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Automated Collision Notification (ACN) Field Operational Test (FOT) Final Report

Cooperative Agreement DTNH22-95-H-07429

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Erie County Sheriff's Office, Rural Metro Medical Services
of Western New York, Cellular One, State University of New York
at Buffalo Department of Industrial Engineering,
Erie County Department of Emergency Services,
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16. Abstract

The goal of Automated Collision Notification (ACN) Field Operational Test (FOT) was to design, develop and field test new technology to automatically detect and characterize potential injury-causing vehicle crashes and then provide 9-1-1 dispatchers with information about the crash events. The effort resulted in the development of specialized ACN equipment. This equipment was designed to be easily installed in vehicles and to operate independently of existing vehicle safety systems. The design integrated commercially available accelerometers, cellular communications equipment, Global Positioning Satellite receivers, and automated map display technologies. A critical component of the system was the crash recognition and characterization software that analyzed crash forces in real time to determine when thresholds indicating the likelihood of serious injuries were exceeded.

The primary objectives of the FOT were to: 1) Identify and evaluate technical issues associated with ACN system reliability, effectiveness, and performance; 2) Evaluate deployment issues relating to the use of ACN systems by Emergency Medical Service and Public Safety agencies, and 3) Collection of data to evaluate the potential benefits of the ACN system.

To achieve these objectives a plan was executed with the following elements: 1) design and development of hardware and software that could reliably sense vehicle crashes that are likely to cause injuries and initiate automatic notification procedures; 2) recruitment of volunteers, 3) design, development and installation of communications, special processing, and display hardware and software, and 4) establishment of data collection procedures. The principal measure of performance was whether the use of ACN systems would reduce the time for delivery of medical care to victims of motor vehicle crashes. Baseline (non-ACN) response time data were collected to compare to the

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1. INTRODUCTION

The final results of the Automated Collision Notification (ACN) Field Operational Test (FOT) are summarized in this report. The FOT began in October 1995 and was completed in September 2000. This program was an ambitious Field Operational Test that was conducted in Western New York by a private-public partnership under the direction of Veridian. The purpose of this report is to provide a high level summary of the program, its objectives and test results. During the conduct of the program a significant body of documentation was generated. These documents provide detailed information on the program. A bibliography identifying these papers and presentations is provided in Section 6 of this report. In addition, specific test data are presented in the appendices. Appendix A contains Newsletters that were issued during the project. Appendix B presents data for each of the specially equipped vehicles that were involved in a crash during the program.

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2. OVERVIEW

2.1 Project Partners

The ACN Project would not have been possible without the cooperation and hard work by a team of private and public agencies, including:

- National Highway Traffic Safety Administration
- Veridian Engineering
- Erie County Medical Center, Department of Emergency Medicine
- Erie County Sheriff's Office
- Erie County Department of Emergency Services
- Cellular One (now Cingular)
- State University of New York at Buffalo, Industrial Engineering Department
- Rural Metro Medical Services of Western New York
- Johns Hopkins University (JHU), Applied Physics Laboratory

2.2 Project Overview

The goal of this FOT was to design, develop and field test new technology to automatically detect and characterize potential injury-causing vehicle crashes and then provide 9-1-1 dispatchers with information about the crash events. It is important to recognize that the ACN Project was initiated in 1995. At that time no commercial Mayday systems, such as Ford RESCU or GM's OnStar, were available, or announced. In that regard, the ACN Project provided the first opportunity to demonstrate and evaluate ACN/Mayday technologies in real-world environments. The effort resulted in the development of the Veridian Automated Collision Notification (ACN) equipment. This equipment was designed to be easily installed in vehicles and to operate independently of existing vehicle safety systems (e.g., airbags). The design integrated commercially available accelerometers, cellular communications equipment, Global Positioning Satellite (GPS) devices, and automated map display technologies. A critical component of the system was the crash recognition and characterization software that analyzed crash forces in real time to determine when thresholds indicating the likelihood of serious injuries were exceeded. A patent was granted to Veridian for the development of the crash recognition algorithm (U. S. Patent No. 6,076,028).

The primary objectives of the FOT were to:

1. Identify and evaluate technical issues associated with ACN system reliability, effectiveness and performance;
2. Evaluate operational deployment issues relating to the use of ACN systems by Emergency Medical Service and Public Safety agencies, and
3. Collection of data to evaluate the potential benefits of the ACN system.

To achieve these objectives a plan was proposed and executed that involved the following elements: 1) design and development of hardware and software that could reliably sense vehicle crashes that are likely to cause injuries and initiate automatic notification procedures; 2) recruitment of 1000 volunteer FOT participants and the schedule and installation of ACN equipment in their automobiles, 3) design, development and installation of communications, special processing, and display hardware and software at two Public Safety Answering Point (PSAP) locations within Erie County, one at the Erie County Sheriff's Office, and one at the Erie County Medical Center's Medical Emergency Radio System (MERS) dispatch center; 4) establishment of procedures to collect the data needed for evaluation when an ACN-instrumented vehicle was involved in a crash. These procedures included the use of experienced accident investigation teams to inspect all instrumented vehicles involved in crashes and to reconstruct the crash events; interviews of police, EMS, dispatchers, and fire/rescue personnel; the collection of notification and response times of emergency services; analyses of dispatcher emergency message records as well as the medical records of injured vehicle occupants.

The principal measure of performance was whether the use of ACN systems would reduce the time for delivery of medical care to victims of motor vehicle crashes. Baseline (non-ACN) response time data were collected to compare to the response times of crashes involving the ACN system. The baseline data were collected with Crash Event Timers (CETs) that were installed in the automobiles of a second set of volunteers from the test area. These CETs, which were also developed during this program, only measured the elapsed time from when a crash occurred. By providing an accurate crash time they enabled the accurate reconstruction of post-crash event timelines for crashes involving non-ACN equipped vehicles. The post-event crash timelines for ACN crashes and non-ACN crashes could then be compared.

The ACN project proceeded through several phases, namely:

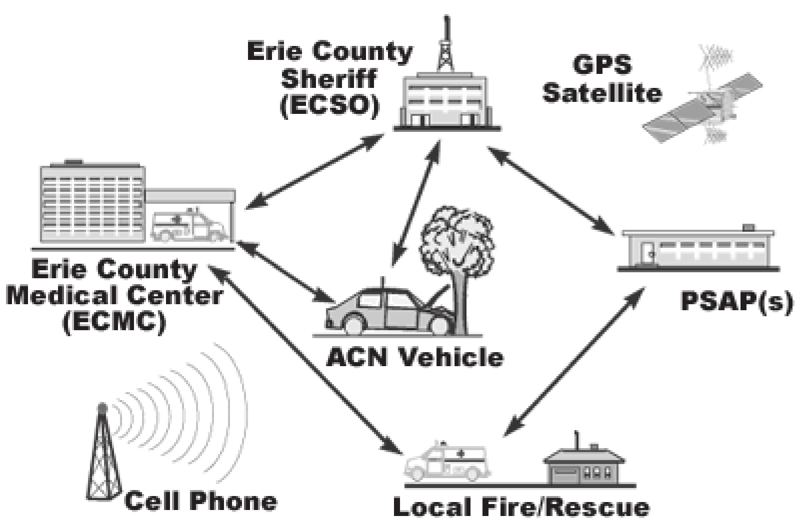
- System Design and Test - During this first phase of the project, the ACN crash sensing and communication equipment were designed and tested using lab and prototype implementations. This included the following equipment:
  - In-Vehicle Module (IVM) - Integrated crash sensors, GPS receiver, micro-processor, and cellular transceiver, which functioned to sense crashes in all directions, to determine whether the crash was severe enough to pose a risk to vehicle occupants and generate a data message that was sent via cellular phone to the 9-1-1 dispatch center. Specialized software was developed to determine when thresholds indicating the potential for injuries were exceeded.
  - Crash Event Timer (CET) - Inexpensive timers that used an inertial switch to detect when a crash had occurred and start the operation of the timer. At some time after the crash (perhaps, weeks later), investigators could access the car and read the CET to determine the elapsed time since the crash and then calculate the absolute time of the crash. CET times, together with times of post crash events obtained from 9-1-1 and Emergency Service records made it possible to calculate post-crash-event elapsed times.
  - Dispatch Equipment - PC-based system that integrated commercial off-the-shelf hardware and software with ACN message reception and display software. This equipment received emergency messages from the in-vehicle equipment, sounded an alarm, and displayed this information to 9-1-1 dispatchers for emergency response action. This equipment also forwarded the crash data to a secondary PSAP and allowed dispatchers to fax data to other PSAPs. Conference calls and forwarding of the voice portion of the call were also available as needed.
- Manufacture - This included fabrication of all ACN system hardware components including over 4,000 CETs, more than 1,000 IVMs, and three dispatch workstations.
- Test Implementation - This included all operational test planning and preparation activities such as: the development of strategies to recruit participants, preparation of recruiting materials (e.g., application forms, disclosure statements), recruiting and installation of ACN and CET equipment; installation of dispatch systems at the Erie County Sheriff’s Office and Erie County Medical Center; and definition of data collection protocols.
- Test Operations - This included managing the data collection activities associated with ACN and CET crashes, maintaining and upgrading in-vehicle equipment with the latest software releases, communicating with test participants, monitoring the ACN dispatch centers and the ACN/CET “hotline” for reports of crashes, and maintaining participant and system evaluation databases.

Other activities included organizing crash investigations, performing simulated crash tests, and coordination with local emergency service agencies.
- Evaluation - This involved evaluation of ACN performance in the operational environment. All crashes involving CETs or ACNs were investigated. Data were collected and used to reconstruct the crash, characterize the extent of injuries, and construct a timeline of emergency response actions.

A diagram presenting an overview of the ACN system operation is shown in Figure 2-1. The system was designed so that when an ACN equipped vehicle was involved in a crash, the following events occurred:

1. In-vehicle equipment sensed the crash by processing data from the unit's triaxial accelerometers,
2. The in-vehicle computer constructed a crash message containing information characterizing the crash, the vehicle location, and direction of travel prior to the crash;
3. The in-vehicle computer established control of the cell phone transceiver and initiated a call to the 9-1-1 PSAP operated by the Erie County Sheriff's Office;
4. Once the call was received the crash data was transmitted and displayed on the PSAP ACN computer;
5. Upon completion of the crash data transfer (approximately 5-10 seconds) the call was automatically switched to a voice mode and dispatchers could attempt to talk to the vehicle occupants;
6. Computers at the Sheriff's PSAP were programmed to automatically transfer the ACN crash message to the PSAP co-located in the Emergency Department at Erie County Medical Center. The most highly trained medical emergency dispatchers in the county were on staff at that location and were available to provide instructions and assistance to crash victims, should they be required. Additional details about the functioning of the ACN system are presented in the first ACN Interim Report [Benz et al., 1997].

Figure 2-1. Automated Collision Notification (ACN) Operational System Overview



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2.3 Overview of Results, Accomplishments and Findings

This section provides a brief summary of ACN program accomplishments and results. Additional information and data obtained during the program are provided elsewhere in this report. Specific accomplishments achieved during the program include the following:

- Designed, developed, built, and deployed an ACN crash detection and notification system. The ACN equipment is capable of detecting crashes including rollovers. It is vehicle independent (i.e., it can be installed in most vehicle makes and models (both new and old) and does not require connections or interfaces with any of the vehicle safety systems) and is easy to install. Of particular significance is the fact that it incorporates an algorithm that permits the system to distinguish between crashes likely to cause injuries and all other driving events. The crash detection software that was developed during this program has been awarded a U.S. Patent.
- Recruited more than 700 volunteer participants and deployed the Automated Collision Notification (ACN) System in their vehicles.
- Developed and installed equipment into two Public Safety Answering Points (PSAPs) to display incoming crash messages from ACN equipped vehicles. These systems employed Geographic Information Systems (GIS) to display crash location and provided the ability to forward emergency data and voice to secondary PSAPs using fax and landline phone. The system automatically determined the appropriate secondary PSAPs based on the crash location.
- Developed and deployed over 3,000 crash event timers (CETs) in privately owned vehicles. The CETs were used to collect baseline crash notification and response event times for crashes that occurred in the test area and involved vehicles that did not have ACN equipment. The CETs were designed to start a timer when a crash was detected. The timer was then read during post crash investigations to determine the exact crash time. Using the accurate time of the crash and other available police, EMS and 9-1-1 records, it was possible to construct accurate post crash event timelines (i.e., elapsed time from crash to 9-1-1 notification, elapsed time from crash to EMS dispatch, etc.). These event timelines were then used as a control in comparisons with ACN crash timelines.
- Coordinated the operational test during the 3-year period of ACN deployment. This effort involved overall test coordination, equipment maintenance, collection of test data, and coordination with the independent evaluator and all public and private test organizations. The activities included administration of surveys and questionnaires, and the conduct of detailed analysis and reconstruction of all crashes experienced during the test. A database was developed to service all of the collected test data and support the evaluation analysis.
- Raised public and professional awareness about ACN technology and its promise to improve the delivery of emergency services to crash victims. The project produced over 15 published papers and over 10 technical presentations at professional conferences. In addition, Good Morning America (Monday May 18, 1999), Dateline NBC (Sunday Oct 17, 1999) and the Osgood File (CBS Radio Network, May 12, 1998) broadcast stories on national networks describing the program and ACN technology. These stories resulted in numerous additional newspaper articles and local television and radio interviews and stories.

A relatively small number of personal injury crashes (i.e., 15 ACN crashes and 26 CET crashes) were experienced during the FOT. These crashes, and the experience gained during three years of field tests permit several observations to be drawn from the program, namely:

- ACN technology works. It is possible to detect crashes, characterize their location and severity; automatically generate messages with detailed crash information; and transmit the messages to PSAPs using existing cellular communications infrastructure.
- Automatic notification of crashes reduces emergency service response times. It is possible to provide quicker emergency services to crash victims by consistently providing crash notification messages, with accurate location, to PSAPs within one or two minutes of the crash. .
- PSAP personnel were able to successfully adapt to their procedures to use the ACN system to improve dispatch operations.

