

The Automated Collision Notification System

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INTRODUCTION

The NHTSA sponsored Automated Collision Notification (ACN) Project was initiated in October 1995 to design, develop, test, and evaluate a system that can detect and characterize crashes and then automatically send a data message to the public safety answering point (PSAP), see Figure 1. The system also opens a cellular telephone voice line between the PSAP and the vehicle occupants after the data message has been received. The system detects crashes in all directions and stores the acceleration time history experienced. The ACN system is able to determine the crash change in velocity, the principal direction of crash force, whether a rollover occurred and the potential for injury in the crash. The system also includes GPS equipment and provides PSAP dispatchers with a mapped location of the crash. The ACN system has been installed in 700 vehicles in Western New York and real world crash data and time of EMS response data is being collected and analyzed.

Automated Collision Notification (ACN)

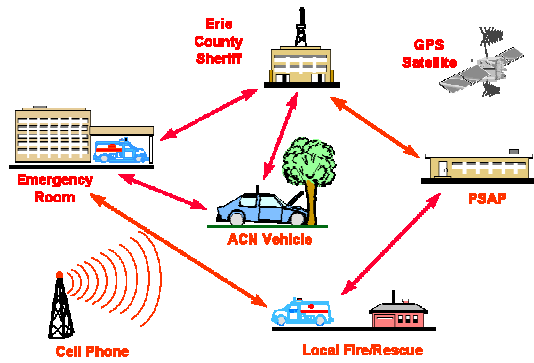


Figure 1: ACN System

In-Vehicle Equipment

The components of the ACN in-vehicle equipment suite are illustrated in Figure 2. These components include: the Veridian developed In-Vehicle Module (IVM), the cellular telephone handset, the cellular telephone transceiver (3 Watt), the back-up battery, and the associated antennas.



Figure 2: ACN In-vehicle Hardware

Transceiver

The transceiver selected for use the ACN system is the JRC 8820DR transceiver which allows automated control via a serial control channel. Commands are available to initiate call processing, dial a number, answer an incoming call, among others. The transceiver can also provide data such as the current RSSI level, active system (A or B or no service available), in-use, roam, etc. These controls may seem trivial, but control of a cellular phone is not as straightforward as a land-line phone where placing a call involves merely dropping an appropriate "off-hook" load across the line, waiting for a dial tone, then sending DTMF tones of the appropriate length and spacing.

Other than the serial control line, the only other connections to the transceiver are a reset signal and audio in/audio out.

Handset

The handset chosen is a JRC 6030 handset. This handset also allows control via a single serial control channel. Messages are sent to the IVM (the "host computer" in the handset's view) whenever any button is pressed or

released. Further, a message is sent whenever the handset is placed in or removed from its cradle. The handset can be directed to operate as a normal "hand-held" unit, or can be operated in a "hands-free" mode in which the audio out is directed to the larger speaker underneath the keypad, and the incoming audio taken from the microphone above the LCD display (two lines of 8 characters, plus icons below). The "hands-free" mode, while obviously intended for use when the handset is in the cradle, is totally under software control via the serial control channel; when the ACN system detects a crash, the car's occupants are connected to the dispatcher in hands-free mode regardless of the handset's position.

Battery

The back-up battery is a gel-cell lead-acid battery kept constantly charged by the IVM and used to provide enough emergency power for collision reporting and an extended duration phone call or two should the car's battery become disconnected or destroyed in an accident.

IVM

The IVM is the key element of the ACN in-vehicle equipment suite. The IVM is packaged in a rugged aluminum housing and contains a high performance (16 bit processor, 13.8 MIP) Digital Signal Processor (DSP), three orthogonally mounted micro-machined accelerometers, an Analog to Digital Converter, a single chip modem employing the robust and conservative V.23 Frequency Shift Keying data transfer protocol, a Rockwell Jupiter 12-channel GPS receiver board, power conditioning circuitry, and a non-volatile FLASH memory (128 Kbytes, expandable to 1024 Kbytes) to store detailed crash event time histories (see Figures 3 and 4).

