11-30-2003

Evaluation of event data recorders in real world crashes and full-scale crash tests

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Evaluation of Event Data Recorders in Real World Crashes and Full-Scale Crash Tests

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A THESIS

PRESENTED TO THE FACULTY

OF ROWAN UNIVERSITY

IN CANDIDACY FOR THE DEGREE

OF MASTER OF SCIENCE

RECOMMENDED FOR ACCEPTANCE

BY THE DEPARTMENT OF MECHANICAL ENGINEERING

COLLEGE OF ENGINEERING

November 2003

Evaluation of Event Data Recorders in Real World Crashes and Full-Scale Crash Tests

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ACKNOWLEDGEMENTS

I would like to thank:

- My family and friends for all their support throughout my schooling and career.
- Dr. Hampton C. Gabler for affording me the opportunity to complete my thesis at Rowan University.
- The National Academy of Science, Transportation Research Board, National Cooperative Highway Research Board, Project 17-24 for their sponsorship of the project that allowed me to complete this thesis.

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ABSTRACT

With the advent of advanced safety systems in U.S. passenger vehicles, there has been increased interest shown by automakers in recording crash related parameters that ultimately lead to the deployment of these safety systems in what are known as Event Data Recorders (EDRs). Since the only other record of these parameters, specifically crash pulse, comes from staged crash tests in a controlled environment, the advent of the EDR has become increasingly important to crash researchers. The purpose of this study is to quantify the performance of EDRs in full-scale crash tests and real world crashes.

Comparison of EDRs with staged crash tests included 6 General Motors vehicles. The EDRs performed well in staged crash tests reporting delta-V accurately in five of six tests. They were able to report other crash related parameters such as driver seat belt and airbag deployment status accurately in five of six tests as well.

Comparison of EDRs with real world accident reconstructions was performed for 315 General Motors cases and 10 Ford cases from the National Automotive Sampling System Crashworthiness Data System (NASS / CDS) database. Computer generated (WinSmash) values for delta-V showed the tendancy to understimate delta-V for high-speed deployment events and overestimate delta-V for low-speed non-deployment events when compared to the GM EDR. The Ford EDR showed a lack of sufficient recording duration to draw any concrete conclusions on the accuracy of its delta-V value.

CHAPTER 1 – INTRODUCTION AND BACKGROUND

Introduction

Over the course of the past several years, the widespread use of Event Data Recorders (EDRs) in automobiles has given researchers an invaluable tool for evaluating collisions. The recorders, sometimes referred to as "Black Boxes" due to their similarity in function to that of the "Black Box" flight recorders used on commercial and military aircraft, store a given set of parameters providing pre-crash, crash, and post-crash data ranging from set-belt usage to engine performance and vehicle metrics such as acceleration profile. These parameters are stored as an event, which has been defined as anything of interest that may occur during the operation of a vehicle [1].

In most cases, the event of most interest is a collision between the vehicle carrying the EDR and some other foreign object. The parameter of the event that is of most interest to crash researchers is change in velocity often referred to as delta-V or ΔV. Researchers are also interested in vehicle acceleration vs. time, sometimes called crash pulse. EDRs range from very simple to very complex in both design as well as the parameters that they record and store. No matter how simple or complex, EDRs have the ability to have a profound impact on highway safety through data collection. Currently, no standard exists for the manufacture of either these devices -or the data that is measured and stored in the event of a collision.

Background

With the introduction of airbags in the 1970s, vehicles gained the ability to detect crash severity. As restraint device technology advanced, vehicle restraints were grouped together to make up a Supplementary Restraint System (SRS). Beginning with its 1994 model year, General Motors (GM) began incorporating EDRs in certain air bag equipped vehicles after much research and development in 1992 with Indy racecars [2]. In 1997, the National Transportation Safety Board (NTSB) recommended that the National Highway Transportation Safety Administration (NHTSA) should pursue crash information using EDRs [1]. In 1998, the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) issued its "Advanced Airbag Technology Assessment" recommending that NHTSA "study the feasibility of installing and obtaining crash data for safety analyses from crash recorders on vehicles" [3]. As a direct result of this recommendation from the NTSB, NHTSA formed a Working Group whose objective in their August 2001 Final Report was "To facilitate the collection and utilization of collision avoidance and crashworthiness data from on-board Event Data Recorders. [1]" Obviously NHTSA and NASA JPL felt the need for further research into these cutting edge technology EDRs.

Since EDRs are now recording information that was previously only available via crash reconstruction or full-scale crash tests, the question of data validity arises. Now that a sufficient amount of EDR data has been downloaded and compiled, a direct comparison between EDR data / crash investigation data and EDR data / crash tests data can be performed. This will afford crash researchers confidence or uncertainty in the data being recorded by the EDR based on the comparison.

Scope

The purpose of this research is to provide a direct comparison between EDR recorded data and that of full-scale crash tests and accident investigations. Comparing EDR data in this way allows accident researchers to see first hand how well EDRs portray crashes and capture the use of a given vehicle safety systems. The comparison is broken into two categories:

1. Evaluation of EDRs in crash tests
2. Evaluation of EDRs in accident investigations

Real-world EDR data comes from databases that have been compiled by NHTSA. The full-scale crash tests performed by NHTSA involved fully instrumented passenger vehicles crash tested into barriers at known test speeds. Data for both comparisons has been downloaded from the EDR and directly compared to the data compiled in the respective collision. The results are synthesized in this paper.