- Widespread deployment of ACN technology will require successful application of commercial models. ACN works when people put it in their cars. This will be achieved when ACN systems are made available through successful commercial offerings.
- Integration of commercial ACN systems with the public infrastructure (9-1-1 system, etc.) is crucial to achieving maximum ACN benefits. The ability to deliver ACN emergency data electronically to the correct PSAPs avoids time-consuming and error-prone verbal protocols in use today. Integration with PSAPs is critical to ACN success.
- Emergency service agencies participating in the program recognized that the data available from ACN systems promise to provide a wide range of benefits beyond reducing notification and response times. The potential benefits of ACN crash-related information include support for the following: decisions concerning equipment that may be needed at the crash scene (e.g., helicopter, jaws of life, multiple ambulances); preparations by EMS staff for on-scene interventions and support, triage decisions; and preparations at emergency medical and trauma care facilities for the arrival and treatment of crash victims.
- The availability of a voice connection between the PSAP and the distressed vehicle provides important advantages over data-only systems. It allows dispatchers to verify that emergency services are required and to obtain additional information that may assist in making response decisions and setting priorities.
- Knowledge of direction of travel can offer important information about emergency response execution. For example, by knowing direction of travel the fastest response route to incidents on divided highways or at overpasses can be determined.
- The conduct of large field tests provides numerous institutional, organizational and management challenges. Tasks such as the recruitment of participants, distribution and tracking of deployed equipment and correlation of subscriber records with the cellular service provider required significantly more time and energy than was anticipated at the beginning of the program.

The conclusions section of this report contains additional information and discussion on program results and observations.

While the ACN Project is complete, the work started during this project is continuing. Commercial Mayday providers are upgrading their systems and expanding their deployed base. The US DOT led National Mayday Readiness Initiative (NMRI) is working to facilitate the integration of ACN systems with the public infrastructure and 9-1-1. Standards setting bodies are developing, and building consensus for, standard communication protocols. The ultimate goal of these efforts is the widespread deployment of ACN equipment and capabilities, and integration of this technology with the national and local public safety infrastructure.

3. PROJECT DESCRIPTION AND RESULTS

3.1 IVM and CET Installation Summary

3.1.1 IVM Installations

The installation of In-Vehicle Modules (IVMs) started in June 1997 and continued through the August 2000. In August of 2000, IVM installations were terminated and the elimination of active units in the field began by remote disabling of the ACN in-vehicle system. The inactivation process occurred when an ACN unit called Veridian Engineering for its bi-monthly check-in. After deactivation the cellular telephone equipment remained functional but the ACN crash recognition components were disabled. The deactivated units have been abandoned to the participants to use as cellular telephones or to remove and dispose of as they wish. If participants request that Veridian Engineering remove the units, we have done so and disposed of the hardware.

Figure 3-1 shows the net number of IVMs installed each month during the FOT (after attrition) and the resulting total number in the field through 1 August 2000. It was originally planned to have 1000 ACN equipped vehicles in the field for one calendar year for a total of 1000 vehicle years-in-the-field. Because of difficulties involved in participant recruitment, installation, maintenance, and attrition this plan was modified. Intensive recruitment and installation efforts resulted in an active fleet of almost 700 vehicles in the field at the beginning of 1999. It can be seen in Figure 3-1 that over the last year of the FOT the active participants slowly decreased from this maximum to approximately 550 as the number of participants leaving the program exceeded the number joining the program. This occurred because active recruitment of new participants effectively stopped at the end of 1998.

Figure 3-1. Net IVM Installations/De-installations by Month (bars) and Total IVMs in Service

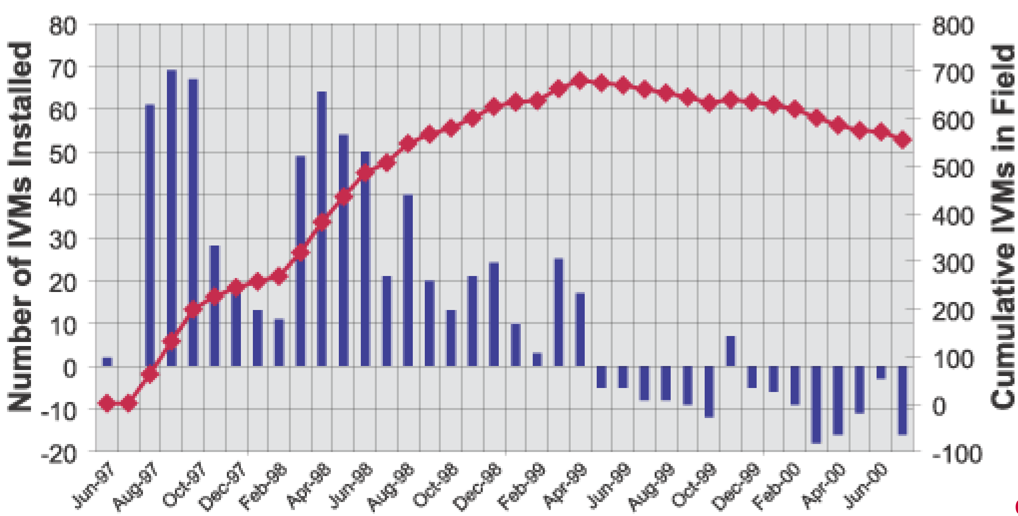

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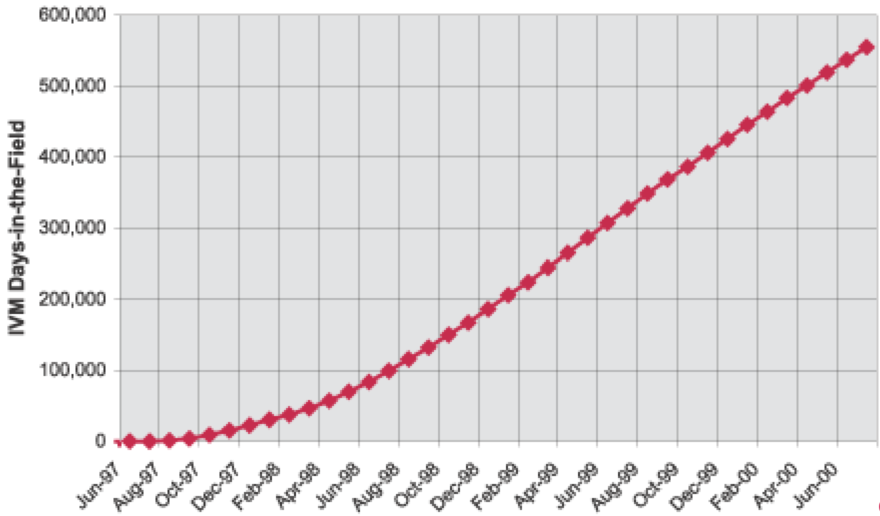
Figure 3-2 shows the cumulative number of ACN days-in-the-field for the FOT. As noted, by 1 August 2000 the program had achieved 554,855 ACN days-in-the-field, or 1520 ACN years-in-the-field. This represented an increase of about 50% over the original program goal.

Over 300 IVMs were removed from vehicles after crashes or for maintenance purposes during the duration of the FOT. They were generally replaced with a new ACN in-vehicle module. Some of these units were defective, some required repair, and others needed a thorough checkout to determine their suitability for reuse. There were sufficient IVM units fabricated so that none of the units removed from service were needed for reinstallation.

Figure 3-2. IVM Days-in-the-Field



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3.1.2 CET Installations

The installation of Crash Event Timers (CETs) started slowly in July 1996 and ramped up to a relatively high installation rate during 1997. At the end of 1997, 2,570 CETs were installed and registered (i.e., paperwork returned and installation recorded in the CET participant database). Since 1997, CET installation continued at a slower pace. By the end of the program, 3,316 CETs had been installed. That number included 347 that were assumed installed but for which paperwork was not returned. These were CETs for which the installing agency: (1) provided verbal confirmation of the installations but was not able to provide installation documentation and (2) had a sufficiently successful record of CET installation that their claim was judged to have credibility.

Over 700 CETs were issued to organizations and were not installed or were returned to Veridian Engineering. Most of these are believed to have been lost.

The number of CETs in service and the monthly installation and de-installation of CETs over the program is depicted in Figure 3-3. Figure 3-4 shows the cumulative CET days-in-the-field. Figures 3-3 and 3-4 are both based on data from the participant database and do not include CETs that were assumed to be installed and does not include those that left the program without notifying us.

Figure 3-3. Net CET Installations/De-installations by Month (bars) and Total CETs in Service

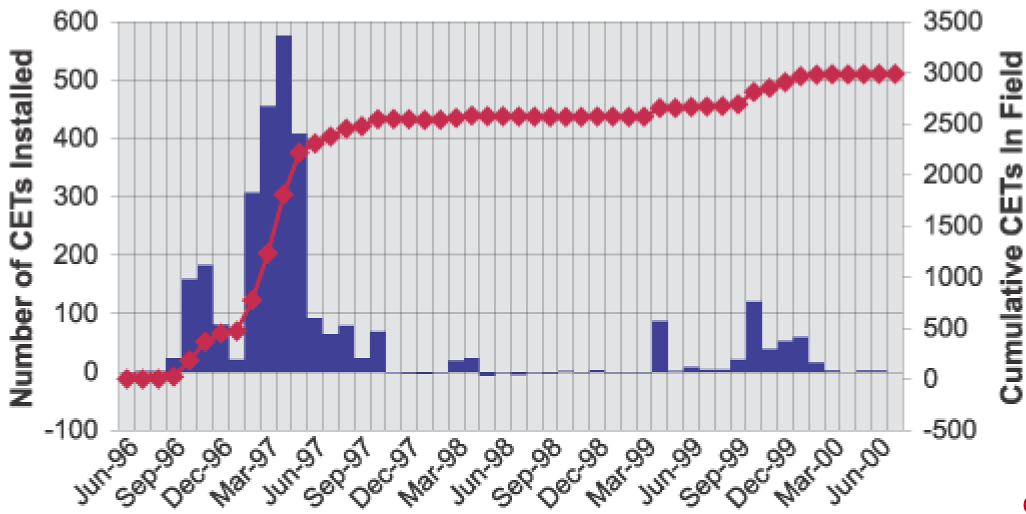

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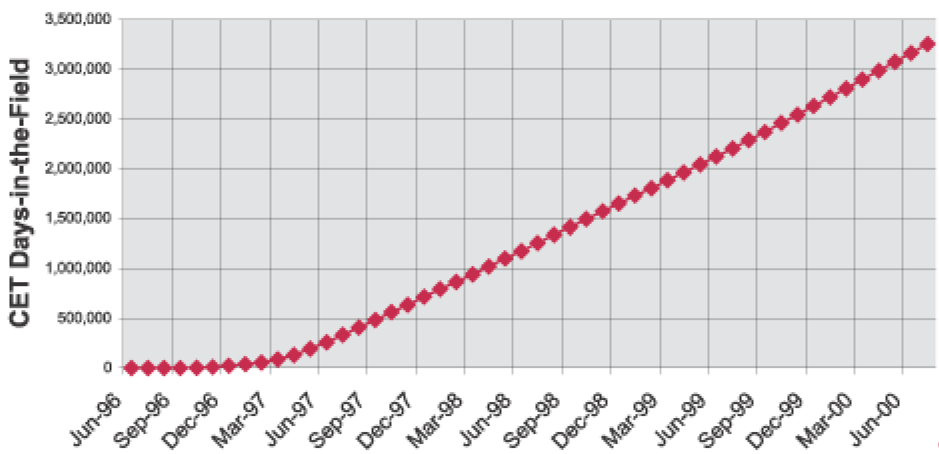
Figure 3-4. CET Days-in-the-Field



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The exact number of CETs actively involved in the test was always uncertain because it was not possible to account for participants who moved or sold their vehicles. A sample of CET participants were surveyed in the summer of 1999 to obtain an estimate of the percentage that had either left the test area or sold their vehicles. Table 3-1 summarizes the results of this CET participant survey. If these results were representative of the full CET fleet, the active CET test sample as of September 1999 should be discounted by about 30%.

Table 3-1. Results of CET Participant Survey

	Number	Percent
Attempted to Contact Survey	**97**	**100%**
Total Surveyed	46	47%
Total Surveyed	**46**	**100%**
Remembered the CET Program	42	91%

Vehicle still in Western NY	33	72%
Still owned the vehicle	31	67%
Knew the CET was attached	30	65%
Knew the window sticker was attached	30	65%
Involved in Crash	7	15%
Involved in Crash	**7**	**100%**
Did not report crash to Veridian Engineering	3	43%
Did not report crash to Veridian Engineering	**3**	**100%**
Forgot to report	2	67%
Tried to report but found voicemail confusing	1	33%
Unaware it was their responsibility	0	0%
Assumed someone else would report it	0	0%

3.2 Participant Outreach

The success of the ACN test depended on the continued support and motivation of the test participants/volunteers. In order to keep participants motivated, and to remind them of their commitment to the test, we periodically issued Newsletters. These were sent to all ACN and CET participants. They served several purposes. First, they thanked participants for their participation and continued support of the program. Second, they provided a summary of the results of the program, citing example crashes and a summary of the total numbers of crashes. By providing a summary of test results, it was hoped that participants' motivation and interest in the program would be maintained at a high level. Third, the newsletters provided participants with important information about the program (e.g., test extensions) and reminded them about their responsibilities (e.g., to call the ACN 1-800 number to report crashes or problems). Finally, the newsletters served as a mechanism for continued solicitation of additional applications for participation. Appendix A includes the ACN and CET newsletters sent to all participants. These newsletters are reproduced in Appendix A.

3.3 ACN and CET Crashes

Table 3-2 summarizes the overall ACN and CET installations and crash investigations during the project. This summary includes the number of units installed and the number of above and below threshold crashes experienced.