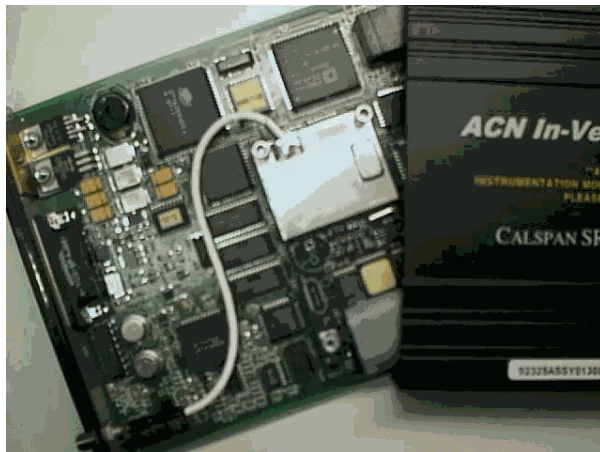


Figure 3: IVM - Internal View

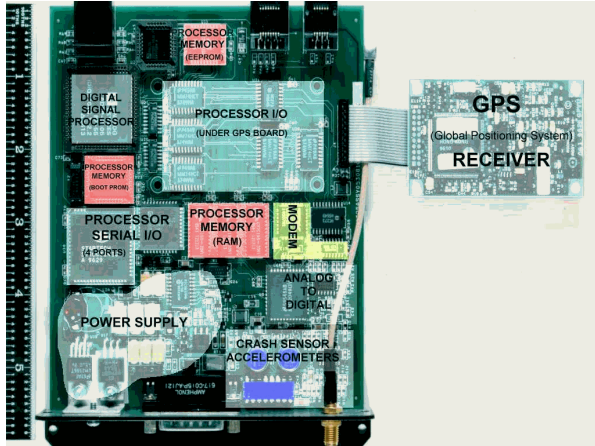


Figure 4: IVM Board With Functional Sections Highlighted

DSP

The IVM's detection and sensor conditioning algorithms are very DSP-intensive; that is, many of the computations are tight loops of multiply-intensive convolutional equations. The IVM uses an Analog Devices DSP, the ADSP2105, to perform all the detection algorithms as well as control all the various peripheral devices and telematics sequencing (see Figure 5).

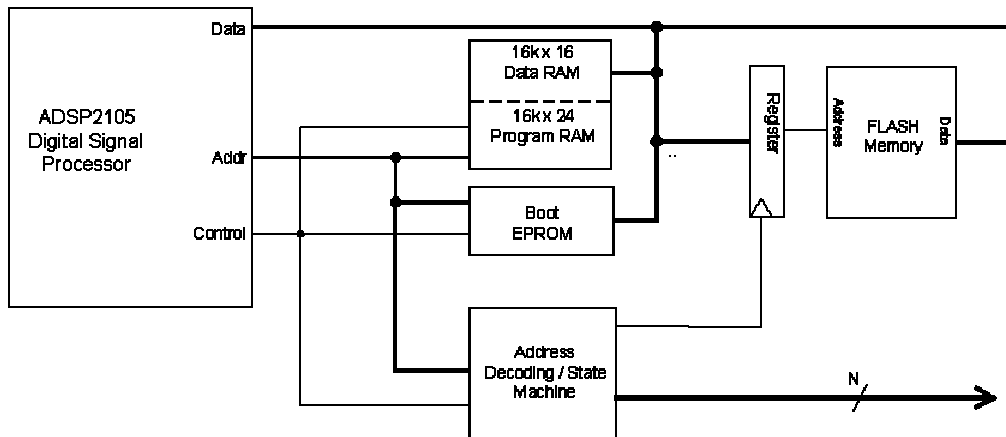


Figure 5: DSP Block Diagram

The ADSP2105 is a 16-bit fixed-point DSP with a modified Harvard architecture; i.e. it has a program data bus and a data data bus (internally) making it possible to, say, multiply an acquired data value by a stored coefficient (stored in program memory) and add it to a previous sum in a single instruction cycle.

The ADSP2105 can address 16k 16-bit words of data memory, including 0.5k words which are mapped to data memory internal to the chip, and 16k 24-bit words of program memory, including 1k words which are mapped to internal program memory. Since the access times required for zero wait state memory accesses are short enough to

make EPROM, ROM, or FLASH memory prohibitively difficult to use, the processor is designed to use fast static RAM for all its external memory. Upon reset, a "bootup" program is transferred from a small, relatively slow BOOT EPROM to the DSP's internal program memory. After transfer, that program in internal program RAM (PRAM) is executed.

The IVM has nearly a full compliment of RAM available to it; as much as the ADSP2105 can directly address, that is. The 2105 allows for 14 k words of external program RAM, allocating 2k words for internal addressing for compatibility with other DSP family parts. The ADSP2105 allows 14 k words of external data RAM also, mapping 1k of address space for its internal registers and 1k of address space for its internal data RAM (again for compatibility with other DSP family parts which have more internal RAM). Of the remaining 14 k words of externally addressable data RAM space, the IVM maps 13 k words into actual RAM, and allocates a 1 k address block for memory-mapped peripheral addressing. The decoding for the peripheral addresses is done with demultiplexors and a PLD; the PLD also includes a state machine to allow slower peripherals enough setup and hold times for their data for, even though the DSP has a programmable wait state generator built in, these wait states simply add time to the middle of the accesses.

Since the program and data busses are multiplexed into a single data bus for external RAM access, the IVM maps both program RAM and data RAM into the same physical set of devices: three 32k by 8 bit RAM chips.

The IVM stores many of its parameters, much of its operational code, and all of the data collected during a collision in FLASH memory. This memory is accessed using a set of memory-mapped address registers, and a single read/write address for data.

Serial I/O

A total of six serial ports are required for the IVM. Two are required for the modem since V.23 allows for an asynchronous bit rate transmission and reception (two different baud rates). One each for communication with the GPS receiver, the handset, the transceiver, and the diagnostic port.

The diagnostic port is used to upload the program and parameters into the IVM, including the transformation matrix provided by the Reference Correction Unit described below, and to upload measured event histories.