Applications of EDRs

Many uses have been identified for EDRs, as has been pointed out by the NHTSA EDR WG and several others. Researchers have listed potential uses and benefits that can be obtained from EDRs [4][5][6][7]. Overall, they include:

- Real time (automatic crash notification – ACN)
- Law enforcement, government (regulation)
- Vehicle design
- Highway design
- Insurance / legal (prosecution and defense)
- Research and development

- Owners / drivers (fleet management)

Each of these categories has unique features and refers to a different type of specific application for the data. Some of the benefits from using EDR data have already been exploited. Several research efforts have already been conducted using crash pulse recorders to determine crashworthiness and the severity of particular injury types. For example, Swedish research groups have used thousands of EDR cases for the purpose of analyzing impact effects on neck injuries [8][9][10][11][12][13][14][15]. A study completed in Japan gives insight into the use of EDRs to track exact movement before and after a collision in a fleet of vehicles [16]. Still, other applications of EDRs that have been explored thus far are for safety assessment [17].

Applications such as law enforcement and Automatic Collision Notification (ACN) will become more prominent as the technology becomes more standardized and the data more readily accessible. ACN applies advanced computer communication technology to crash notification. Once an event occurs, information regarding the type of event, its location and other pertinent information such as crash pulse to emergence response units. Several authors have inspected ACN systems [18][19][20][21]. Of course, along with the advent and implementation of such systems there are other issues that need to be addressed such as ownership of the data and standardization regulation.

Current Technology

Two categories of EDRs are currently being installed in motor vehicles: original equipment manufacturer (OEM) devices and aftermarket devices. Currently, the OEMs have tailored their systems around, or more literally "in", the airbag control module. These EDRs are the devices that control restraint system deployment including the seat belt pre-tensioners and airbags as well as record crash information. The aftermarket systems are designed for specific purposes and thus vary in the parameters that they record. Aftermarket systems are also completely independent of the vehicles safety restraint systems including the airbags.

Original Equipment Manufacturer Technology (OEM)

As mentioned above, the OEM EDRs are part of the airbag control module. They record the data that caused the airbag system to deploy or nearly deploy in such cases. Currently, the only OEMs that have publicly released the information regarding their EDR are General Motors (GM) and Ford Motor Company. Other major manufacturers that using EDRs include:

- BMW
- Daimler-Chrysler Corporation
- Honda
- Mercedes-Benz
- Toyota
- Volkswagen
- Volvo

NHTSA has tabulated some of the parameters available or the current state of the EDR by their respective manufacturers in Event Data Recorders [1]. The information that has been made available from GM includes complete download and viewing capabilities of the data stored in their Sensing and Diagnostic Module (SDM). This is accomplished by plugging into either the vehicles On Board Diagnostics (OBD II) port or directly into the vehicles airbag control module with a laptop or personal computer (PC) using the Crash Data Retrieval (CDR) system from Vetronix Corporation. The GM system capabilities are discussed in detail by Correia et al. (2001) [4].

Ford Motor Company's version of the EDR is the Restraint Control Module (RCM). Again this EDR is the airbag control module. In order to access the data from the Ford RCM, a user can again plug into either the On Board Diagnostics (OBD II) port or directly into the airbag control module of the vehicle. Some of the information that has been provided by Ford Motor Company has been published and discussed [6]. A detailed description of the uses and limitations of the Ford RCM has also been included in the Vetronix viewer itself.

Volvo has disclosed information regarding their version of the EDR, the Digital Accident Research Recorder (DARR). Volvo has equipped all models equipped with airbags with DARR [22]. Additional research is required for information with regards to the other OEMs listed above.

Aftermarket Manufacturer Technology

Several different types of aftermarket systems exist on the market today; each type intended for a different purpose and tailored to that particular application. The applications range from racing installations to devices for consumers seeking extra protection in the event of a crash [2][23][24]. Greater detail on the features and applications of the individual aftermarket EDRs are described in the annotated bibliography under Aftermarket Manufacturer Articles.

Thesis Organization

This thesis is broken down into chapters and appendices. Chapter 1 discusses the introduction and background of EDRs, the scope of this research, applications of EDRs and current technology. Chapter 2 compares six GM EDRs to the results from staged crash tests. Chapter 3 evaluates 315 GM EDRs and 10 Ford EDRs in accident investigations. Chapter 4 draws conclusions based on chapters 2 and 3. Chapter 5 is a detailed list of references used throughout the text. The appendices A through E include the following information: the annotated bibliography, the problems encountered with specific EDR cases, GM SDM database elements, Ford RCM database elements, and finally examples of data provided by the Vetronix Crash Data Retrieval Software for both GM and Ford.

CHAPTER 2 – EVALUATION OF EDRS IN CRASH TESTS

Objective

Each year the National Highway Traffic Safety Administration (NHTSA) performs full-scale crash tests on vehicles as part of their New Car Assessment Program (NCAP). Each vehicle that is used in an NCAP test is fully instrumented with sensors to measure vehicle performance including deceleration profile and forces experienced during the collision. The tests are completed with such high quality equipment and care that the results from these tests are considered to be a very reliable source of data.

The results from the NCAP tests provide a means to determine the accuracy of the parameters stored in the EDR. This section compares the data retrieved from several EDRs with that from the lab instrumentation used in NCAP tests.

Description of NCAP Tests

The NCAP test program tests new passenger vehicles in frontal-barrier collisions into rigid walls. Figure 1 shows an NCAP test just after the vehicle contacts the barrier. The vehicles are then given a vehicle safety rating based on their crash performance. Although the vehicles do not get a pass or fail rating, the results are highly publicized. In this way, vehicle manufacturers are forced to improve vehicle safety.