Table 3-2. Summary of ACN and CET Installations and Crashes

Recruiting and Installation	ACN	CET
Total Installed During Program	874	3,316
Peak Base Installed at Single Point in Time	680	N/A
Days-in-Field (rounded)	555,000	3,254,000
Operational Test	**ACN**	**CET**
Total Crashes	70	76
Below-Threshold Crashes	48	40
Above-Threshold Crashes	22	36
Not Notified (False Negative)	5	5
Not Investigated*	2	5
Investigated	15	26
Crashes with Injury	9	16
Crashes with EMS Response	8	15
Crashes with EMS Transport	8	8
Occupants in Crashes	51	69
Occupants with Injury	17	24
Maximum AIS in Crashes	3	2
Min. Notification (rounded)	0 min.	0 min.
Max. Notification (rounded)	2 min.	46 min.
Out of Study Area	2	5
Delayed Notification	7	7
False Notifications (# of ACN units)	**31**	**N/A**

*Crashes that were not investigated include: one ACN and two CET crashes that occurred significantly outside of the study area, one CET crash in which the CET was missing from the vehicle, one CET crash with delayed notification (the timer had already reset) and one CET crash that was not police-reported. One ACN crash could not be fully investigated because the participant would not cooperate with the investigation.

As noted in Table 3.2, a total of seventy ACN crashes occurred over the duration of the program; twenty-two of these were above threshold crashes of which five did not call the Sheriff (see Section 2.5 for a discussion of false negative crashes). Two crashes were not investigated and forty-eight were below the crash detection threshold.

A total of seventy-six CET crashes occurred over the duration of program. Thirty-six of these were above the crash detection threshold. Of these there were five crashes in which we never received notification and five crashes that were not investigated because they occurred out of the test region. Forty crashes were below the crash recognition threshold leaving twenty-six CET crashes for which a full investigation was performed.

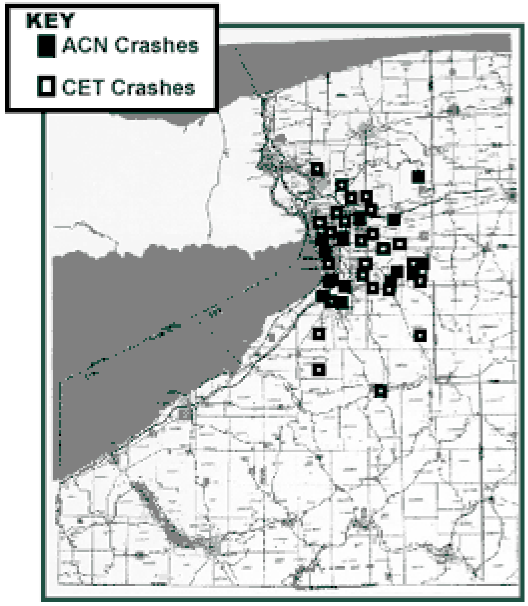
A summary of ACN and CET crash totals is presented in Table 3-3.

Table 3-3. Number of Crashes

	ACN	CET
Total Crashes	70	76
Below Threshold	48	40
Above Threshold	22	36
Not Notified	5	5
Not Investigated	2	5
Full Investigation	15	26

A map of the locations of all of the ACN and CET crashes is shown in Figure 3-5.

Figure 3-5. Locations of ACN and CET Crashes Experienced During the FOT

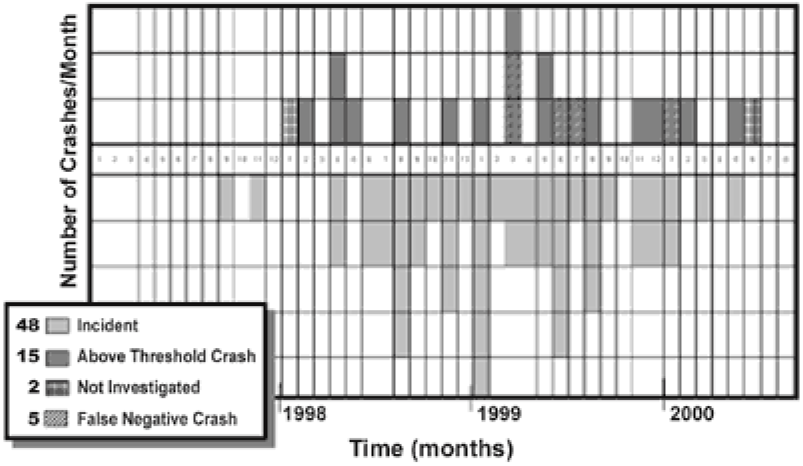


3.3.1 ACN Crashes

Figure 3-6 shows the temporal distribution of ACN crashes during the ACN FOT. It graphically shows crashes according to the following definitions:

- Crashes - Crashes that were above the threshold for alerting Sheriff dispatchers and that were correctly and successfully reported by the ACN System. The ACN crash threshold was designed to make an emergency call for crashes likely to produce AIS greater than or equal to 1 injuries.
- Incidents - Crashes (manually reported) that were below threshold (e.g., fender benders) for which the ACN System correctly did not send an automatic crash notification.
- Not investigated - One crash that occurred far outside the ACN test area and was not investigated. Also one crash in which the driver of the ACN vehicle (a young adult whose parent had volunteered to be a participant) would not cooperate with investigators and the crash was not investigated.
- False negatives - Crashes that were above threshold (as determined by post crash reconstruction) but for which Central Dispatch was not automatically notified by our system (a missed crash). This includes cases where there was no cellular coverage and where the IVM apparently was damaged during the crash.

Figure 3-6. Occurrence of ACN Incidents and Crashes



A total of 874 vehicles had ACN equipment installed for some period of time over the duration of the program. The total number of ACN vehicle days-in-the-field was 554,855, or 1,520 vehicle years-in-the-field, through the end of July 2000.

If the total number of crashes experienced in the ACN program is divided by the number of ACN vehicle years-in-the-field, a crash rate of 0.046 is obtained. If the number of above threshold crashes is divided by the years-in-the-field an above-threshold crash rate of 0.015 is obtained. In 1997 the national crash rate was 0.063 and the national crash rate with injury was 0.022 [NHTSA 1998]. The lower than average crash and injury rates experienced in the program may be a result of the fact that ACN participants were volunteers and concerned about crash safety and therefore were safer drivers than average or it may be that people who are able to pass the CellularOne (now Cingular) credit check are generally more responsible individuals and safer drivers. In any case, the ACN crash rates are somewhat lower than the national crash rates.

In addition to the crashes and incidents shown in Figure 3-6, there have been thirty-one systems that have produced false positive alarms. These are vehicles that sent a crash notification when, in fact there was no crash. False positive alarms have been due to accelerometer failures -- a failure of the accelerometer itself or an improperly installed accelerometer that indicated a high acceleration and when there was an unstable or intermittent power supply (e.g., when participants attempted to "jump-start" their vehicles). The causes of these faulty accelerometer outputs and ways to prevent them have been identified. False positive alarms are discussed in more detail in Section 3.4 along with false negative crashes.

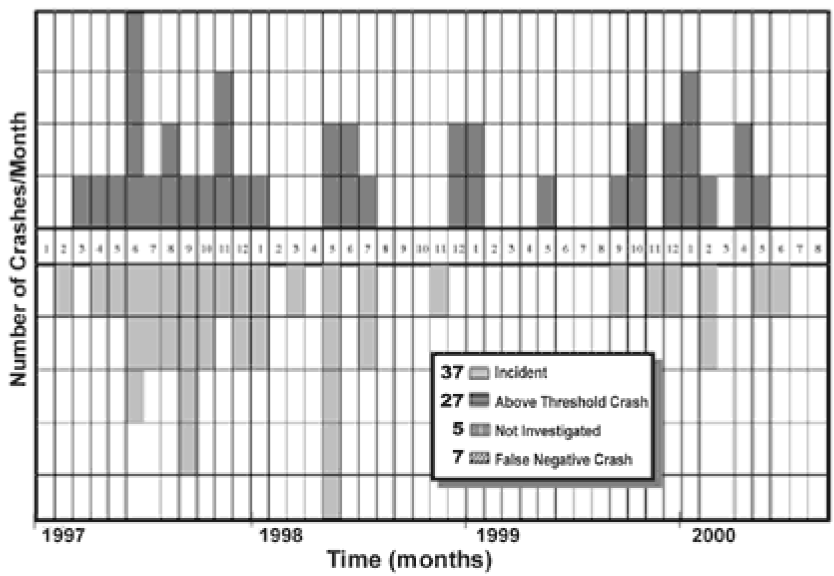
3.3.2 CET Crashes

Figure 3-7 shows the temporal distribution of CET crashes since the beginning of the ACN FOT. It graphically shows crashes in the following categories: ·

- Crashes - Crashes that were above the threshold for initiating the timer. The CET crash threshold was approximately 12 kph in any direction.
- Incidents - Crashes that were below the crash threshold (e.g., fender benders) for initiating the timer.
- Not Investigated - Crashes that occurred outside the CET test area or were not investigated for some other reason, i.e., the CET was missing or notification was received too late to calculate the crash time.
- False negatives - Crashes that were above threshold (as determined by post crash reconstruction)

but for which the CET was not functioning and did not initiate timing.

Figure 3-7. Occurrence of CET Incidents and Crashes



During the three and a half years during which CETs were in the field, a total of thirty-nine above-threshold crashes were reported. Of these crashes, seven did not have a functioning CET onboard and the time of the crash could not be calculated, five were not investigated because notice of the crash was not received until after the CET had reset (i.e., more than three weeks). An additional thirty-seven crashes that were below the CET crash threshold were reported. A total of 3,044 CETs were installed in vehicles over the duration of the ACN program. A total of 3,254,159 days-in-the-field, or 8,916 years-in-the-field, were accumulated for the CETs through July 2000. If the total number of crashes experienced in the CET program is divided by the number of CET vehicle years-in-the-field, a crash rate of 0.0085 is obtained. If the number of above threshold crashes is divided by the years-in-the-field, an above-threshold crash rate of 0.0038 is obtained. As mentioned above, in 1997 the national crash rate was 0.063 and the national crash rate with injury was 0.022 [NHTSA 1998]. The ACN crash rate was 0.046 and the above threshold crash rate was 0.015. The CET crash rates were far below the national rates and far below the ACN crash rates.

Original estimates of crash frequency had indicated that with 3,000 CETs in the field, approximately ninety crashes per year could be expected. Our best explanation for the difference between actual and expected crash rates was that the drivers and the police were not reporting CET crashes to Veridian Engineering when they occurred. In order to verify this assumption, a list of the license plate numbers for every vehicle enrolled in the CET program was sent to the State of New York Department of Motor Vehicles where the list was cross-referenced with the license plate numbers of every crash that had occurred in New York State during the program period. The results supported the explanation: 146 CET vehicles had been involved in a crash in New York State during the program period. Of these 146 crashes, 91 involved personal injury and 55 involved property damage only. Because we did not receive the expected notifications, the CET program was unable to collect data to reconstruct emergency response timelines for 91 injury-producing cases.

In an attempt to correct this problem, a pro-active crash identification policy was implemented. Under this policy, Veridian personnel contacted all local, county and state police jurisdictions in Western New York at least once every two weeks and collected a list of the license plate numbers of all vehicles involved in crashes. This contact was by telephone or fax, or in some cases a personal visit was made to the police station: whatever methodology best suited each local police department. Veridian personnel actively created a list of license plate numbers for all crashes, which was cross-referenced with the license plate numbers of CET (and ACN) program participants. In this way all CET (and ACN) crashes that occurred in the program test area were identified. The participants and the local police were then contacted by telephone and if there was an emergency response of any kind, the crash was investigated and a response timeline was constructed. Because the CET resets the internal crash timer three weeks after a crash has occurred, this process had to take place within that three week time period. This active and aggressive crash identification process was pursued for approximately four months.

After four months, only four above threshold and four below threshold CET crashes were identified (see Figure 3-7). There were several potential reasons for the low crash rates that were observed. First, the City of Buffalo Police Department did not fully cooperate with the crash data collection effort (they wished to be paid for police reports), which meant many crashes were not being identified. It should be noted that the City of Buffalo would have accounted for approximately 40% of the total number of crashes in Erie County, New York. However, the identified total number of crashes is far too small even considering that the City was not included. It can only be assumed that many CET vehicles had been removed from the fleet in Western New York over the three and a half year duration of the program or that CET vehicles were not involved in crashes for some reason. It should be noted that the CET participant recruitment methodology was to utilize civic organizations in rural and suburban areas to install CETs into vehicles, which may also have been a factor in this failure to identify CET crashes. The active collection of police reports and license plate numbers was terminated after four months due to the expense of the program and the failure to produce the desired result.

3.4 ACN False Positive Alarms and False Negative Crashes

3.4.1 False Positive Alarms

False alarms are produced by an accelerometer (or accelerometers) indicating an above threshold crash when one did not occur. One cause of these faulty accelerometer outputs was hardware related. When an accelerometer is not properly mounted parallel to the board surface, it can contact the board causing a ground short which creates an acceleration spike. The addition of a spacer between the accelerometers and the board that would prevent this contact is a possible design solution. Thirteen of the thirty-one units that caused false alarms did so as a result of ground shorts due to poor accelerometer installations. Another cause of false alarms is unstable or intermittent power supplied to the in-vehicle system. Examples of unstable power that were experienced include: jump-starting a vehicle's dead battery; intermittent contact between a loose wire or cable and the vehicle's engine or body; ignition shut-off that does not cause the vehicle's voltage to drop immediately to zero but instead drops slowly and confuses the IVM; and one case in which the in-vehicle system became submerged in water when the vehicle's windows were left open during a rain storm.

The false alarms caused by grounding of accelerometers were eliminated through a software upgrade (version 1.3). The upgraded IVM software recognized unrealistic spikes in acceleration and did not report a crash. For the case where the vehicle's voltage is low and unstable after the ignition is switched off, a relay was installed that immediately cut the voltage to the in-vehicle system when the vehicle was turned off. The false alarm rate was reduced significantly as the number of ACN vehicles in the field with the new software increased. It was not possible to upgrade every system in the field. Software upgrades were implemented in those units that generated a false alarm and in any other units that were conveniently available. A notice offering the software upgrade to participants was included in the ACN newsletter (see Appendix A) and many participants brought their vehicles to Veridian Engineering to receive the upgrade. The status of the software upgrade installations is given in Section 3.6.