Modem and Audio Multiplexing

The IVM uses a TDK 73K321 single chip modem which employs CCITT V.23 standard modulation and signaling. The call is initiated by the IVM at "normal" V.23 originate baud rates of 75 baud transmit, 1200 baud receive. Since the IVM will transmit the preponderance of information and reception is required only for commands and verification, after connection the channels are immediately reversed so that the IVM transmits at 1200 baud, receives at 75 baud.

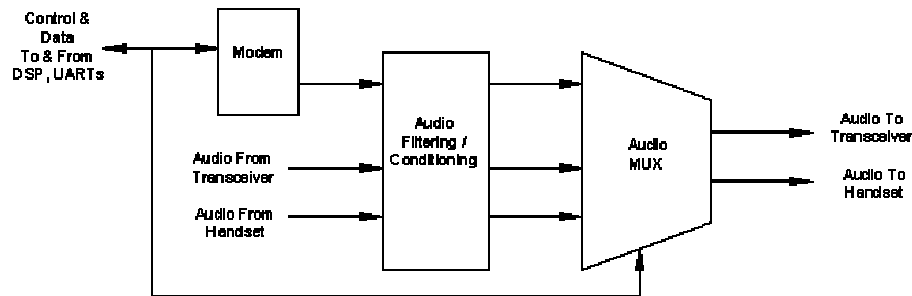


Figure 6: Modem, Audio Path Block Diagram

Audio path control is achieved using CMOS FET switches after proper conditioning, filtering, level shifting and amplification (see Figure 6).

GPS Receiver

As stated above, incorporated into the IVM is a Rockwell Jupiter GPS receiver. This "daughter board" is connected to and controlled by the DSP via a serial port and discrete lines.

Sensors, Conditioning, and A/D

The collision sensing is performed using three inexpensive monolithic micromachined accelerometers, two Analog Devices' ADXL50s and one Motorola MMAS40G, and a lot of signal conditioning in the DSP.

The two ADXL50s are arranged on the board so that their (linear) axis of sensitivity is parallel to the board and at right angles to each other. The MMAS40G has an axis of sensitivity that is perpendicular to the circuit board, so that all three of the sensors are mounted orthonormally without requiring a daughter board arrangement to achieve 3-axis sensitivity.

The acceleration outputs are anti-alias filtered before being converted to digital values by a 12 bit Analog to Digital converter.

Our pass band of interest extends up to 60 Hz, and the internal processing of the actual detection algorithm and storage of vehicle dynamics is done at 180 samples per second. However, in order to effectively and economically filter to 12 bit accuracy across automotive temperatures, the accelerations are oversampled by a factor of 8 at 1440 samples per second. The DSP filters to a 60 Hz cutoff and decimates the results from 1440 to 180 samples per second. This greatly reduces the demand on the order and accuracy of the analog filters.

The acceleration outputs from the ADXL50 are proportional to absolute voltage levels. However, the MMAS40G is a *ratiometric* device, where the measured acceleration is proportional to a percentage of the supply voltage, rather than an absolute voltage. Typically, the A to D converter's reference is driven by the same supply voltage so that any variance in the voltage is compensated. Either technique is workable, but mixing the two on a single A to D

converter creates difficulties. The IVM solves the problem by monitoring the 5V analog supply voltage and correcting the ratiometric sensor in software.

Power Regulation and Control

Power for the IVM is derived from the automobile's power, diode isolated and diode "ORed" with the back up battery. After a series of protection and filtering components, the voltage is converted to 5V using a switching regulator from the National Semiconductor Simple Switcher® family.

Power for the transceiver and handset is taken from the diode "ORed" node, and switched under computer control using a FET.

The battery is float charged whenever the ignition line is on. The charging of the battery is current limited by a PTC (Positive Temperature Coefficient) thermistor.

The switching regulator, and thus the power for the preponderance of the IVM, is controlled by a tiny, extremely low power PIC microcontroller (see Figure 7). This processor is continually powered (through an independent micropower linear voltage regulator) running from the time of installation on so long as the IVM is connected to any power source (the main automobile power line or the back up battery). This processor serves as a power-up sequencer, a reset circuit, a wake-up timer, and a watchdog timer.