Figure 1. NCAP Test 4476 Ford Crown Victoria – Vehicle After Full -Frontal Barrier Test

Test Configuration

In an NCAP test, the subject vehicle travels at 35 mph (56 km/h) and collides in full frontal engagement with a fixed, rigid barrier. Full frontal engagement implies that the entire frontal structure of the vehicle impacts the barrier as shown in Figure 2. [25]. The vehicle is accelerated to its test speed of 35 mph with the use of a pusher sled. Flammable liquids are replaced with non-flammable fluids similar in density and viscosity to those used in the vehicle.

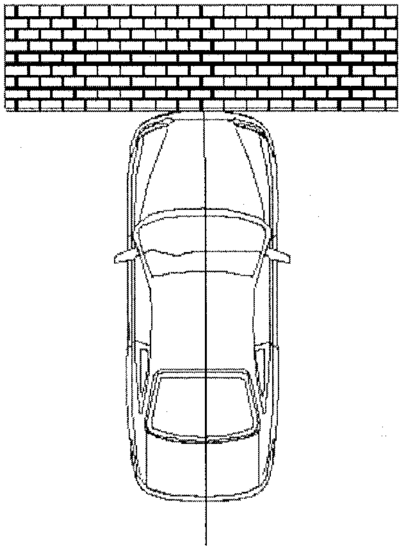

Figure 2. Full Frontal Fixed Barrier

The full frontal fixed barrier crash test is designed to represent a vehicle-to-vehicle full frontal engagement collision with each vehicle traveling at the same initial velocity prior to engagement. Its intent is to represent real world vehicle-to-vehicle and vehicle-to-fixed object collisions with considerable frontal engagement in the perpendicular direction. These rigid barrier tests cause the vehicle to change velocity quickly upon contact with the barrier. For this reason they often produce what is referred to as a "stiff" crash pulse [25]. A crash pulse is defined as the change in acceleration with respect to time.

Federal law requires that all vehicles pass a 30 mph frontal crash test in order for that vehicle to be considered legal for sale and distribution in the United States. NCAP tests are performed at 35 mph making the safety differences between different vehicles more apparent.

Crash Test Dummies

Each vehicle used in an NCAP test is fitted with test dummies in both the right and left front seats. The dummies are belted into the vehicle the same way that an occupant would be if they were operating the vehicle. These dummies are fully instrumented with load cells to measure forces, accelerometers to measure crash pulse, and displacement transducers to measure deflection properties. The sensors used in this type of testing are of very high quality; that is they have very high dynamic response width and wide full-scale ranges on the order of 10 kHz as a minimum.

The dummy currently used in all NCAP tests is the Hybrid III dummy, shown in Figure 3. Since humans vary greatly in both height, weight, and build, the Hybrid III takes the form of what is known as a 50th percentile male. This means that the dummy takes its dimensions from what is considered to be an average male passenger based on the U.S. Census. Other types of dummies exist to simulate other size occupants such as the 95th percentile male, which is considered to be larger and heavier than 95 percent of all males, and the 5th percentile female, which is considered to be smaller that 95 percent of all females. Having test dummies of various sizes and weights allows crash researchers to better cover the broad spectrum of body sizes and weights common to the general public.

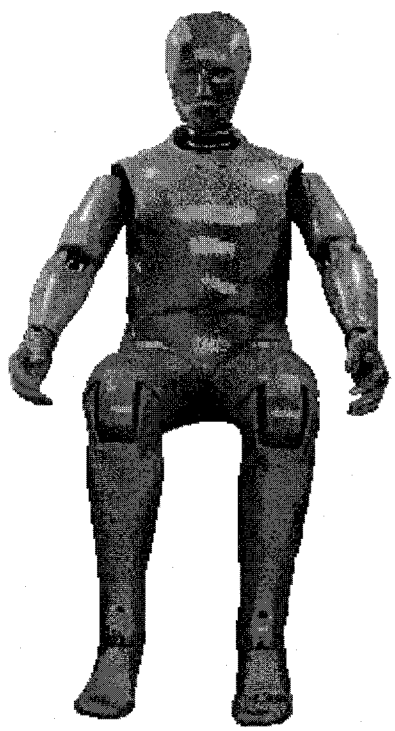

Figure 3. Hybrid III Dummy

Typical test dummies are instrumented with sensors located in the head, neck, chest, pelvis, tibia / fibula, and femurs. Readings from these sensors allow researchers to gage the forces and accelerations experienced by an occupant (the crash dummy in this case) in a crash. Based on these measurements, the vehicles are rated for safety.

Table 1 shows the ratings that are given to vehicles based on their performance in these tests. Note that serious injuries are those that require immediate medical attentions or hospitalization and may even be life threatening. A five star rating is the best possible rating while a one star rating is the worst [26].

Table 1. Vehicle Safety Rating Based on Crash Test Performance

Rating	Definition
5 Star	<= 10% Chance of serious injury.
4 Stars	11-20 % Chance of serious injury.
3 Stars	21-35 % Chance of serious injury.
2 Stars	36-45 % Chance of serious injury.
1 Stars	>= 46% Chance of serious injury.

Vehicle and Barrier Instrumentation

Vehicles used in NCAP tests are typically instrumented with a number of accelerometers to measure crash pulse. Their locations may vary depending on vehicle body type and style, however the most common locations are under the seats (on the seat frames themselves), on the engine, on the brake calipers, on the dash panel, and on the doorsills. Sensor location is important as it affects the type of crash pulse recorded.