3.4.2 False Negative Crashes

There were five false negative ACN crashes. False negative crashes are defined as those crashes that should have been recognized by the ACN in-vehicle module and for which a crash call should have been made to the Erie County Sheriff. In these false negative cases, the system did not operate properly and notification of the crash was not received at the Sheriff's dispatch center. The five false negative cases were: No. 1346 on March 3, 1999; No. 1289 on March 22, 1999; No. 1632 on June 18, 1999; No. 1323 on July 4, 1999, and No. 1408 on January 13, 2000. These false negatives fall into two categories: (1) the crash was detected but the call was not received; and (2) the crash was not detected.

Four of the 5 false negatives fall into the first category, crash detected by the in-vehicle ACN system, but call not received. The reasons for this were: (1) poor cellular coverage so that the call could not go through; (2) ACN modem at the Sheriff's Office was inadvertently disconnected; (3) ACN back-up battery failure when vehicle power was lost due to the crash (crash detected but call could not be made); and (4) equipment was damaged during the crash (crash detected but call could not be made).

One false negative was in the not detected category. Although this crash was carefully analyzed, the cause of this failure was not determined.

During the program a great deal of attention was devoted to understanding the reasons for the false negative crashes. The causes for four of the five false negative crashes that occurred were determined (as described above) and steps were taken, when possible, to avoid additional occurrences of these problems. The other case, No. 1346, is not understood and will likely remain a mystery. Each of these cases is discussed below.

ACN False Negative Crash No. 1346

This ACN crash occurred in the winter and resulted from one, or both, of the involved vehicles crossing the center line and impacting each other on their left front side structures in an angled frontal-side impact. The ACN failed to call the dispatch center and the husband of the injured driver/occupant of the ACN vehicle informed Veridian about the crash several days after the crash. Veridian personnel retrieved the ACN hardware from the crashed vehicle. The ACN was packed in heavy snow because the roof had been removed to extract the injured driver and it had snowed during the time following the crash. The retrieved ACN was not working when it was tested in the laboratory. After drying out the hardware in the laboratory, it began working again; however, there were no data in the permanent ACN memory. Since the ACN unit was extremely wet when retrieved, it was not considered surprising that the memory was blank. It is not known if the ACN recognized the crash and recorded the crash data, which was subsequently erased due to the wet conditions and short circuiting of the power, or if the data was never recorded. The crash was clearly of sufficient severity that it should have been recognized by the ACN. The cellular coverage at the site of the crash was acceptable and a cellular call should have been possible. The crash intrusion did damage the fuse panel and may have interfered with ACN power; however, it is felt that by the time the fuse box was damaged the crash recognition should have been in progress and the back-up battery should have provided power. At this time, no explanation is available for this false negative case.

ACN False Negative Crash No. 1289

This false negative ACN crash occurred on a foggy, snowy evening on a rural expressway during the rush hour commute. The ACN vehicle driver failed to see the vehicle in front of him stop and impacted that vehicle in the rear. The ACN vehicle was then struck in the rear twice more as vehicles behind the ACN vehicle also failed to stop. A total of sixteen vehicles were involved in this chain reaction crash. The ACN system's back-up battery was found to have corroded terminals and the battery was not providing power to the system. At the time of the crash, the ACN vehicle was using lights, heater, defroster and rear window defroster. After the crash the vehicle was turned off and it is felt that the power provided by the vehicle battery, under heavy load from the accessories being used, dropped to less than 11 volts. Since the back-up battery was not available, there was insufficient voltage to place a cellular call. The ACN unit recognized the crash and the acceleration time history was stored in memory. Modified software was subsequently incorporated into the ACN transceiver that will allow calls to be made with voltage as low as 9 volts. It was felt that this design modification would eliminate this type of false negative problem in the future.

ACN False Negative Crash No. 1632

This false negative ACN crash occurred in a rural village in a remote southeast area of Erie County, New York. The ACN unit recognized the crash and crash data was stored in the permanent memory. The cellular coverage at the location of the crash was extremely poor - almost not existent - and the cellular call to the Sheriff's dispatch center could not be completed. This type of false negative is unavoidable but will become less likely as cellular coverage improves.

ACN False Negative Crash No. 1323

This ACN false negative crash occurred when the ACN vehicle was impacted in the right side at high speed by another vehicle. The delta V of the crash was approximately 50 kph and intrusion into the ACN vehicle was massive (approximately 100 cm). The ACN hardware was impacted by the intruding side structure of the vehicle and the power line to the transceiver was short-circuited. The ACN recognized the crash and the data was stored in permanent memory and was later retrieved for analysis. This type of ACN false negative is difficult to avoid and can only be prevented by locating the ACN in areas that are not likely to be impacted and by "ruggedizing" the hardware to withstand severe crashes.

ACN False Negative Crash No. 1408

This ACN false negative crash when the ACN vehicle lost control and ran off of the road in snowy and icy conditions. The vehicle entered a ditch on the left side of the road and impacted the side of the ditch with the driver's side of the vehicle. The IVM memory recorded a nine o'clock impact with a change of velocity of 19 kph, which was sufficient to trigger an emergency message call. For an unknown reason the modem cable for the ACN system server at the Sheriff's office was disconnected and the call could not be received. Since the server could not receive the call, it could not route the call to the Sheriff's dispatcher or to the MERS dispatcher. Subsequent inspection of the system discovered the disconnected cable. Undisturbed dust on the cable, the cable connector and the server back plane indicated that no person had disconnected the cable and that it was probably accidental. After connecting the modem cable the system began working normally.

3.5 ACN Reliability

Of the twenty above-threshold ACN crashes that occurred in this field operational test, nineteen were correctly recognized, correctly processed, and an attempt was made to call the Erie County Sheriff's Dispatch Center. Although only fifteen of those calls were received at the dispatch center, the in-vehicle module (IVM) performed its design function correctly nineteen out of twenty times. The five calls that were not received, the false negative cases, were discussed previously in Section 3.4.2. Four of the five false negative cases had acceleration data in memory and attempted to call the Dispatch Center. ACN

1346 is the false negative case for which there is no explanation as to why the system did not function and it is not known whether the system attempted to call or not. Of the forty-nine below-threshold ACN crashes, the ACN recognized that the crash was not sufficiently severe to call the Dispatch Center and did not call. The IVM was reliable in the sense that it recognized crashes correctly, processed the data correctly, and attempted to place a call to the Dispatch Center when appropriate. The IVM reliability is summarized in Table 3-4.

Table 3-4. ACN In-Vehicle Module Reliability

	Above Threshold Crashes	Below Threshold Crashes
Crash Detected	19	0
Crash Not Detected	1 (?)	49

The ACN system includes the IVM and the Gateway call receiving stations at the Erie County Sheriff's Dispatch Center and at the Mobile Emergency Radio System (MERS) at the Erie County Medical Center. The reliability of the total ACN system includes the entire crash notification process: recognizing a crash, processing the data correctly, and completing an emergency call to the Dispatch Centers. The ACN system failed to complete an emergency call five times as discussed previously in Section 3.2.4. In addition to these false negative cases, there were thirty-one units that called the Dispatch Center when there was no reason to do so, i.e., false positive calls. As discussed previously these calls were due to ground faults and voltage control problems. These thirty-one false positive, or false alarm, units were a small portion of the 874 units that were in the field over the duration of the ACN Field Operational Test and they should not be compared, in quantity, to the relatively small number of ACN crashes. ACN system reliability is summarized in Table 3-5, below.

Table 3-5. ACN System Reliability

	Above Threshold Crashes	Below Threshold Crashes	Non-Crash Events
Call Received	15	0	31*
Call Not Received	5	49	N/A

*30 out of 874 Units in the field. These hardware problems would be eliminated in production version.

3.6 System Maintenance and Upgrades

This section summarizes the ACN System maintenance activities that were performed throughout the operational test. The largest part of this effort was maintaining the in-vehicle equipment with the dispatcher equipment requiring only occasional maintenance. This section summarizes the maintenance activities.

The maintenance of the in-vehicle ACN units was very labor intensive. It involved:

- Responding to questions and requests for maintenance from participants (this frequently included questions about cellular phone bills and other issues unrelated to ACN equipment operation).
- Identifying units that were not performing their scheduled self-test calls and following up to diagnose the problem and initiate repair actions as needed.
- Scheduling and confirming appointments with participants for field service.
- Traveling to participants' residences to repair in-vehicle equipment. This included inspection of equipment for loose wires and obvious damage, working with the participants to understand all symptoms, and replacing equipment components as needed. This sometimes involved removal and replacement of the IVM, transceiver, handset, wiring, or back-up battery.
- Troubleshooting removed equipment to determine the cause of problems that were not readily identified in the field.
- Completing maintenance paperwork for logging and tracking maintenance status and updating the maintenance database.

During the program, 115 of the problems were reported for maintenance. Service was performed on all but two of the 115 ACN units. The other two units were reported to produce false alarms that were caused by jump-starting the vehicle. These units were not permanently affected and required no additional maintenance. In almost all cases a Veridian ACN technician performed the service. Ninety-two components were replaced during service. Many of the components that were removed did not have a confirmed defect but were replaced for expediency, allowing the removed unit to be inspected at a later time. The 113 ACN units that were serviced are categorized by maintenance area in Table 3-6. A description of each category follows.

Table 3-6. Maintenance Categories

Maintenance Area	Units Serviced
Accelerometers	16
Back-up Battery	1
Flash Memory	1
GPS	8
Handset	5
IVM	32
Power Cable	7
RCU	7
Transceiver	15
Other	23

The following section describes ACN system problem areas and the criteria used to classify problems as either defective or failed components or as installation and environmental problems.

Accelerometers

Accelerometer errors were sometimes reported via self-test call status (Error 01(X), 02(Y), 04(Z)). Most accelerometer errors resulted in the erroneous initiation of an emergency call to the Sheriff's office resulting in a false alarm (false positive).

Backup battery

Most battery problems resulted from harsh environments and were discovered during physical examination of an ACN system. Corroded terminals caused by inadequate ventilation or pooling of moisture were found to prevent the battery from charging correctly. Occasionally the chemicals within the battery had begun to sulfate, an operational defect, which renders the battery dead and irreparable.

Flash memory

Flash memory failures were reported in self-test calls. If the memory failed, the self-test would report an "Error020" or the self-test call would be overdue.

GPS

Most participants did not check the handset for a GPS icon when they used the vehicle or the telephone; therefore, most reports of GPS system problems were generated by self-test calls. A self-test call would either report a GPS error or the self-test call would be late because the ACN system uses GPS to regulate its internal clock. A few verbal reports were received from participants who noticed that the handset was displaying "Error08."

Handset

The handset was used by the driver for making calls; therefore, all handset problems were easily detected and reported by the participant. Most handset problems were due to a malfunction or abuse. Common handset malfunctions included faint or absent start-up tones, scratchy sound quality from the speaker, absence (failure) of the hands-free operation feature, loss of backlighting on the display, or the loss of the LCD display. There were also a few problems, such as pinched cables, resulting from incorrect installation.

Power cable

Malfunctions of the power cable would cause the power to the IVM to fail completely or to become intermittent. These problems were most commonly reported by the participant, but were also found by reviewing the self-test call log (the system might call in late or not at all). Power cables could be pinched and damaged during installation or the main power wires to the vehicle could be incorrectly installed. Power cable problems, such as a pinched cable or a broken thumbscrew on the IVM D-connector, could also be a result of accidental damage or abuse.

Reference Correction Unit (RCU)

The RCU was designed to electronically account for the IVM alignment within the vehicle. During the ACN installation process it was used to generate a coordinate reference matrix that was downloaded into the IVM. This allowed the measured accelerations to be correctly translated into the principal axes of the vehicle. The in-vehicle module would report an “Error 040” if the transformation matrix generated by the RCU was absent or corrupted. All reports of this error were via self-test call because participants were unaware of the existence of the transformation matrix.

Transceiver

Most transceiver problems were discovered from the biweekly self-test call made by each IVM to Veridian Engineering or from participant telephone calls. Faulty transceivers could cause self-test calls to be intermittent and overdue or could be reported as errors reported in the self-test call data. A faulty but operational transceiver could report an internal error (error 10) at the conclusion of a self-test call. On occasion, participants called Veridian Engineering to report dropped cellular telephone calls indicating a transceiver problem. Almost all transceiver problems were caused by internal transceiver malfunctions. Only a small number of transceiver problems were found to be due to an external problem such as disconnected power supplies.

Other

Other miscellaneous problems occurred and are briefly listed below.

- Phone stays on after key is turned off
- Erratic IVM operation due to improper wiring during installation
- Antenna cable was damaged during installation
- Handset cable was damaged during installation resulting in erratic handset operation
- Erratic IVM operation due to a poor ground connection
- The system would not call in because it was removed without informing Veridian
- Antenna was not replaced when a broken window was replaced
- IVM would not boot due to internal hardware or software problems

In addition to conducting maintenance on ACN units in response to problem indications, software upgrades were being performed on all IVMs. Table 3-7 shows all IVM software releases with a description of the changes implemented in each.

Table 3-7. IVM Software Releases

Software Version	Description
1.0	Initial release
1.1	This upgrade was required due to a change in IVM hardware (new modem chip). The software was not applied to correct bugs and was only applied to units in stock.
1.2	This upgrade fixed a mathematical error related to the RCU transformation matrix; the error could have potentially effected principal direction of force (PDOF) calculations. This upgrade corrected a false indication of a GPS error. The error was appearing on the display of some participant’s handsets as “SYSTEM

	ERROR 08" even though there was no actual error. This software upgrade also limited the length of time a cellular self-test call could remain connected to ten minutes. This was done in response to some large cellular charges incurred by participants whose units made self-test calls while in roam mode. This was a temporary solution until the problem was further researched.
1.3	This upgrade prevented cellular self-test calls while in roam mode. The ten-minute call time limit allowed by version 1.2 was still enabling participants to incur expensive cellular bills. The problem was identified as an incompatibility with older equipment used by some cellular providers outside of the local area. The cellular phones were not receiving the signal to disconnect. This caused phones to remain connected to these cellular sites and accrue roaming charges. This was only a problem with data calls (i.e., self-test calls), not voice calls. This upgrade also enhanced the reliability of receiving crash calls in areas with older cellular technology. This upgraded software version recognized unrealistic accelerations and filtered these occurrences to prevent false alarm messages from being sent (See Section 3.4.1). This upgrade made several enhancements to the handset's display making it more user-friendly and easier to read.