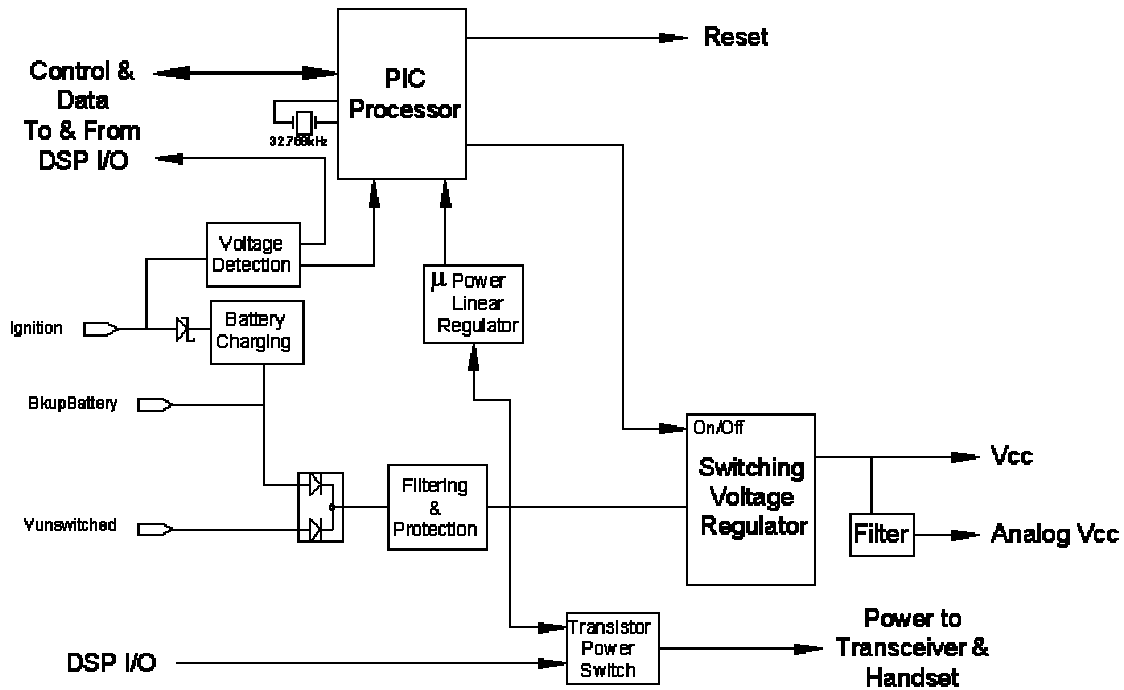


Figure 7: PIC and Power Conditioning Block Diagram

The PIC will monitor the ignition sense line (reduced to TTL voltage levels) and determine if the ignition comes on. If so, the PIC will turn on the power to the rest of the IVM, and hold the DSP reset line for an appropriate duration. The DSP can also read the ignition sense line. In normal operation, when there is no collision event and the phone is not in use, the DSP will poll the ignition line and, when it is de-asserted, will perform any "clean-up housekeeping" necessary. Then, it will inform the PIC by sending it a code that it wishes to be shut down, and woken up after a set duration. This allows the IVM to perform periodic self-test functions and report its status to a remote computer. If the DSP is in the process of reporting a detected collision, even if the ignition line becomes de-asserted the unit will remain powered on until the entire event is processed.

To guard against any momentary soft upsets, the PIC also acts as a watchdog timer. During normal operation, the

DSP will toggle an I/O line being read by the PIC, setting it to one polarity in the Interrupt Service Routine (ISR), and to the other in the background processing loop. If the PIC does not detect this bit toggle after a few minutes, it will reset and re-initialize the IVM.

Dispatcher Interface (Gateway)

The ACN crash messages are received at the Erie County Sheriff's Office on a PC based dispatcher interface console and a voice line is immediately opened between the Sheriff's Office and the ACN equipped vehicle. The dispatcher interface monitor displays a map with the crash location, the previous ten seconds of vehicle location and speed, an icon showing the principal direction of crash force, the crash change in velocity, whether a rollover occurred and the vehicle final rest position (see Figure 8.). An estimate of the probability of serious injury is also available if desired. The voice line is opened as soon as the monitor display is complete and the dispatcher establishes contact with the occupant within two minutes of the crash if the occupant is able to respond. Medical advice can be tele-conferenced to the crash vehicle from the Erie County Medical Center if it is needed. For Erie County crashes, the dispatcher alerts the appropriate responding agency and EMS, Police and Fire response is initiated regardless of where the crash is located, whether the crash was observed by a bystander or passerby and whether or not the occupants were conscious. For out of area crashes, the Cross Country national message center is notified and the call is passed to the appropriate local response agency.

