be delivered directly to a PSAP by dialing 9-1-1. It should be noted that this process of going through a private response center, instead of directly to a PSAP via 9-1-1 lines, may increase the response time as well as provide an opportunity for the introduction of errors into the crash information. The U.S. Department of Transportation (DOT) in collaboration with other organizations, is attempting to address the issues, including the routing of ACN calls into the 9-1-1 network and the transfer of data messages, that arise in dealings between private response centers and PSAPs. Until such dedicated emergency notification facilities are available, private response networks will continue to be available.

At least until a nationwide ACN public response network is deployed, given the need for public infrastructure development and deployment, it is likely that such infrastructures will be deployed over an extended period of time. As multiple commercial ACN systems are deployed and an eventual public ACN system developed, there will be a need for compatibility of these systems with the public infrastructure. Standardization of communications protocols and crash notification messages to allow for interoperability between systems and equipment will also be needed. In addition, institutional issues such as liability when an ACN does not work as intended or privacy issues associated with ACN data and its collection need to be resolved.

SUMMARY

The development and deployment of ACN systems is technically feasible. This was demonstrated in the ACN FOT and is supported by current activity in the commercial marketplace. The potential benefits of an ACN system would result from reduced PSAP notification times, improved knowledge of the vehicle location, and estimates of crash severity and the probability of serious injury.

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