During the program, participants who required an IVM software upgrade or needed their equipment serviced were offered a $5 certificate for groceries at a local supermarket as incentive to bring their vehicle to Veridian for service. This saved about $25 in labor and expenses otherwise required for travel, and was viewed very positively by the participants.

4. ANALYSIS AND EVALUATION

4.1 ACN Crashes: Reported and Reconstructed Data

Each ACN crash was fully investigated by Veridian Crash Investigators. The crash was reconstructed to develop an independent measure of the crash characteristics (i.e., Principal Direction of Force (PDOF), delta Velocity, Final Rest Position and Rollover) and location accuracy (i.e., Latitude/Longitude and Heading). Emergency notification and response timelines were also constructed and documented. Complete sets of descriptive data for all above threshold ACN and CET crashes are presented in Appendix B.

In addition to the collection of this data, a comparison between the ACN-derived crash data and the reconstructed crash data is presented in Table 4-1.

As can be seen in Table 4-1, there was generally good agreement between the ACN derived crash characteristics and those determined independently by Veridian Crash Investigators. A more complete discussion of each of the crashes is presented in Section 4.3.

Table 4-1. Comparison of ACN Reported Crash Parameters with those Derived by the Crash Investigator

- **ACN ID #:** 1129
- **Date:** 1/3/98
- **Time:** 7:55p
- **Location:** Urban area (outside of test area) in a 4-way intersection (ACN failed to call-in)
- **Crash Description:** ACN vehicle impacted the principal other vehicle in the left side at 90 degrees
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 12 o'clock, Reconstruction: 1 o'clock
  - **delta V -** ACN: 19.9 kph, Reconstruction: <24 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: N/A, Reconstruction: Normal
  - **Latitude -** ACN: Unknown, Reconstruction: Unknown
  - **Longitude -** ACN: Unknown, Reconstruction: Unknown
  - **Heading -** ACN: Unknown, Reconstruction: Unknown

- **ACN ID #:** 1104
- **Date:** 2/18/98
- **Time:** 1:49p
- **Location:** Urban area in a four-way intersection
- **Crash Description:** ACN vehicle turned into path of an oncoming vehicle
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 2 o'clock, Reconstruction: 2 o'clock
  - **delta V -** ACN: 22.5 kph, Reconstruction: 17.2 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: N/A, Reconstruction: Normal
  - **Latitude -** ACN: 42.90566 degree, Reconstruction: 42.90472 degree
  - **Longitude -** ACN: 78.86873 degree, Reconstruction: 78.86855 degree
  - **Heading -** ACN: 194 degree, Reconstruction: 120 degree

- **ACN ID #:** 1239
- **Date:** 4/4/98
- **Time:** 3:21a
- **Location:** Rural village area on a curving road
- **Crash Description:** ACN vehicle ran off the road to the right, hit a utility pole guy wire and tipped over onto the right side
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 3 o'clock, Reconstruction: 3 o'clock
  - **delta V -** ACN: 12.9 kph, Reconstruction: 9-15 kph
  - **Rollover -** ACN: No, Reconstruction: Yes
  - **Final Rest -** ACN: N/A, Reconstruction: Right Side
  - **Latitude -** ACN: 42.79156 degree, Reconstruction: 42.79165 degree
  - **Longitude -** ACN: 78.55404 degree, Reconstruction: 78.55453 degree
  - **Heading -** ACN: 200 degree, Reconstruction: 200 degree

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- **ACN ID #:** 1046
- **Date:** 4/15/98
- **Time:** 5:41a
- **Location:** Rural unpopulated area on a two-lane road
- **Crash Description:** ACN vehicle ran off of road to the right and hit a tree stump
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 12 o'clock, Reconstruction: 12 o'clock
  - **delta V -** ACN: 30.6 kph, Reconstruction: 26 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: N/A, Reconstruction: Normal
  - **Latitude -** ACN: 42.69661 degree, Reconstruction: 42.69538 degree
  - **Longitude -** ACN: 78.62294 degree, Reconstruction: 78.62345 degree
  - **Heading -** ACN: 172 degree, Reconstruction: 160 degree

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- **ACN ID #:** 1109
- **Date:** 5/8/98
- **Time:** 7:48a
- **Location:** Urban area at an intersection
- **Crash Description:** ACN vehicle was waiting at a red light and was impacted from behind and pushed into the vehicle in front
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 6 o'clock , Reconstruction: 6 o'clock/12 o'clock
  - **delta V -** ACN: 29.0 kph, Reconstruction: 30.1 kph / 12.9-16.1 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: N/A, Reconstruction: Normal
  - **Latitude -** ACN: 42.87411 degree, Reconstruction: 42.87372 degree
  - **Longitude -** ACN: 78.84379 degree, Reconstruction: 78.84345 degree
  - **Heading -** ACN: not moving, Reconstruction: not moving

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- **ACN ID #:** 1254
- **Date:** 8/31/98
- **Time:** 6:47p
- **Location:** Suburban area on a residential street
- **Crash Description:** ACN vehicle turned left into path of an oncoming vehicle
- Rollover No Final Rest Latitude Longitude Heading

- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 12 o'clock, Reconstruction: 11-12 o'clock
  - **delta V -** ACN: 16.1 kph, Reconstruction: 18.6 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: N/A, Reconstruction: Normal
  - **Latitude -** ACN: 42.71766 degree, Reconstruction: 42.71755 degree
  - **Longitude -** ACN: 78.82840 degree, Reconstruction: 78.82845 degree
  - **Heading -** ACN: 99 degree, Reconstruction: East

- **ACN ID #:** 1463
- **Date:** 11/15/98
- **Time:** 3:19p
- **Location:** Urban area (outside of test area) at a four-way intersection
- **Crash Description:** ACN vehicle was struck in the right front by the principal other vehicle
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 3 o'clock, Reconstruction: 2 o'clock
  - **delta V -** ACN: 22.5 kph, Reconstruction: 29.3 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 42.78604 degree, Reconstruction: 42.78639 degree
  - **Longitude -** ACN: 78.81125 degree, Reconstruction: 78.81104 degree
  - **Heading -** ACN: 314 degree, Reconstruction: North West

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- **ACN ID #:** 1094
- **Date:**1/31/99
- **Time:** 4:40p
- **Location:** Suburban business area at a three-way intersection
- **Crash Description:** ACN vehicle was struck in the left front and subsequently struck an icy snow bank with the right rear wheel
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 2 o'clock, Reconstruction: 11 o'clock/3 o’clock
  - **delta V -** ACN: 25.8 kph, Reconstruction: 16-19 kph/8-11 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 42.86777 degree, Reconstruction: 42.86800 degree
  - **Longitude -** ACN: 78.74248 degree, Reconstruction: 78.74242 degree
  - **Heading -** ACN: 92 degree, Reconstruction: 91 degree

- **ACN ID #:** 1343
- **Date:** 3/4/99
- **Time:** 9:06p
- **Location:** Rural area on a two-lane road
- **Crash Description:** ACN vehicle skidded on ice and hit a utility pole with the front structure
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 12 o'clock, Reconstruction: 11 o'clock
  - **delta V -** ACN: 19.0 kph, Reconstruction: 21 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 43.03348 degree, Reconstruction: 43.03451 degree
  - **Longitude -** ACN: 78.47298 degree, Reconstruction: 78.47249 degree

- **Heading -** ACN: 51 degree, Reconstruction: 54 degree

- **ACN ID #:** 1478
- **Date:** 5/8/99
- **Time:** 5:45p
- **Location:** Suburban area on a four lane road
- **Crash Description:** ACN vehicle was struck in the left front by a vehicle that crossed the center line
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 11 o'clock, Reconstruction: 11 o'clock
  - **delta V -** ACN: 37.3 kph, Reconstruction: 32 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 42.77601 degree, Reconstruction: 42.77677 degree
  - **Longitude -** ACN: 78.82337 degree, Reconstruction: 78.82370 degree
  - **Heading -** ACN: 1 degree, Reconstruction: North

- **ACN ID #:** 1268
- **Date:** 5/24/99
- **Time:** 11:24a
- **Location:** Suburban area with businesses at a four-way, multiple lane intersection
- **Crash Description:** ACN vehicle was struck in the right front by a vehicle that went through a red light
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 2 o'clock, Reconstruction: 2 o'clock
  - **delta V -** ACN: 27 kph, Reconstruction: 27 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 42.78604 degree, Reconstruction: 42.78639 degree
  - **Longitude -** ACN: 78.81125 degree, Reconstruction: 78.81104 degree
  - **Heading -** ACN: 95 degree, Reconstruction: East

- **ACN ID #:** 1707
- **Date:** 8/9/99
- **Time:** 9:43a
- **Location:** Suburban commercial 3 way intersection
- **Crash Description:** ACN vehicle struck the other vehicle's left front when the other vehicle pulled onto roadway
- **ACN/Reconstruction Comparison:**
  - **PDOF -** ACN: 12 o'clock, Reconstruction: 12 o'clock
  - **delta V -** ACN: 22.5 kph, Reconstruction: 19-22 kph
  - **Rollover -** ACN: No, Reconstruction: No
  - **Final Rest -** ACN: Normal, Reconstruction: Normal
  - **Latitude -** ACN: 42.95094 degree, Reconstruction: 42.95043 degree
  - **Longitude -** ACN: 78.69574 degree, Reconstruction: 78.69673 degree
  - **Heading -** ACN: 12 degree, Reconstruction: North

- **ACN ID #:** 1729
- **Date:** 11/23/99
- **Time:** 6:19a

- **Location:** Rural two lane road
- **Crash Description:** Deer struck ACN vehicle on the left side causing the driver to lose control and run off of road to the left side into a drainage ditch
- **ACN/Reconstruction Comparison:**
    - **PDOF -** ACN: 9 o'clock, Reconstruction: 9 o'clock
    - **delta V -** ACN: 21 kph, Reconstruction: NA (sideswipe)
    - **Rollover -** ACN: No, Reconstruction: No
    - **Final Rest -** ACN: Normal, Reconstruction: Normal
    - **Latitude -** ACN: 42.80846 degree, Reconstruction:
    - **Longitude -** ACN: 78.53596 degree, Reconstruction:
    - **Heading -** ACN: 3 degree, Reconstruction: North

- **ACN ID #:** 1205
- **Date:** 12/27/99
- **Time:** 5:11 p
- **Location:** Suburban commercial four lane roadway
- **Crash Description:** A vehicle was making a left turn across traffic into a parking lot. The driver's foot slipped off of the brake pedal and the vehicle moved into the path of the ACN vehicle. The front of the ACN vehicle struck the right front corner of the turning vehicle.
- **ACN/Reconstruction Comparison:**
    - **PDOF -** ACN: 11 o'clock, Reconstruction: 11 o'clock
    - **delta V -** ACN: 12 kph, Reconstruction: 13 kph
    - **Rollover -** ACN: No, Reconstruction: No
    - **Final Rest -** ACN: Normal, Reconstruction: Normal
    - **Latitude -** ACN: 42.88700 degree, Reconstruction:
    - **Longitude -** ACN: 78.75465 degree, Reconstruction:
    - **Heading -** ACN: 181 degree, Reconstruction: South

- **ACN ID #:** 1760
- **Date:** 2/5/00
- **Time:** 9:12 p
- **Location:** Rural residential two lane roadway
- **Crash Description:** The ACN vehicle was following another vehicle on a slippery snow covered roadway. The other vehicle slowed down and the ACN vehicle struck it from behind.
- **ACN/Reconstruction Comparison:**
    - **PDOF -** ACN: 12 o'clock, Reconstruction: 12 o'clock
    - **delta V -** ACN: 23 kph, Reconstruction: 15 kph
    - **Rollover -** ACN: No, Reconstruction: No
    - **Final Rest -** ACN: Normal, Reconstruction: Normal
    - **Latitude -** ACN: 42.78286 degree, Reconstruction:
    - **Longitude -** ACN: 78.64684 degree, Reconstruction:
    - **Heading -** ACN: 335 degree, Reconstruction: North

- **ACN ID #:** 1302
- **Date:** 5/15/00
- **Time:** 1.53 p
- **Location:** Suburban commercial five lane roadway
- **Crash Description:** The driver of the ACN vehicle failed to recognize that traffic had stopped and impacted the rear of a vehicle.
- **ACN/Reconstruction Comparison:**

- **PDOF -** ACN: 12 o'clock, Reconstruction: 12 o'clock
- **delta V -** ACN: 42 kph, Reconstruction: > 23 kph
- **Rollover -** ACN: No, Reconstruction: No
- **Final Rest -** ACN: Normal, Reconstruction: Normal
- **Latitude -** ACN: 42.75664 degree, Reconstruction:
- **Longitude -** ACN: 78.85997 degree, Reconstruction:
- **Heading -** ACN: 151 degree, Reconstruction: South-southeast

4.2 ACN Crash Location and Vehicle Heading Accuracy

In addition to the accuracy of the ACN reported crash PDOF and delta V, the accuracy of the reported location of the crash was assessed. The ACN obtains the crash location latitude and longitude from the Global Positioning System (GPS). The error in the GPS reported position varies with the number of GPS satellites available at the time, and includes error that was intentionally included by the United States government to prevent GPS from being used for military targeting functions. This latter intentional error is called Selective Availability. (Note: at the very end of the program, the government removed selective availability)

The error in the location of the crash was determined by comparing the location transmitted by the ACN that was involved in the crash with the location obtained from a Differential GPS system positioned at the crash site at a later time. Differential GPS eliminates the error due to Selective Availability by comparing the location signal received from the GPS satellites with the position of a known location near the crash location. The error due to Selective Availability was quantified and subtracted from the standard GPS location signal. This differentially corrected GPS location was then compared to the ACN location and a vector subtraction calculation was performed to obtain the error in crash location in meters on the surface of the earth.

Table 4-2 shows the error calculated using the Differential GPS location. It was generally accepted that standard (non-Differential) GPS location is accurate to within 100 meters, 67% of the time (one sigma). It can be seen that in seven out of the eleven ACN crashes, or 64% of the crashes, the error is less than 100 meters. The ACN system location accuracy was within expected standard GPS accuracy.