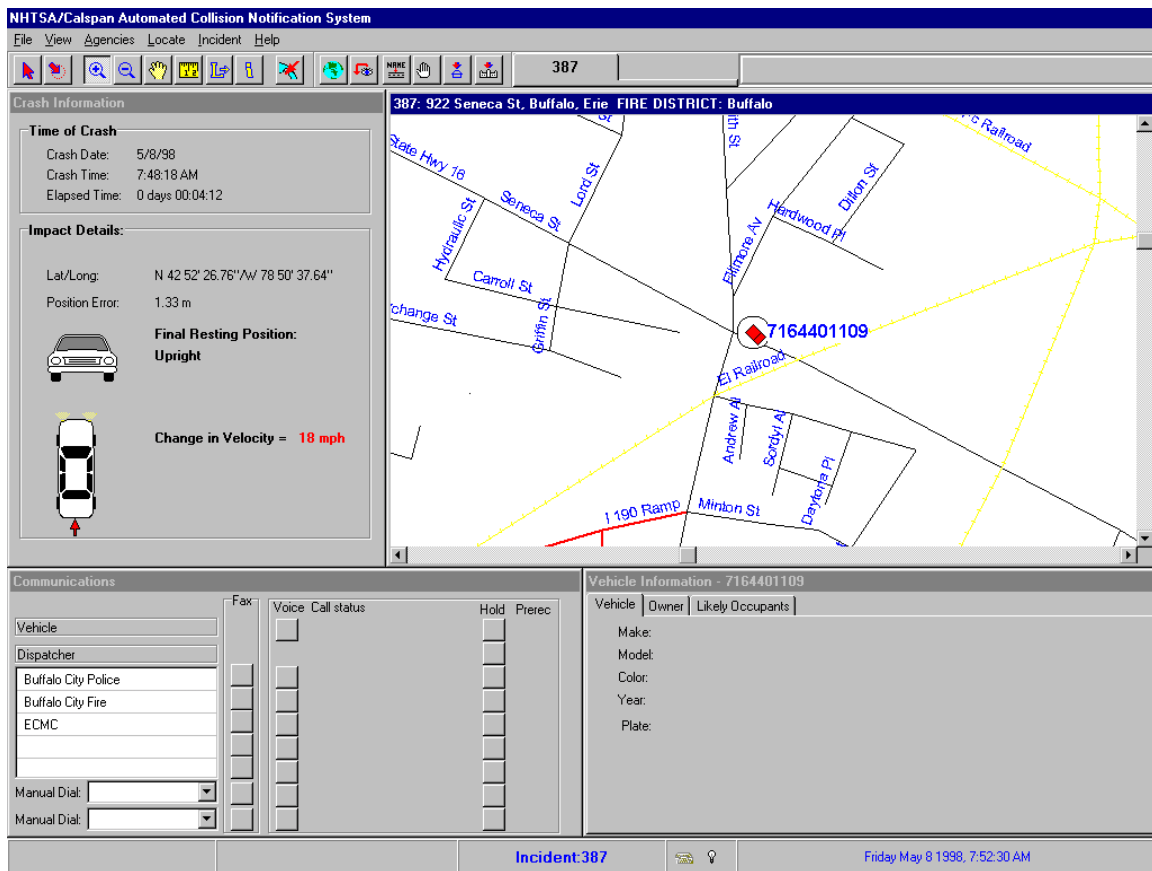


Figure 8: Dispatcher Interface Screen

Description of the field Operational Test

ACN System

Over 700 vehicles in Western New York have been equipped with ACN systems to provide over 1000 vehicle years of driving exposure. Volunteer participants from the more rural areas of Erie County were recruited to have the

ACN in-vehicle equipment installed into their vehicles by Cell-One who also provided the cellular telephone service. In most cases the equipment was installed under the rear seat. The In-Vehicle Module (IVM) is calibrated in place after installation, using a reference correction unit (see Figure 9), such that the triaxial accelerometer output is in the standard SAE Cartesian vehicle coordinate system regardless of the vehicle or the installation location. Several cellular telephone usage plans were offered by Cell-One to the participants; however, emergency calls and calls to Veridian are always free of charge to the participant. After a crash occurs the crash is investigated in depth. A time line listing crash time, notification times, dispatch times and response times is constructed and analyzed to identify the effect of the ACN time on response time.



Figure 9. Reference correction unit.

Crash Event Timer

In addition to the ACN system, 3000 crash event timers (CETs) have been installed in vehicles in Western New York to collect the baseline notification and response times for crashes when ACN systems are not involved. The field operational test will include 4000 CET vehicle years in the field. These data provide the control times required to measure the improvement in notification and response time obtained with the ACN system. The CET consists of a small timer unit (see Figure 10) that is attached to the firewall of the vehicle and a small inertia sensor that recognizes a crash and starts the timer. The timer runs for three weeks before it automatically resets itself. After being notified of the crash by the vehicle owner, Veridian investigators go to the crash vehicle and read the timer to obtain the elapsed time since the crash. The actual crash time is calculated from the time of the reading and the elapsed time. The EMS, Police and Fire records then are analyzed to yield the baseline notification and response times for non-ACN crashes.

Status of Test

At the present time the program is approximately 60% complete in terms of days-in-the-field with 639 ACN equipped vehicles in the field and 2930 CET equipped vehicles in the field. To date nineteen CET crashes have been experienced of which six are rural and nine ACN crashes have been experienced of which three are rural. The operational field test will be complete in September 1999.

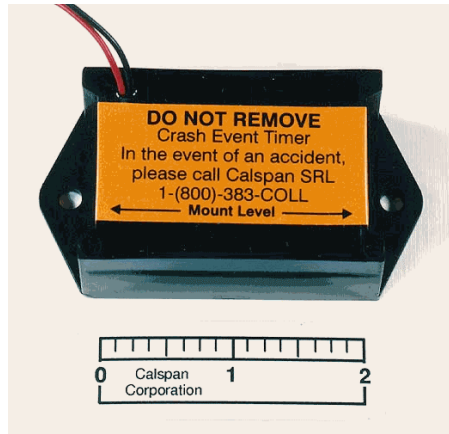


Figure 10. Crash Event Timer

Results

To date thirty-six ACN crashes have occurred of which ten were above the crash threshold. These ten above threshold crashes are summarized in Table 1. In eight out of the ten cases the ACN system provided an emergency notification message to the Sheriff's office in less than two minutes. In the other two cases a message was not sent because (1) the in-vehicle equipment was not operational at the time of the crash due to incorrect wiring during installation and (2) the crash occurred in Chicago, Illinois and although the system did detect the crash and assemble a message it did not make a long distance telephone call to New York.