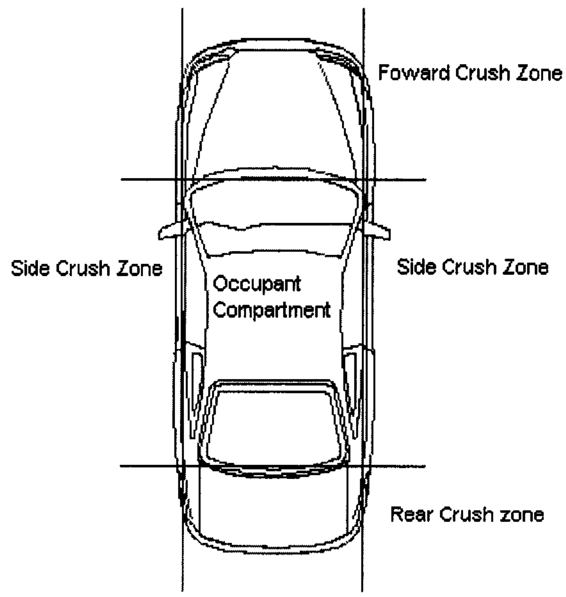

Figure 4. Vehicle Zones

Modern automobiles are designed in zones with regard to collisions as shown in Figure 4. The two different types of zones are the crush zones and the occupant compartment. The crush zones are located in the front and rear of the vehicle and to some extent, in the vehicle doors. The front crush zone begins at the front bumper and stops at the vehicles firewall located behind the engine forward of the dash panel. The rear crush zone begins at the vehicles rear bumper and ends at the rear firewall or trunk area. The doors themselves are also designed as crush zones to protect the occupant compartment from side impacts. The occupant compartment, as its name implies, houses the occupants and secures them in their respective seats.

Crush zones of the vehicle are designed to soften the impact of a collision by crushing in a controlled way as to absorb some of the collision energy and protect the occupant compartment (and thus the occupants). In a full frontal collision, sensors located forward of the occupant compartment i.e. those on the front brake calipers and engine tend to record pulses that are more severe as they lie in the vehicles crush zone. Again, since this area is designed to absorb the energy of a collision, it records a more severe crash pulse. Sensors located in the vehicles occupant compartment record a slightly less severe or "softer" crash pulse as the crush zone has already absorbed some of the collision energy.

The barrier shown in Figure 2 is instrumented with load cells. A grid of 36 load cells or force transducers four high and nine across spans the barrier and measures the forces applied by the colliding vehicle. A frontal schematic of the barrier is shown in Figure 5. When measured, the data from these load cells can then be summed to get the total load on the barrier.

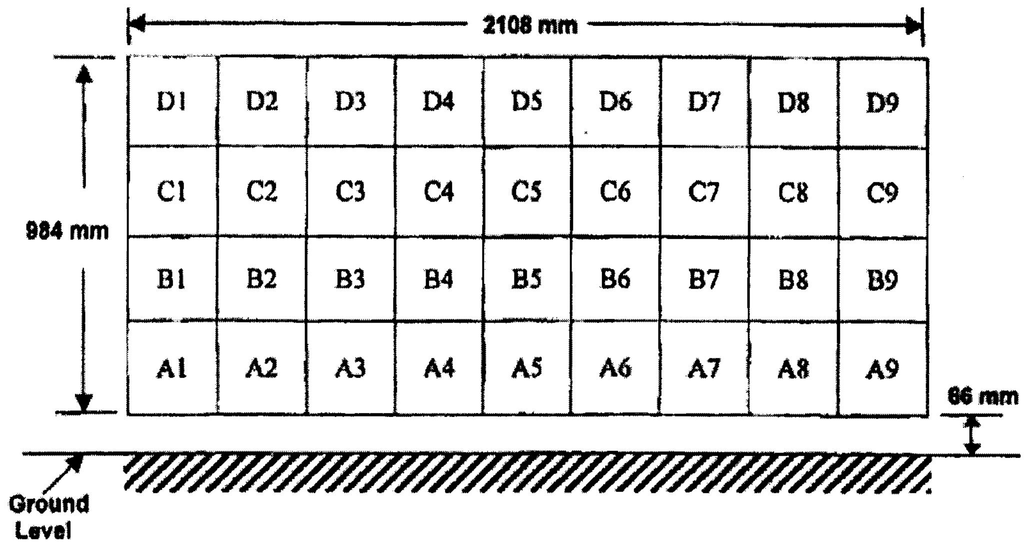

Figure 5. Rigid Barrier with 36 Load Cell Array labeled using the NHTSA Standard Convention

NCAP Tests: EDRs vs. NCAP Lab Instrumentation

Since some of the vehicles used in NCAP tests contain EDRs, a comparison of the crash pulse recorded by the NCAP test accelerometers and the crash pulse recorded by the EDR is possible. EDRs are often located under the seats or in the dash panel but more importantly in the occupant compartment. Knowing this, an accelerometer must be chosen from the NCAP test that is located somewhere in the occupant compartment, as well, in order for the comparison to be viable. Choosing an appropriate accelerometer is then simply a matter of finding one that is located somewhere in or on the occupant compartment of the test vehicle and comparing it to the EDR velocity-time profile.

The first step in making this comparison is to obtain EDR data from vehicles that were used in NCAP tests. Table 2 shows the NHTSA NCAP test number and the respective vehicles for six (6) such tests. Note that all the vehicles are General Motors (GM) vehicles. The GM version of the EDR is the Sensing and Diagnostic Module (SDM). From this point forward, we will refer to the EDRs in this chapter specifically as SDMs since they are all GM vehicles.