Table 4-2. ACN Crash Location Accuracy

ACN ID#	Location Error (meters)
1104	118.0
1239	41.2
1046	142.9
1109	54.2
1254	12.9
1463	21.5

1094	31.5
1343	123.8
1478	87.9
1268	13.6
1707	113.5
1729	40.6
1205	11.2
1760	73.8
1302	52.0

The error shown in Table 4-2 is a measure of the absolute accuracy of the ACN reported crash latitude and longitude. Very few public safety agencies use GPS equipment to locate the scene to which they have been sent. The ability to travel safely and quickly to a crash location is more important to the EMS and police responders than the absolute error in the reported crash location. Key information of importance to emergency response agencies includes: the road the vehicle is on, the direction the vehicle was traveling immediately prior to the crash, and the position of the crashed vehicle with respect to the road. Other factors that may affect response time are the quality of the crash site location description that the dispatcher receives, the quality of the crash site description that the dispatcher gives to the EMS and police responders, and the ability of the responders to choose a time-efficient travel route. In some of the cases of large location error shown in Table 3-2, the crash was located very efficiently. For example, case #1343 occurred in a rural area with no trees, whereas, in case #1046 the vehicle was off of the road and out of sight. In the later case an accurate location would have been very helpful in finding this crash. It was felt that the map display of the crash location that the ACN system provides is a valuable aid in efficiently locating and reporting the crash site. The heading direction graphically shown on the map also aids the dispatcher in determining the lane of travel for limited access roads. When the map is faxed to EMS responders or to the local police it was found to be of great assistance by reducing confusion due to ineffective verbal communication of a crash location. The ability to fax the map and vehicle description is a tool provided to the dispatchers by the ACN system. The value of the map visual aid is difficult to measure in an objective manner. The error in location of crash sites listed in Table 4-2 is only one of the factors associated with locating a crash site.

The ACN in-vehicle module (IVM) obtains heading information from the GPS satellites. Heading is actually the direction of travel of the IVM between GPS satellite location calculations. In this report the term heading should be considered to be the direction of vehicle travel for both the ACN reported and displayed information and for the crash reconstruction.

4.3 Assessment of Agreement between ACN Reported Crash Parameters and Reconstruction

4.3.1 Case-By-Case Comparisons

ACN Crash No. 1129

This crash occurred early in the program in Chicago, Illinois and the ACN system did not report the crash because the proper long distance telephone coverage was not in effect. This problem was corrected to ensure that any subsequent out of area crashes would be properly reported. While the call was not successfully completed, the ACN did correctly sense the crash and the in-vehicle module retrieved and the crash data downloaded. The reconstruction data shown in Table 4-1 was based on photographs of the crashed ACN vehicle and an interview with the driver. The agreement between the ACN calculated crash characteristics and the reconstruction appeared reasonable, even though a detailed reconstruction could not be performed. The actual crash latitude and longitude and the vehicle heading immediately prior to the crash are not known.

ACN Crash No. 1104

The ACN vehicle turned left in front of an oncoming vehicle and was struck in the right front portion of the vehicle. The ACN system calculated a PDOF of 2 o'clock and delta V of 22.5 kph. The reconstruction also found a PDOF of 2 o'clock and delta V of 17.2 kph, providing reasonable agreement with the ACN derived crash data. The crash impact included the left front wheel and transaxle. These are very stiff structures that crush only small amounts making it difficult to estimate the delta V from the post-crash deformation. This may explain why the reconstruction delta V is less than the ACN delta V that is based on the actual vehicle crash accelerations. The error in location was approximately 104 meters (see Table 4-2) which is a substantial distance; however, at this large intersection location the EMS and police responders would most likely have found the crash easily. The discrepancy in heading is also rather large. The post-crash heading angle was taken using a magnetic compass from inside of a motor vehicle, which would have resulted in an erroneous reading of magnetic north due to the steel body. A heading of approximately 180°, taken from the map display, is probably more accurate as compared to the ACN heading of 194°.

ACN Crash No. 1239

This crash occurred in the very early morning in a rural village. The ACN vehicle ran off of the road to the right, drove over a ditch and a driveway, struck a utility pole guy wire with the vehicle left front bumper, rode up the wire and tipped over onto the vehicle's right side. The ACN system recognized the impact of the vehicle with the ground as a right side impact with a PDOF of 3 o'clock and a delta V of 12.9 kph. The crash reconstruction yielded a PDOF of 3 o'clock and a delta V of between 9 and 15 kph. Because the vehicle rolled onto the right side it was difficult to use standard reconstruction techniques and a range of possible delta Vs was obtained. The ACN system (at the Sheriff's Office) did not properly display the fact that the vehicle's final rest position was on the right side (although the in-vehicle equipment did properly sense final rest position). This display problem was corrected following this crash. Other than this display problem, there was good agreement between the ACN and the manual crash reconstruction. The location error was 41 meters, which is quite good. The vehicle would have been easily visible from the road at that distance. The heading angle as reported by the ACN system and as measured with a magnetic compass at the scene were the same at 200°.

ACN Crash No. 1046

The ACN vehicle ran off of the road very early in the morning, hit a few small trees and then hit a larger tree stump, which resulted in the impact recognized by the ACN system. The ACN system calculated a PDOF of 12 o'clock and a delta V of 30.6 kph. The reconstruction found a PDOF of 12 o'clock and a delta V of 26 kph. This is excellent agreement. The location error was 140 meters which is substantial. This vehicle was well off of the road in a wooded area and may have been difficult to find if the driver were not conscious and able to alert the police and EMS responders. The heading angles agree very well at 172° and 160°.

ACN Crash No. 1109

This crash occurred during morning rush hour when the ACN vehicle was struck from behind while waiting at a red light. The ACN vehicle was pushed forward into the vehicle in front at which time the air bags deployed. The ACN recognized the first crash (from the rear) and also recorded data for the second crash. The ACN calculated the first crash to be at a PDOF of 6 o’clock and a delta V of 29.0 kph. The crash reconstruction yielded a PDOF of 6 o’clock and a delta V of 30.1 kph. The second crash was calculated by the ACN to be at a PDOF of 12 o’clock and a delta V of 16.0 kph. These second crash characteristics were not sent to the dispatch center since the ACN system only reports the most severe of the crashes. The crash reconstruction found a PDOF of 12 o’clock and a delta V of 12.9-16.1 kph for this second crash. The agreement for both of the crashes was quite good. The location error for this crash was 42 meters and the vehicle would have been easily located at the intersection shown on the dispatch map display. The heading angle was reported by the ACN to be 0°. In this case the vehicle was not moving at the time of the crash and as a result there was no direction of travel and, therefore, no heading. The reconstruction also estimated that the vehicle was not moving at the time of the crash.

ACN Crash No. 1254

The ACN vehicle turned left in front of an oncoming vehicle and was struck in the front. The PDOF was calculated by the ACN to be 12 o’clock and the delta V was found to be 16.1 kph. The crash reconstruction yielded a PDOF of 11 or 12 o’clock and a delta V of 18.6 kph. This is good agreement and the post-crash photographs indicate that the crash damage was left of center as would be the case in an 11 o’clock crash, which affected the reconstruction estimate of PDOF. The location error was 14 meters which is excellent. The heading angle reported by the ACN was 99° as compared to a heading of East (approximately 90°) obtained from reconstruction.

ACN Crash No. 1463

This crash occurred out of the test area in Rochester, New York. The ACN system made a call to the Erie County Sheriff’s Office dispatch center and the dispatcher was able to call the Rochester police and verify that the proper authorities were handling the crash. The ACN vehicle was struck in the right front in a four-way intersection. The ACN calculated a PDOF of 3 o’clock and a delta V of 22.5 kph. The crash reconstruction found a PDOF of 3 o’clock and a delta V of 29.3 kph. The location error was 24 meters, which is excellent agreement. The ACN reported heading was 314° as compared to a reconstruction estimate of North West (approximately 315°), which is also excellent agreement.

ACN Crash No. 1094

This ACN crash was interesting and a thorough understanding of the crash events was only possible through analysis of the data collected by the ACN unit. The ACN vehicle was struck in the left front fender, in a sideswipe type of crash, by a vehicle turning left into the path of the ACN vehicle. The ACN vehicle swerved right as a result of this impact and struck an icy snow bank with the right rear wheel. The second impact with the snow bank was the more severe of the two impact events although there was very little visible damage to the vehicle. The first sideswipe impact was not sufficiently severe to trigger the ACN. The second impact with the icy snow bank was above threshold and recognized by the ACN. The manual crash reconstruction was unable to calculate a delta V for the snow bank impact because there was no visible damage. For the second crash (the snow bank) the ACN calculated a PDOF of 2 o’clock and a delta V of 25.8 kph. For the first crash (sideswipe) the ACN did not report crash characteristics (since this crash was below threshold) but the ACN recorded and stored data indicated a PDOF of 10 o'clock and a delta V of 15.4 kph. The reconstruction of the first impact found a PDOF of 11 o'clock and a delta V of 16 to 19 kph. There was good agreement between the ACN and the manual crash reconstruction for the first crash, but the second crash was only detected by the ACN System. The location error for this crash was 30 meters, which is excellent. The heading angle reported by the ACN system was 92° as compared to a post-crash heading angle measurement of 91° obtained from a magnetic compass. The heading agreement was also excellent.

ACN Crash No. 1343

In this single vehicle crash the ACN vehicle skidded out of control on icy pavement and struck a utility pole with the front structure of the vehicle. The ACN calculated a PDOF of 12 o'clock and a delta V of 19 kph. The crash reconstruction found a PDOF of 11 o'clock and a delta V of 21 kph. The ACN system and the reconstruction agreed quite well. In this case the post-crash photographs support the 12 o'clock PDOF. The location error was 121 meters which is a large error. In this case the terrain was cleared farmland and the vehicle would be easily found even if it were not on the road; however, in a wooded area a vehicle located 121 meters off of the road might be difficult to locate. The ACN reported heading angle was 51° and the post-crash measurement with a magnetic compass was 54°, which is excellent agreement.

ACN Crash No. 1478

The ACN vehicle was struck in the left front structure by a vehicle that crossed the centerline. It was determined that the driver of the non-ACN vehicle had suffered a heart attack causing him to lose control of his vehicle. The ACN calculated an 11 o'clock PDOF and a delta V of 37.3 kph. The manual crash reconstruction found a PDOF of 11 o'clock and a delta V of 32 kph. This is good agreement for a crash that included considerable sideswipe deformation, which makes reconstruction difficult. The location error was 92 meters. At this busy intersection, police or EMS responders would have easily located this vehicle. The estimated reconstruction heading was North (approximately 0°) as compared to the ACN reported heading of 1°, which is excellent agreement.

ACN Crash No. 1268

A vehicle entering a four-way intersection against the traffic control signal struck the ACN vehicle in the right front structure. The ACN calculated a PDOF of 2 o'clock and a delta V of 27 kph. The manual crash reconstruction yielded a PDOF of 2 o'clock and a delta V of 27 kph. The agreement between the ACN system and the reconstruction was perfect. The location error was 51 meters, which was adequate to locate the crash vehicle. The heading angle reported by the ACN system was 95° as compared to the post-crash estimate of heading of East (approximately 90°), which is excellent agreement.

ACN Crash No. 1707

The ACN vehicle struck another vehicle in the left front fender when that other vehicle pulled out into traffic at a three-way intersection. The ACN calculated a PDOF of 12 o'clock and a delta V of 22.5 kph. The crash reconstruction found a PDOF of 12 o'clock and a delta V of 27.0 kph. This is good agreement. The location error was 7 meters, which is excellent. The post-crash estimated heading was North (approximately 0°) as compared to the ACN system reported heading of 12°, which is also acceptable agreement.

ACN Crash No. 1729

The ACN vehicle came over a slight rise and encountered a deer crossing the road from left to right. The deer struck the vehicle in the left side door. The driver steered right onto the shoulder of the roadway in an unsuccessful effort to avoid the deer and then steered left to return to the roadway but over-compensated and ran off of the road to the left and into a drainage ditch. The vehicle struck it's left rear into the embankment and came to rest leaning left in the ditch. The ACN unit calculated a PDOF of 9 o'clock and a delta V of 20.8 kph. The crash reconstruction found a PDOF of 9 o'clock but was not able to calculate an accurate delta V for this sideswipe type of impact. The location error was 40.6 meters, which is acceptable agreement. The heading angle reported by the ACN unit was 3 degrees, essentially due north, which is the same direction of travel as found in reconstruction. The agreement between the ACN reported crash characteristics and the reconstruction is excellent except for the delta V. The value of 20.8 kph reported by the ACN unit includes the change in velocity in the longitudinal direction as well as the lateral direction making it a much larger value than can be estimated from vehicle side structural damage.

ACN Crash No. 1205

The ACN vehicle was traveling south in the inside lane of a four lane suburban commercial roadway when a vehicle turning left across traffic crossed the center line and moved into the lane. The front of the ACN vehicle struck the right front corner of the turning vehicle. The ACN unit calculated a PDOF of 11 o'clock and a delta V of 12.1 kph. The crash reconstruction found a PDOF of 11 o'clock and a delta V of 13 kph, which is excellent agreement. The location error for this crash was 11.2 meters, which is also excellent. The police were able to locate this crash very easily. The ACN reported heading was 181 degrees, essentially due south, and the roadway is oriented in a north-south direction. The agreement between ACN and reconstruction was excellent for this case.

ACN Crash No. 1760

The ACN vehicle was following another vehicle on a roadway that was partially covered with drifted. The vehicle ahead of the ACN vehicle slowed in a snow covered area and the ACN vehicle struck it from behind. The ACN calculated a PDOF of 12 o'clock and a delta V of 23 kph. The crash reconstruction found a PDOF of 12 o'clock and a delta V of 15 kph. The location error for this crash was 74 meters. The ACN reported heading was 335 degrees, or north-northwest, as compared to the roadway direction of north. The discrepancy in delta V is thought to be due to the amount of snow on the road at the crash site. Although the snow was melted when the crash investigation took place, an interview with the ACN vehicle driver indicated that several inches of snow might have been drifted across the road at the time of the crash. This layer of snow acting on the vehicle tires might cause the vehicles to decelerate an additional 5 to 8 kph over the duration of the crash. This additional velocity change, not reflected in vehicle structural damage, may account for the difference between the ACN reported delta V and the crash reconstruction delta V. Further, a significant layer of drifted snow on the road would explain the sudden deceleration of the vehicle in front of the ACN vehicle and the subsequent crash.