Crash #	ACN I.D. #	Incident or Crash?	Crash Date	Crash Location	Geographic Area	Total Occupants (all vehicles)	Injuries & Max. AIS	Medical
1	440-1129	Crash	1/3/98	Chicago, IL	Urban	8	Neck strain and contusions (AIS-1)	2 of 8 on transport ambulance
2	440-1104	Crash	2/18/98	Buffalo, NY	Urban	2	Sternum fracture (AIS-2)	Both drivers on transport ambulance
3	440-1239	Crash	4/4/98	Marilla, NY	Suburban	1	Right shoulder contusion (AIS-1)	None
4	440-1046	Crash	4/15/98	East Aurora, NY	Rural	1	No injury	None
5	440-1109	Crash	5/8/98	Buffalo, NY	Urban	5	Right leg contusions (AIS-1)	4 of 5 on transport ambulance
6	440-1254	Crash	8/31/98	Hamburg, NY	Suburban	3	No injury	None

7	440-1463	Crash	11/15/98	Rochester, NY	Urban	5	Driver - seat belt related contusions (AIS 1)	None
8	440-1094	Crash	1/31/99	Cheektowaga, NY	Suburban	3	RF Passenger Fx vertebra - L1 (AIS 2)	Ambula
9	440-1346	Crash	3/3/99	East Aurora, NY	Suburban	2		Ambula
10	440-1343	Crash	3/4/99	Newstead, NY	Rural	1	No injury	None

Table 1: Summary of ACN Above-threshold Crashes

ACN Crash 440-1109

Crash I.D. #440-1109 involved an ACN equipped 1993 Plymouth Voyager mini-van that was struck from the rear while waiting at a red traffic signal. The mini-van was pushed forward and into the rear end of the vehicle waiting in front of it. The result was two collisions, a rear and a frontal, both of which exceeded the crash thresholds of the IVM. Figure 11 summarizes the crash, shows photographs of the mini-van and shows the triaxial accelerometer data recorded by the IVM and stored in flash memory. Both events are clearly seen in the acceleration time history as a positive x acceleration excursion (the rear crash) followed by a quiescent period and a negative x acceleration excursion (the frontal crash). The IVM calculates the crash delta velocity and the principal direction of force (PDOF) for each crash event, indicates whether a rollover occurred and determines the final rest position of the vehicle after the crash is over (see Figure 11). Figure 12 is a crash scene diagram showing the events of the crash as reconstructed by a crash investigator. The IVM obtains the same information as post-crash reconstruction and makes it immediately available to EMS, Police and Fire dispatchers to be used in the dispatch process.

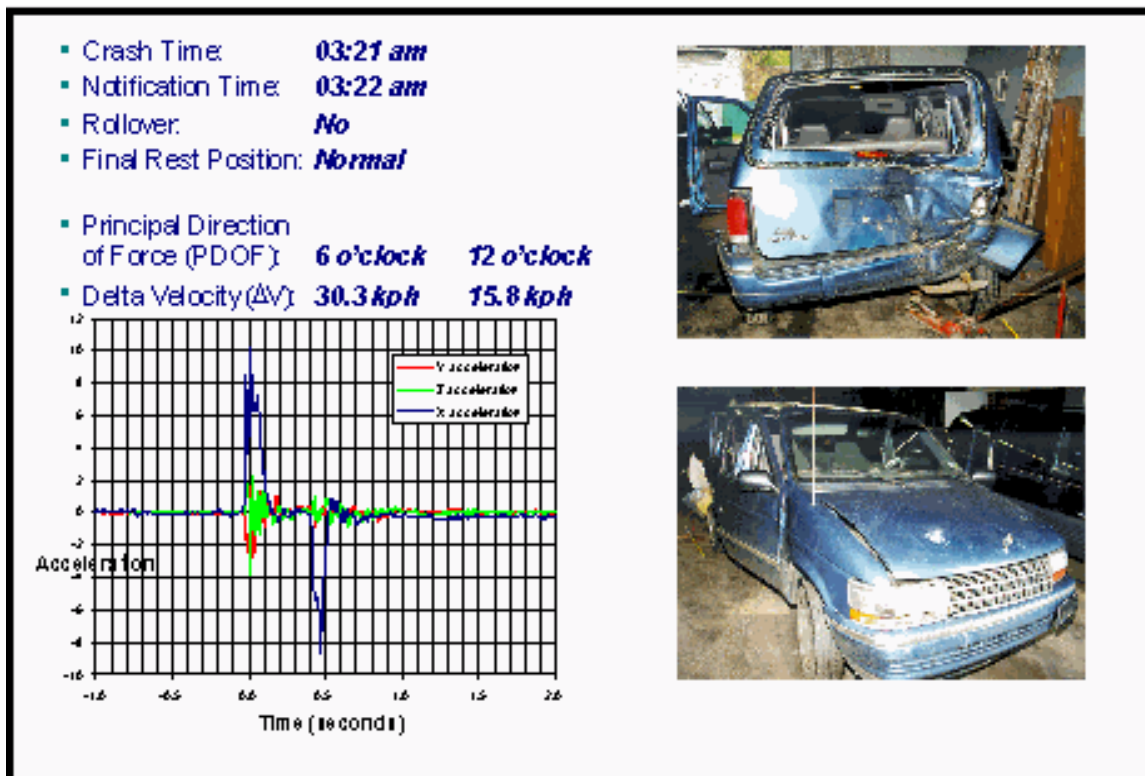


Figure 11. Crash summary for ACN Crash No. 440-1109.