Table 2. NCAP Test Vehicles with Sensor Number and Location

NHTSA Test No.	Vehicle Model Year	Vehicle Make	Vehicle Model	Sensor / Channel No.	Sensor Attachment
3851	2002	Chevrolet	Avalanche 1500 4x4 Utility	107	FloorPan – Left Rear
3952	2002	Buick	Buick Rendezvous 4x4 Utility	107	FloorPan – Left Rear
4198	2002	Saturn	Vue	101	FloorPan – Left Rear
4244	2002	Chevrolet	Trailblazer	98	Seat – Left Rear
4472	2003	Chevrolet	Silverado	89	Sill – Left Rear
4487	2003	Saturn	Ion	89	Sill – Left Rear

Comparison Methodology

This section describes the methodology used in comparing the NCAP test deceleration profile against the SDM recorded deceleration profile.

Preparing the NCAP Data

Using the test number and sensor number, anyone with access to the World Wide Web can download and plot the curves listed via NHTSA's website [27]. After obtaining the appropriate test number and loading the website, clicking on the test number brings up a screen which contains all of the tests sensor information in several different formats. From here, the complete file of sensor information is downloaded in NHTSA UDS-1992 format. Now an appropriate sensor must be chosen from the list using the "Instrumentation Information" section of the respective test screen. The "Instrumentation Information" section breaks down the complete list of sensors by Curve No., Test No., Vehicle No., Sensor Type, Sensor Location, Sensor Attachment, Axis Direction of Sensor, Date Measurement Units, and Data Status. A sensor is chosen based on sensor type: accelerometer (units in G's or acceleration), sensor attachment: somewhere in or on the occupant compartment, axis direction of sensor: X-Global.

Once a sensor number is chosen, that sensor data is viewed using the NHTSA PlotBrowser software. The data are integrated from acceleration into velocity and zeroed with respect to time. It is then filtered at 60 Hz per SAE J211-1 [28]. PlotBrowser allows users to easily and quickly perform these operations. The data is checked for validity based on the user's knowledge of deceleration profiles and a comparison to other sensors in the vehicle occupant compartment.

With an acceptable deceleration profile decided upon, the data must be saved and exported into Microsoft® Excel. This is done in PlotBrowser by clicking File, Save, ASCII and saving the data. ASCII format allows the data to be opened in Microsoft® Notepad, which can then be cut and pasted directly into Excel. The velocity profile of the chosen sensor can now be plotted.

Preparing the GM SDM Data

The data contained in the GM SDM must be extracted using the Vetronix Crash Data Retrieval (CDR) Tool. Each SDM must be plugged into the CDR and downloaded to the personal computer (PC) via the Vetronix software. With the data downloaded, it can be viewed using the Vetronix software. From here, the user must manually enter the data into Microsoft® Excel. Since the SDM used in the NCAP test contains velocity-time data, it can now be plotted against the data from the NCAP test velocity profile described in the previous section.

Matching the GM SDM Data to the NCAP Data for Plotting

Matching the SDM data to the NCAP data posed a challenge. In an NCAP test, time zero corresponds to the time when the vehicle first comes into contact with the load cell barriers. The SDM does not record the change in velocity at time equal zero because there is no velocity change before the event occurs i.e. the velocity is considered to be constant before the collision yielding a change in velocity or delta-V equal to zero (acceleration / deceleration zero). This means that in order to overlay the NCAP data on the SDM data, the SDM data must have an initial point inserted. This initial point is the initial velocity of the vehicle corresponding to time equals zero.

In addition, the SDM records the velocity profile of the vehicle with respect to the vehicle whereas the NCAP instrumentation records the velocity profile of the vehicle with respect to the ground. This means that for a vehicle traveling at a constant velocity, the SDM would record a change in velocity (delta-V) of zero. When the vehicle decelerates as in a collision, the SDM records the change in velocity (delta-V) as a negative value. The NCAP instrumentation records the same velocity profile, but starts from the initial velocity of the vehicle and decelerates toward zero velocity; the same thing that would be seen if an onlooker watched the vehicle hit the barrier. To compensate for the difference between the two recording methods, the initial velocity of the vehicle was added to each of the change in velocity (delta-V) values recorded by the

SDM. With this completed, the two sets of data will both start at the initial velocity of the vehicle and decelerate towards zero velocity.

GM SDM vs. NCAP Velocity Profile Comparison

The following graphs present a comparison between SDM and NCAP sensor velocity profiles. NHTSA removed the GM SDMs from the vehicles following the crash test, and Rowan University downloaded the SDMs to obtain their velocity profiles. The velocity profile as measured by the crash test instrumentation and recorded by the SDM were plotted on an overlay graph so that a direct comparison could be made. Percentage differences are taken with respect to the NCAP measurements as the laboratory grade instruments used in the NCAP tests are far more precise than the SDMs and can be cross-referenced easily against other NCAP sensors to check for validity.

NHTSA Test 3851

NHTSA test 3851 was performed on a 2002 Chevrolet Avalanche 1500 4x4 Utility. Channel 107 was chosen for comparison with the SDM data. This channel was an accelerometer on the left rear floor pan of the vehicle. This sensor was chosen because like the SDM, it is located in the non-deformed occupant compartment.