ACN Crash No. 1302

In this complicated crash the driver of the ACN vehicle failed to recognize that traffic had stopped in the outside lane of the five lane suburban commercial roadway. The vehicle that was two vehicles in front of the ACN vehicle was making a right turn into a driveway and had stopped in the lane to allow another vehicle to exit the same driveway, turning right into the same traffic lane. The vehicle behind this vehicle also stopped in the lane. The ACN vehicle struck the second vehicle in line and pushed it into the first vehicle in line. The ACN reported PDOF was 12 o'clock and the delta V was 42 kph. The crash reconstruction found a PDOF of 12 o'clock and a delta V of approximately 23 kph. The ACN reported heading was 151 degrees and the roadway was oriented south-southeast. The location error for this crash was 52 meters. The discrepancy in delta V was attributed to shortcomings in the ability of the WINSMASH model to properly calculate delta V for a complicated three-vehicle crash, such as occurred in this case. In this crash the ACN vehicle strikes the vehicle in front of it and the two vehicles then proceed to strike a third vehicle in front of both. A significant portion of the kinetic energy of the ACN vehicle is absorbed in the middle and forward vehicles. WINSMASH only accounts for crush in two vehicles and, as a result, underestimates the velocity change.

4.3.2 ACN Accuracy

A summary of the accuracy of the ACN system reporting of crash characteristics is provided in Table 4-3. Criteria were established at the beginning of the ACN program against which the various crash characteristics could be measured. For the fifteen fully reconstructed ACN cases accuracy is summarized by calculating the number of cases for which each quantity was accurately reported divided by the denominator of fifteen total cases. It can be seen that the accuracy of ACN reported crash characteristics was generally quite good. The differences between investigator estimates of delta V and ACN measurements of delta V were attributed to the inability of the crash investigator to reliably reconstruct sideswipe or multiple crash events. It was felt that in these difficult reconstruction cases the ACN measured and reported delta V was probably more accurate than the reconstruction.

It can be seen in Table 4-3 that the reported location accuracy was only 73% for the ACN cases based on an allowable distance error of 100 meters. Most of the ACN crash reported locations included GPS Selective Availability error (Selective Availability as described earlier was removed from the GPS signal in May 2000). As a result of Selective Availability being included in the location position, several ACN crashes were reported at locations greater than 100 meters from the actual crash location. GPS now provides much more accurate location information.

A more realistic measure of location accuracy should include the ability of the responders to locate the crash promptly. The actual location error in meters on the surface of the earth is less important than the capability to find a crash without lengthy searching. With this in mind, a method of measuring the ease of locating the ACN crashes was developed based on a variety of location data such as the correct road name, the correct nearest intersection, the correct direction of travel, the nearest address as well as the distance of the reported crash location from the actual crash location. Using this method, a point was given for each location attribute that was correct and a scale from 0 to 8 was established with 0 being difficult to locate and 8 being easy to locate. This method is demonstrated in Figure 4-1. It can be seen that using this methodology all but one of the ACN crashes were reported with a location attribute of 5 or greater. This indicates that with one exception, all ACN crashes were could be readily located.

Table 4-3. Summary of ACN Reporting Accuracy

Quantity	Criterion	Accurate
Delta V	within 10 km/h	87%
PDOF	within 1 o'clock	100%
Rollover	yes/no	93%
Final Rest	yes/no	100%

Location	within 100 meters	73%
Heading	within 15 degrees	100%

SCALE VALUES for Figure 4-1
0=Cannot Locate, 3=Locate with effort, 5=Locate Readily, 8=Drive Directly to Site

Figure 4-1. The Ease of Locating an ACN Crash

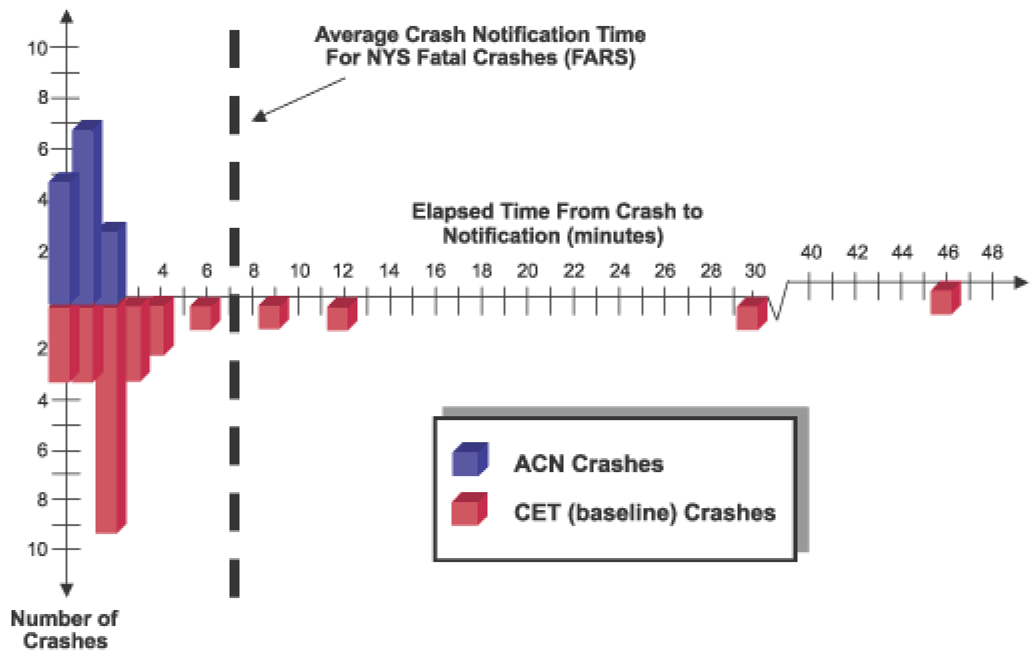
ACN ID	Correct Town	Correct Road	Correct Nearest Intersection	Correct Address	Correct Direction of Travel	Location Error <200m	Location Error <100m	Locatio Error <30m
1046	1	1	1	0	1	1	0	0
1094	1	1	0	0	1	1	1	0
1104	1	0	0	0	1	1	0	0
1109	1	1	1	1	1	1	1	0
1239	1	1	1	0	1	1	1	0
1254	1	1	1	1	1	1	1	1
1268	1	1	1	0	1	1	1	1
1343	1	1	1	0	1	1	0	0
1463	1	1	1	0	1	1	1	1
1478	1	1	1	0	1	1	1	0
1707	1	1	1	0	1	1	0	0
1729	1	1	1	0	1	1	1	0
1205	1	1	1	1	1	1	1	0
1760	1	1	1	1	1	1	1	1
1302	1	1	1	1	1	1	1	0

4.4 ACN Crash Response Time Analysis

An important goal of the ACN FOT was to measure the extent to which automatic crash notification can reduce emergency response time. To serve this goal the ACN field operational test included the CET program. About three thousand CETs (crash event timers) were fielded to quantify the baseline notification times for non-ACN vehicles involved in crashes. CETs are timers that were activated by an inertial switch. When a crash occurred, the CET was started allowing post crash determination of exactly when the crash occurred.

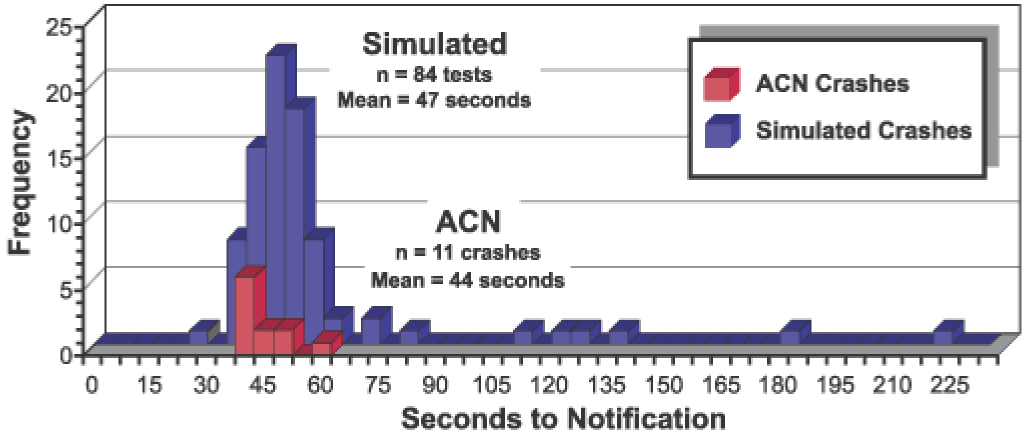
The notification times for all ACN crashes and for all CET crashes are shown in the histogram of Figure 4-2. It is clear that the ACN system was able to notify the Erie County Sheriff of a crash in two minutes or less and usually in less than one minute. The non-ACN notification times range from one minute to as long as forty-six minutes. The average crash notification time in New York State, as reported from FARS, is approximately seven minutes (see Figure 4-2). It is clear that the ACN system reduced average notification times to less than two minutes.

Figure 4-2. Histogram of ACN and CET Crash Notification Times



In addition to the ACN and CET crashes, a series of simulated crash calls were made to the Erie County Sheriff dispatchers throughout the ACN program. These calls were made using a portable system that triggered a simulated crash call by manually pushing a button. The portable system consisted of an IVM, installed in a suitcase, with a push-button that grounded an accelerometer to generate a high voltage signal which the digital signal processor interpreted as a large delta V crash. Once activated, the unit generated a crash call. The suitcase system was utilized for three purposes; (1) to generate a large number of calls and to measure the crash notification time, (2) to routinely test the ACN system to ensure that it was working properly and (3) to provide ongoing training for the dispatchers so they were ready to deal with actual crash calls when they occurred. Hundreds of suitcase calls were made during ACN program and many of those were logged as simulated crash calls. Figure 4-3 is a histogram showing the notification times for these suitcase calls overlaid with the notification times of the actual ACN crash calls. It can be seen that the mean notification time of the ACN crash calls was 44 seconds and the mean notification time of the simulated calls was 47 seconds. There were several suitcase test calls that did have relatively long crash notification times (see Figure 4-3). It was determined that the long notification times were a result of heavy cellular network call traffic that resulted in long message transmission times. The simulated crash message tests demonstrated that in 87% of the time, the ACN system completed the crash call in less than a minute.

Figure 4-3. Histogram of Actual and Simulated ACN Crash Notification Times



NOTE: Four crashes pre-date the ACN System's automatic synchronization with NIST time. They were only accurate to the nearest minute and therefore not included.

It was hypothesized that any reduction in notification time due to ACN would be most significant in rural areas where travel distances are greater, the opportunity for secondary reports from passers-by is less, and the ability for vehicle occupants to know precisely where they are is reduced. This hypothesis is somewhat supported by national crash databases, such as the FARS, but has never been rigorously verified with quantitative data.

In order to test this hypothesis, it was necessary to define a more quantitative measure of "rural", and apply this definition to evaluate response times as a function of "ruralness." The measure that was created for this purpose tried to capture the most relevant attribute of "ruralness" from the perspective of crash notification. This attribute relates to the likelihood that the crash will be witnessed or found shortly following the crash event. This measure of "ruralness" was defined to be the Conspicuity Index.

The Conspicuity Index is a means of quantifying how "noticeable" a crash might be in a particular location. In this sense, "noticeable" means; the likelihood that someone will see, hear, or otherwise become aware that a crash has occurred and that help is needed. The term conspicuity is therefore defined to mean the innate characteristic of being observable in some way. It is defined as a function of the number of vehicles that pass by a particular crash site and by the number of people that live or work within sight and sound of the crash site. The Conspicuity Index is defined in Table 4-4.

Table 4-4. Conspicuity Index

	Roadside Development Level			
Traffic Density	**Very Low = 0**	**Low = 1**	**Medium = 2**	**High = 3**
None=0	0	1	2	3
Low=1	1	2	3	4
Medium=2	2	3	4	5

High=3	3	4	5	6

Traffic Density (at the time of the Crash)

- **0 = no traffic, i.e., an off-road location mostly or completly hidden from the road**
- **1 = local, rural road with fewer than thirty cars per hour**
- **2 = commuter road, village or business area, 30-120 cars per hour (1/2 - 2 cars per minute)**
- **3 = heavily traveled road, main highway or urban business area, 121 or more cars per hour**

Roadside Development Level

- **0 = no inhabited buildings in sight in any directions, no intersectiosn within 200 meters**
- **1 = few inhabited buildings in sight**
- **2 = several inhabited buildings in sight, homes and/or business, with space between them**
- **3 = many inhabited buildings in sight, homes and/or businesses**

Other

Subtract 1 for:

- **crash times of 10:00 PM - 6:00 AM OR**
- **unlit road at night OR**
- **bad visibility due to weather**

The Conspicuity Index was applied to evaluate the crashes experienced during the ACN operational test. The results of this evaluation are summarized in Table 4-4. The traffic flow is shown in the column on the left side of Table 4-4 and is labeled Traffic Density. The levels of traffic density are defined below the matrix. The number of people who could have observed the crash, either immediately or within a short time, was estimated by quantifying the number and type of buildings near the crash site, i.e., the Roadside Development. The Roadside Development is shown across the top of the matrix in Table 4-4 and is defined below the matrix. It should be noted that the Conspicuity Index score for a given location would be expected to vary with the time of day since traffic density will vary with time.

Table 4-5 shows the Conspicuity Index and the notification time for the fifteen above threshold ACN crashes that occurred and for which notification time data is available. Table 4-6 shows the same information for the 26 CET cases that occurred and for which there is notification time data. In each of these tables the actual notification times are shown in the left most column while the calculated conspicuity parameters are shown in other columns.

These data are plotted in Figure 4-4 with a line showing the trend for notification time of CET crashes as a function of conspicuity, i.e., those crashes for which an ACN system was not available to provide immediate notification. The difference between the CET notification time line and the ACN crash notification times is the expected time saved due to the ACN providing immediate notification of a crash.