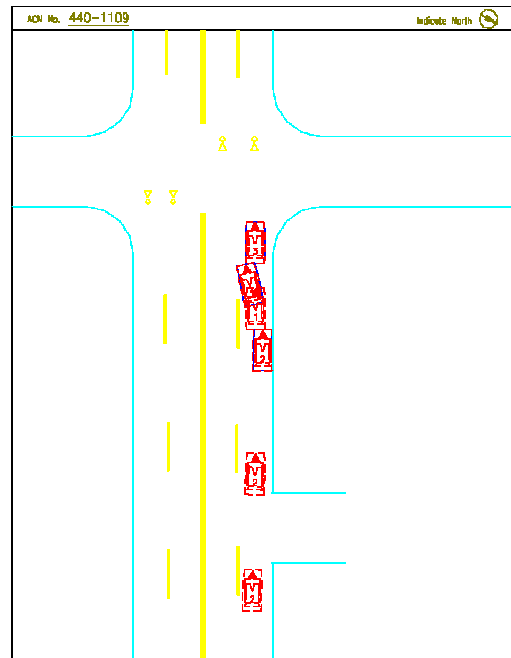


Figure 12. Crash scene diagram for ACN Crash No. 440-1109.

ACN Crash 440-1094

Crash I.D. #440-1094 involved an ACN equipped 1991 Ford Explorer sport utility vehicle that was struck in the left side by a vehicle making a left turn across the Explorer's lane. The Explorer went into a counterclockwise skid and subsequently struck a frozen snow bank on the right side of the road before finally coming to a controlled stop further down the road. The right front passenger of the Explorer was unrestrained and suffered a compressed fracture of a lumbar vertebrae during the event. Figure 6 summarizes the crash, shows photographs of both vehicles involved in the crash and shows the triaxial accelerometer data recorded by the IVM and stored in flash memory. Both the initial impact event and the snow bank impact are clearly seen in the acceleration time history as a positive y acceleration excursion (the initial side impact) followed by a negative y acceleration excursion (the snow bank impact). The IVM calculates the crash delta velocity and the principal direction of force (PDOF) for the crash event, indicates whether a rollover occurred and determines the final rest position of the vehicle after the crash is over (see Figure 13). Figure 14 is a crash scene diagram showing the events of the crash as reconstructed by a crash investigator.

It is interesting to note that the initial side impact crash was not sufficiently severe to trigger the IVM and make a call to the Sheriff. The snow bank impact that occurred subsequent to the side impact was sufficiently severe to trigger the IVM and a call was made to the Sheriff who answered in less than two minutes. There was no visible body damage to the Explorer and it was not clear during post-test reconstruction that the snow bank impact was more severe than the initial side impact. Analysis of the acceleration time history stored in the IVM made it clear that the snow bank impact, resulting in the right front passenger impacting the right interior door panel, was most likely the cause of this occupant's lumbar vertebrae fracture. The availability of a complete acceleration time history for this real world crash led to an improved understanding of the crash kinematics and the injury causative mechanism.