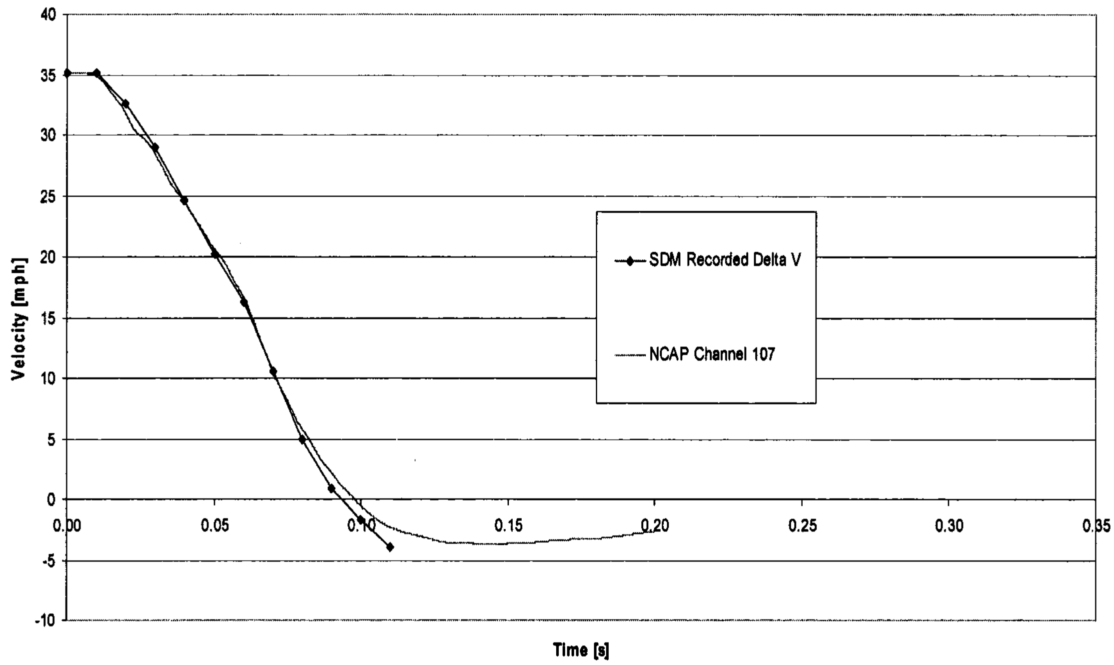

Figure 6. - NHTSA NCAP Test 3851 SDM vs. NCAP Delta V

As seen in Figure 6, the curve looks smooth and matches extremely well with the SDM velocity profile for the first 0.08 seconds. The change in velocity for that interval is roughly 30 mph, well over the threshold that would deploy the safety systems such as the airbags and seatbelt pretensioners. After this point, the SDM and the NCAP sensors seem to deviate from each other slightly before the SDM stops collecting data at 0.11 seconds. This deviation leads to a slightly different value for the maximum velocity change recorded by the two devices. The SDM recorded a maximum velocity change of 39.05 mph whereas the NCAP accelerometer recorded a maximum velocity change of

38.87 mph. The difference in maximum velocity change between the SDM and the NCAP accelerometer is 0.46 %.

NHTSA Test 3952

NHTSA test 3952 was performed on a 2002 Buick Rendezvous 4x4 Utility. Channel 107 was chosen for comparison with the SDM data. The accelerometer location was on the left rear floor pan of the vehicle.

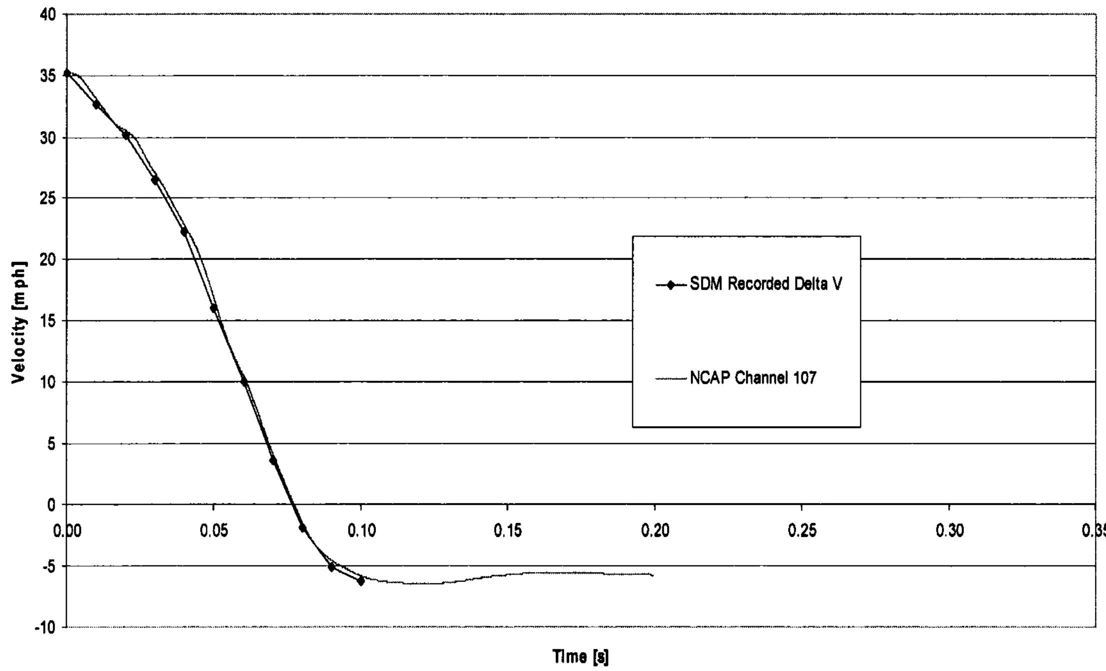

Figure 7. - NHTSA NCAP Test 3952 SDM vs. NCAP Delta V

Figure 7 shows the velocity profiles of both NCAP channel 107 and the SDM recorded delta-V. These two deceleration profiles match extremely well throughout the entire 0.10 seconds. Though the SDM stops recording at 0.10 seconds, the SDM maximum-recorded velocity change is 41.39 mph. The NCAP accelerometer maximum-recorded velocity change is 41.63 mph. The data matches well as indicated by the 0.58 % difference.