Table 4-5. Conspicuity Indices for ACN Crashes

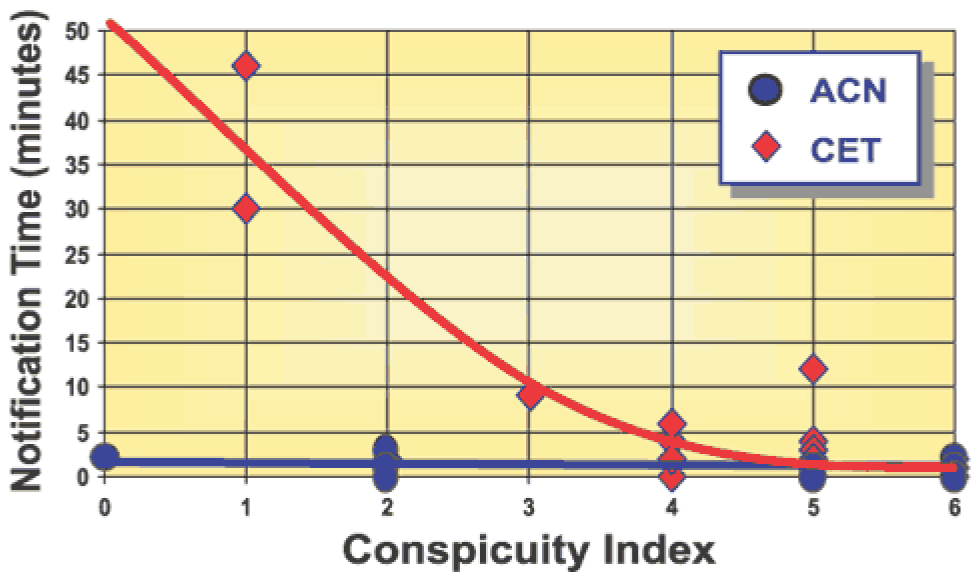
Case	ACN Notification Time (min)	Traffic Density	Roadside Development	Poor Visibility	Conspicuity Index
1046	2	1	0	-1	0
1094	5	3	2	0	5
1104	1	3	3	0	6
1109	2	3	3	0	6
1205	0	3	3	0	6
1239	1	1	2	-1	2
1254	1	2	3	0	5
1268	0	3	3	0	6
1343	1	1	1	0	2
1463	0	3	3	0	6
1478	0	3	3	0	5
1707	0	3	3	0	6
1729	0	1	1	0	2
1760	1	2	1	0	2
1302	0	3	3	0	6

Table 4-6. Conspicuity Indices for CET Crashes

Case	CET Notification Time (min)	Traffic Density	Roadside Development	Poor Visibility	Conspicuity Index
00150	0	2	3	0	5
00685	2	2	3	0	5
00710	2	2	3	0	5
00776	30	1	0	0	1

00850	4	2	2	0	4
01077	0	3	3	0	6
01104	2	2	2	0	4
01135	2	2	2	0	4
01288	2	3	1	0	4
01469	3	3	2	0	5
01478	1	3	2	0	5
01610	1	3	3	0	6
02330	approx. 10	1	2	0	3
02344	2	3	3	0	6
02374	1	3	3	0	6
02571	4	3	2	0	5
02904	3	2	3	0	5
03136y	46	1	1	-1	1
03136z	0	2	2	0	4
3445	6	3	1	0	4
03733	2	3	2	0	5
04051	9	2	1	0	3
04112	2	1	1	0	2
04139	2	3	3	0	6
A1408	3	1	1	0	2
P037	12	3	2	0	5

Figure 4-4. Notification Time versus Conspicuity Index



It can be seen that the ACN system notification times are always less than two minutes while the CET notification times have been as long as forty-six minutes. The data are limited at this point, with only twenty-six CET cases, and therefore the trend is only suggested. More data are needed before clear conclusions can be drawn about the relationship between conspicuity and notification time. However, if our hypothesis is correct, the ACN system can reduce the notification time, and consequently the emergency medical response time, significantly in instances where a crash occurs in an inconspicuous location.

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5. CONCLUSIONS

The following paragraphs summarize the results of the project, present conclusions based on the results, and provide additional discussion of issues and lessons learned associated with the design and conduct of the Operational Test.

ACN Technology Works.

As noted earlier, when this project was initiated there were no vehicles on American highways with ACN systems. It was during this program that the first 'primitive' ACN systems, using air bag deployments to trigger the crash message, were offered commercially. To this day, the ACN technology developed and deployed in this Field Operational Test is the most advanced crash detection and characterization system. The Field Operational Test demonstrated that this technology works and has the potential to save lives on our highways. The program demonstrated that ACN systems can measure vehicle accelerations in three dimensions, automatically alert PSAP dispatchers about the crash and then switch to voice so that the dispatcher can talk to the vehicle occupants. By using crash data transmitted by the ACN device, injury estimation algorithms, and possibly information obtained from occupants of the vehicles, dispatchers can assess the probability that a serious injury crash has occurred.

Over seven hundred ACN systems were deployed in privately owned, volunteer participant vehicles across the Western New York test area during the FOT. During the 3-year deployment period valuable information was obtained on the ACN system reliability and performance. While the ACN system worked well in most cases, there were instances in which crash messages were sent when no crash had occurred, or no crash message was received at the 9-1-1 center even though a crash had occurred. In five instances, ACN equipped vehicles experienced above threshold crashes and no message was received at the 9-1-1 center. The reasons for these failures included: the receiving computer was disconnected at the 9-1-1 center; very poor cellular coverage at the crash scene; severe damage to the ACN system during the crash; and failure of the backup ACN battery. These crashes provided valuable information on potential system failure points. Two of the failures were attributable to the ACN system and may have been avoided by a more robust ACN design or a different equipment installation strategy. Two of the failures were due to circumstances beyond the control of the ACN system. One failure was of unknown causes. Valuable information was also obtained in those cases in which vehicles transmitted crash messages when no crash had occurred. This occurred with 31 of the 874 units (i.e., 3.5%) that were fielded. These cases were of great interest because one of the concerns of the public safety community was that they might receive large numbers of false crash calls if unreliable automated crash-messaging systems were widely deployed. The results of the ACN FOT experience indicated that all the false crash messages were attributable either to improper installation of accelerometers on the printed circuit board, inadequate signal conditioning, or voltage spikes that resulted from participants attempting to "jump-start" their vehicles. System modifications were developed that corrected these deficiencies and when modified systems were installed the false alarm rate was reduced.

Finally, in all but one crash, the existing Western New York AMPS cellular network and message routing capability was sufficient for getting messages to the appropriate PSAPs.

Automatic notification of crashes reduces notification times.

The elapsed time between the crash and when the 9-1-1 dispatch center was alerted was defined to be the crash notification time. Prior research into crash response event timelines has been greatly hampered by lack of accurate information on the time of the crash. This is because crash times are based on estimates made by those involved (i.e., crash victims, witnesses, first responders). Since people are poor at estimating durations of time, especially during times of stress, these estimates are often inaccurate. For unwitnessed crashes that involve serious occupant injuries, the police at the scene must estimate the time of the crash. FARS data (based on these estimates) indicates that the national average for crash notification times is about 7 minutes for rural fatal crashes and 4.5 minutes for urban fatal crashes. However, there are wide spreads in notification times, ranging from less than a minute to several hours or more. In the FOT, we found that ACN consistently provides notification within two minutes as long as there is cellular coverage. The CET data collected during the FOT indicated that although urban and witnessed rural crashes are typically reported within a few minutes, unwitnessed crashes in rural areas can take much longer. During the ACN FOT most CET crashes occurred in urban areas and had notification times of a few minutes, although there were some crashes in which notification times of between 10 and 45 minutes were measured. ACN would have provided a significant reduction of response time for these crashes.

Public Safety community was able to successfully use ACN.

The primary focus of the ACN program was the development and evaluation of the in-vehicle equipment. With that in mind, no attempt was made to optimally integrate the ACN message reception equipment with equipment existing in the participating 9-1-1 PSAPs. To the contrary, the ACN message reception equipment was operated as an independent, standalone system. Nevertheless, PSAP dispatchers quickly adapted their procedures to include the use of ACN technology. Dispatchers reported that having immediate notification of crashes with an accurate crash location improved their ability to provide rapid and appropriate emergency services.

Widespread deployment of ACN technology will require successful application of commercial models.

ACN can provide immediate and accurate notification of crashes to PSAPs but only if people are willing to purchase the equipment and put it in their vehicles. This will be achieved when ACN systems are made available through successful commercial offerings. This means that the systems need to offer valued service at acceptable prices. It also requires that issues of privacy and liability be dealt with in a ways that do not create fears that make these systems unattractive.

Integration of commercial ACN systems with the public infrastructure is crucial to achieving maximum ACN benefits.

The ability to deliver ACN emergency data electronically to the correct PSAPs avoids time-consuming and error-prone verbal protocols in use today. Integration with PSAPs is critical to ACN success. This will require the application of standard communications and operational protocols that are acceptable to the Mayday industry as well as the PSAP community.

The data available from systems like ACN can provide a wide range of benefits beyond simply dispatching first responders.

One of the products of the ACN field Operational test has been to stimulate the EMS community to consider how ACN systems might further improve the delivery of emergency services. In addition to knowing crash occurrence and location, ACN systems can provide information that characterizes the crash severity. This information can aid dispatchers in deciding what equipment is needed (e.g., helicopter, jaws of life, multiple ambulances); provide information to prepare EMS staff for on-scene intervention and triage decisions; and support preparations at emergency medical and trauma care facilities. These data can also be provided to assist in traffic management and incident response functions (e.g., dispatching tow trucks, cleaning spills, repairing damage to roadway).

Voice and data systems offer significant advantages over those that are data-only.

The availability of a voice connection between the PSAP and the distressed vehicle provides important advantages over data-only systems. First, it allows dispatchers to verify that there was a crash and to determine the extent of injuries (i.e., number of people injured and seriousness of injuries). This was apparent during the ACN FOT when the system malfunctioned and sent a crash message when none had occurred. With a voice link between dispatchers and vehicle occupants, the dispatcher was quickly able to confirm whether or not an emergency existed. In the event of a crash, the voice mode assists the dispatchers with decisions regarding what organizations should respond and with what type and quantity of personnel and equipment. It may also allow dispatchers to gather information about the crash scene that is important in managing the response execution. For example information of interest could include: traffic lanes blocked as a result of the crash; conditions that increase the possibility of secondary crashes (e.g., heavy traffic, icy road, etc.); and fire or other hazards associated with the crash. For each of these cases a different set of response actions may be needed. Finally, and perhaps most importantly, the dispatcher can provide medical advice to the injured occupants and can assist frightened or confused occupants as needed.

Knowledge of direction of travel is important for optimizing emergency response execution.

There are many situations in which emergency response can be more optimally executed with knowledge of the direction vehicles were traveling prior to a crash. This information enables the dispatcher to determine on which side of a divided highway the crash has occurred. Response times may be increased by several minutes if emergency response vehicles must re-deploy to an opposing lane or to roadway crossing via an overpass.

During the ACN FOT dispatchers were provided with locations for the 10 seconds prior to the crash as well as the location of impact. This was useful in providing information on the exact travel lane or roadway. This was especially important during the ACN FOT because GPS selective availability was not yet disabled and GPS location accuracy was only within about 100 meters. Although GPS selective availability is no longer used to degrade GPS for non-defense applications, it is still possible to confuse location without knowledge of direction of travel. This is true, for example, when a crash or emergency occurs under an overpass or overhanging structure because in these situations GPS accuracy is reduced, even without selective availability.

Operational Tests Demand Special Focus on Operations.

Because field operational tests involve operations in real world environments they demand special attention to operational issues that are not typically associated with research and development projects. These issues include: participant recruiting, operational integration, training and participant support, field system maintenance, and maintenance of participant relations. It is easy to underestimate the extent and full scope of these tasks. If an FOT involves participants from the general population recruiting can be a difficult task. Mechanisms for reaching out to desired populations need to be devised and implemented. Potential participants need to be contacted and educated about the goals, benefits, and requirements of the project. They also need to be trained and integrated within the project. An objective of the ACN program was to recruit 1,000 ACN participants and 4,000 CET participants. Many outreach methods and forums were employed to attract participants. Once volunteers were identified, efficient procedures were needed to install equipment and provide participants with ongoing program information to maintain their interest and support. In addition, it was necessary to establish help desk and field maintenance operations that could identify and deal with problems, as well as keep up with people changing vehicles and moving out of the test area. It is also necessary to monitor system performance to ensure operability throughout the test. This required periodic system tests and the ability to fix problems without disrupting ongoing operations. Termination of the project also required carefully planned procedures to ensure that all participants were notified that the test was ending and that they had to have their equipment removed or disabled.

Storehouse of Lessons Learned.

The ACN FOT provided unique insights and lessons that can be applied to other operational tests and commercial Mayday system deployments. The FOT provided the first opportunity to evaluate systems that provided PSAPs with immediate notification of crashes, an accurate crash location, a description of the crash severity, an estimate of the severity of occupant injuries, and related vehicle and potential occupant information. The insights gained during this test offer valuable guidance as ACN technology becomes more widely deployed. It is hoped that this FOT will play a role in opening the door to future research that will allow full advantage to be taken of ACN technology.

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APPENDIX
Participant Outreach Material

- Veridian Engineering Letter to ACN Participants (Adobe PDF File)
- Veridian Engineering End of ACN Test Program Waiver and Release Statement (Adobe PDF File)
- ACN System News Fall 1999 (Adobe PDF File)
- CET Newsletter Fall 1999 (Adobe PDF File)
- ACN System News Summer 1998 (Adobe PDF File)

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LIST OF ACRONYMS AND ABBREVIATIONS

- ACN – Automated Collision Notification
- CET – Crash Event Timer CETs Crash Event Timer(s)
- ECMC – Erie County Medical Center
- ECSO – Erie County Sheriff's Office FOT Field Operational Test GPS Global Positioning Satellite
- IVM – In-Vehicle Module JHU John Hopkins University
- MERS – Medical Emergency Radio System
- NHTSA – National Highway Traffic Safety Administration
- PDOF – Principal Direction of Force
- PSAP – Public Safety Answering Point
- RCU – Reference Correction Unit