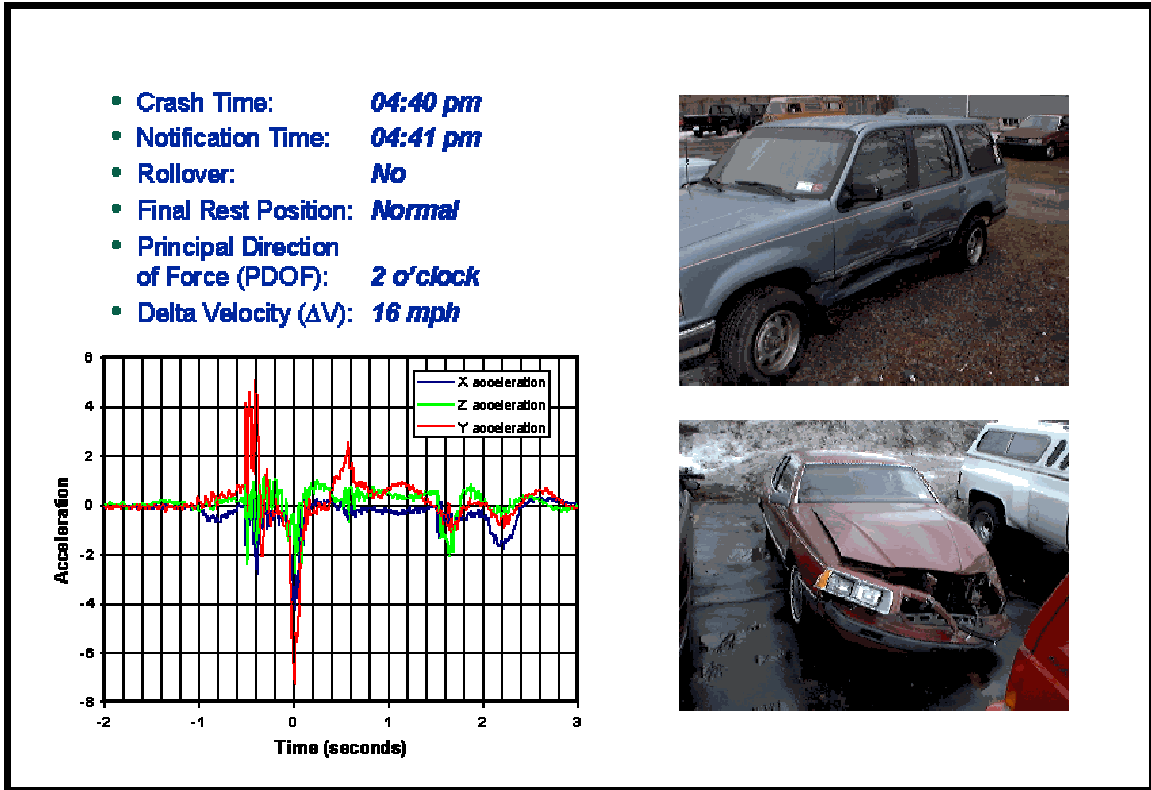


Figure 13. Crash summary for ACN Crash No. 440-1094.

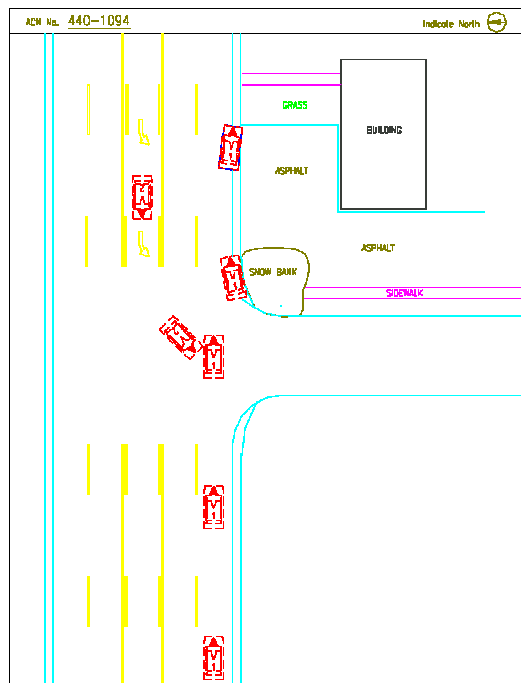


Figure 14. Crash scene diagram for ACN Crash No. 440-1094.

POTENTIAL BENEFITS OF ACN

The principal benefit of the ACN system is a significant decrease in notification and response time for crash injuries. An accurate crash location is provided through GPS and the dispatcher interface displays a map to aid in locating the crash. The ACN system also provides immediate in-vehicle medical assistance, if required, by conferencing the Emergency Medical Dispatchers, located at the Erie County Medical Center with the occupants by cellular telephone. The crash descriptive information and the prediction of injury severity allows the dispatcher to respond to a crash with the appropriate personnel and equipment. The immediate and automatic notification of EMS is especially beneficial in remote areas where a crash may not be observed or a telephone is not available to call for help.

Of particular interest to the crash analyst is the fact that ACN crash acceleration time histories, in digital form, are available for real world crashes. This allows the study of crash injury mechanisms in much greater detail than is normally possible. The acceleration time history can be used as input to occupant simulation models allowing careful study of the occupant kinematics and dynamics. This data will improve understanding of crash mechanics and aid in the development improved countermeasures for preventing or mitigating crash injury.

The ACN field operational test is also providing valuable information regarding institutional and infrastructure issues. The working relationships between and among the various emergency responders and the protocols that must be modified or developed for ACN response are as important as the hardware and the software. For example, a major issue in the development of ACN systems is that of how the initial call is handled. A PSAP such as the Erie County Sheriff might handle ACN calls or a privately operated message center might handle the call and transfer the relevant information to the PSAP. In the first case ACN dispatch stations must be installed at the PSAP location, which may be local or regional, and the crash information is directly available to the EMS dispatcher. In the latter case, the dispatch stations are required only at the message center but the crash information is transferred verbally by telephone or by Fax and is not directly available to the dispatcher.

Conclusions

The ACN system has been implemented in over 700 vehicles in Western New York and is currently providing improved emergency response in a real world environment. The ACN system alerts the EMS dispatcher to an ACN crash in less than two minutes. The system incorporates advanced technology and a more efficient infrastructure to provide immediate notification and response as well as improved communication and crash descriptive information. The ACN system allows the current emergency response system to deal with crashes more quickly and more efficiently. The most effective application of the system is in remote locations where a crash may not be observed and reported or where there may not be a telephone nearby to call for help. The ACN system also provides crash acceleration time histories from real world crashes to aid in understanding crash mechanics. Finally, the ACN program is providing information on institutional and infrastructure issues needed to implement ACN type programs in other locations.

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Veridian

Erie County Medical Center

Erie County Sheriff

Cellular-One

Johns Hopkins University, Applied Physics Laboratory

Erie County Division of Emergency Services