NHTSA Test 4198

NHTSA test 4198 was performed on a 2002 Saturn Vue. NCAP channel 101 was chosen for comparison. Attachment for the accelerometer was on the left rear floor pan in the occupant compartment.

NHTSA test 4198 experienced a time shift in its SDM data; where the first point recorded by the SDM was a delta-V = 0 at 0.01 seconds. With the initial point of delta-V equal zero at time equal zero inserted, the first two values of the SDM recorded delta-V would have been equal to zero. Obviously, this did not match the NCAP data that began recording velocity values at time equal to zero. Moving the first point recorded by case 4198's SDM to time equal zero and shifting the rest of the SDM data back in time respectively compensated for this. Total time shift for the SDM was negative 0.02 seconds. This adjustment made the SDM data match the NCAP data well.

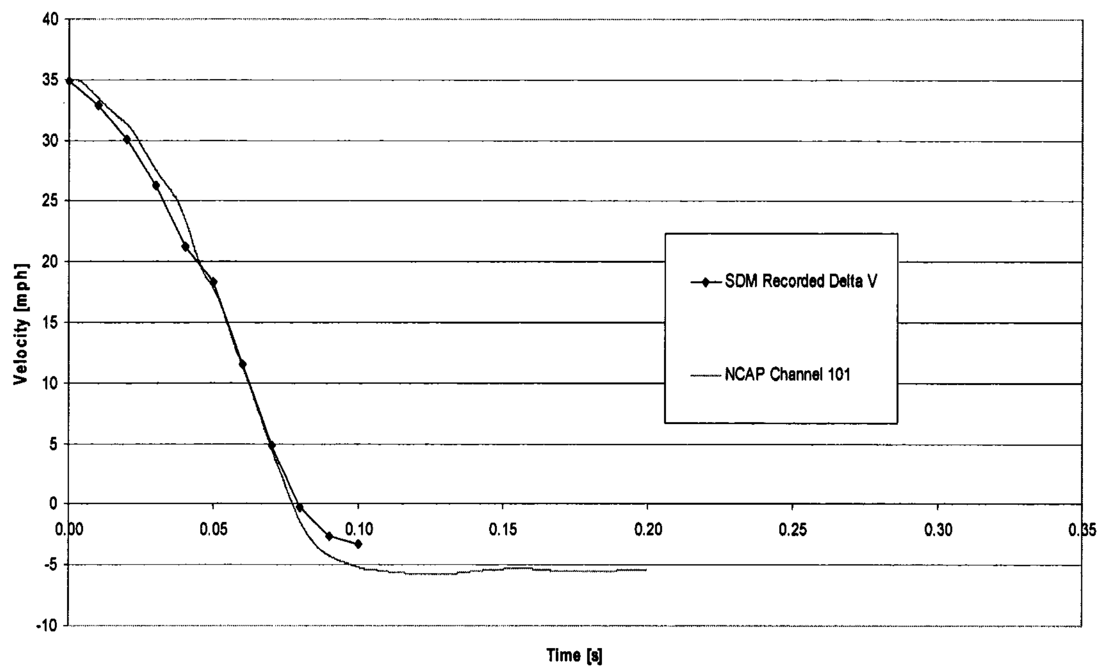

Figure 8. - NHTSA NCAP Test 4198 SDM vs. NCAP Delta V

As seen in Figure 8, the profiles deviate from each other slightly for the first 0.04 seconds and then coincide from 0.04 to 0.08 seconds. The SDM deceleration profile does begin to flatten off after 0.08 seconds, sooner than the NCAP channel 101 profile. This is noted by the difference in maximum-recorded velocity changes of the SDM (38.31 mph) and NCAP sensor 101 (40.72 mph), a 5.92% difference with respect to the NCAP maximum delta-V.

NHTSA Test 4244

NHTSA test 4244 was performed on a 2002 Chevrolet Trailblazer. The NCAP channel 98 was chosen for the comparison. The attachment for this accelerometer was on the left rear seat in the occupant compartment.

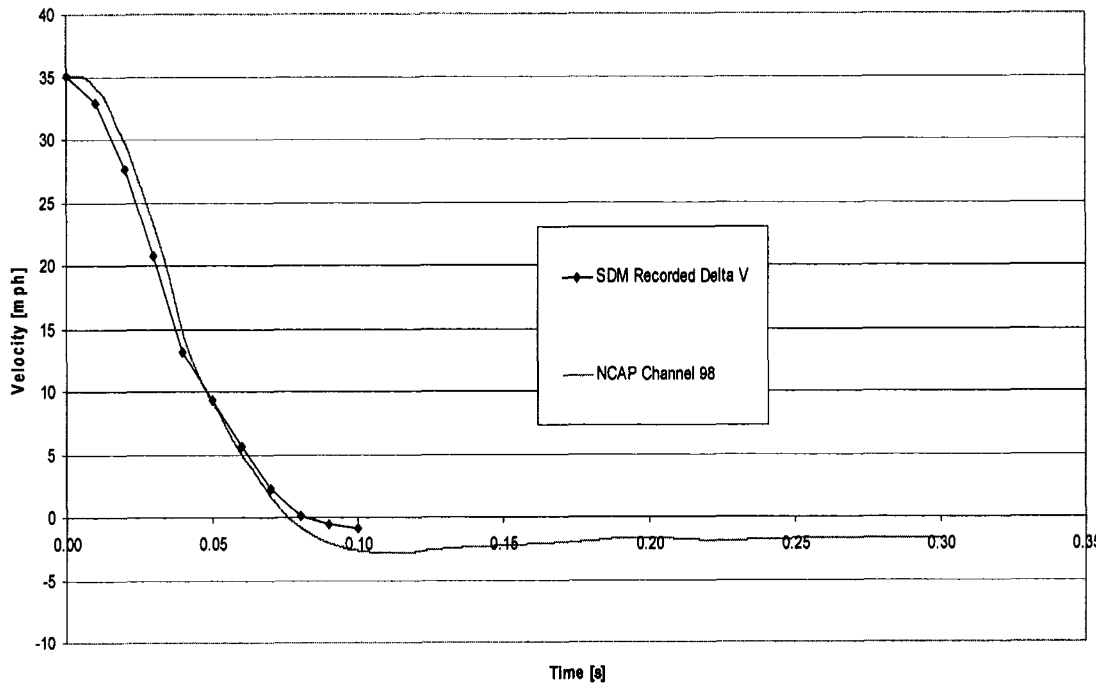

Figure 9. - NHTSA NCAP Test 4244 SDM vs. NCAP Delta V

Figure 9 shows the velocity profiles of NCAP channel 98 and the SDM recorded delta-V. Again a slight deviation occurs in the beginning of the deceleration profile until about 0.04 seconds, then coincides between approximately 0.04 and 0.07 seconds. After 0.07 seconds, both the SDM and the NCAP data begin to flatten out, though the SDM data does so at a greater rate. Maximum-recorded velocity change from the SDM was 35.96 mph, while the maximum-recorded velocity change from the NCAP sensor was 37.92 mph, resulting in a 5.17 % difference.

NHTSA Test 4472

NHTSA test 4472 was performed on a 2002 Chevrolet Silverado. NCAP channel 89 was chosen for the comparison. The attachment for the accelerometer was on the left rear doorsill of the occupant compartment.

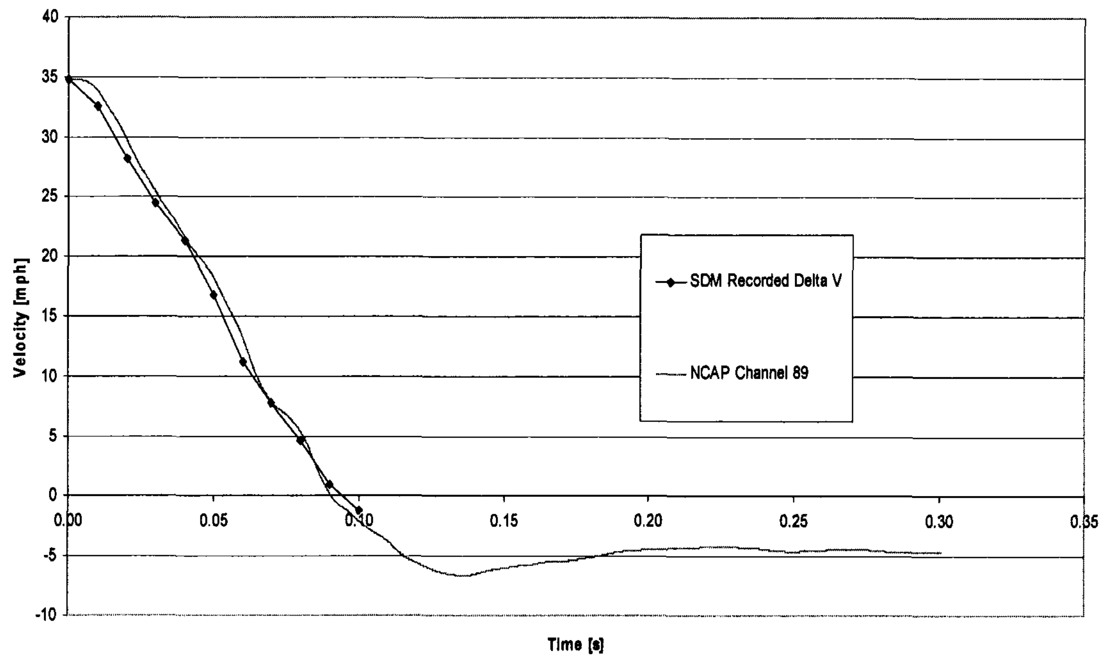

Figure 10. – NHTSA NCAP Test 4472 SDM vs. NCAP Delta V

Figure 10 shows the velocity profile of both NCAP channel 89 and the SDM recorded delta-V. These two curves cross each other several times generally resulting in a good average approximation by the SDM for the actual crash pulse experienced by the vehicle during the collision. The data recorded by the SDM again falls short of the data recorded by the NCAP accelerometer, though this time the resulting capture of the maximum-recorded velocity change is drastic. Due to the SDM not recording for a longer duration, it only captures an SDM maximum-recorded velocity change of 35.96 mph at 0.10 seconds. NCAP sensor 89 recorded a maximum velocity change of 41.39 mph at 0.137 seconds, about 0.03 seconds later. The trend shows that the SDM probably would have recorded the maximum velocity change experienced by the vehicle if it had kept recording data. Since the SDM stopped recording, it reported a maximum-recorded velocity change that was 13.12 % less that that reported by NCAP channel 89 which is a significant error.

NHTSA Test 4487

NHTSA test 4487 was performed on a 2002 Saturn Ion. NCAP channel 89 was chosen for the comparison. The accelerometer attachment was on the left rear doorsill on the occupant compartment.

It does not seem that the channel 89 deceleration profile returns to steady state at the end of its recording time. The sensor was checked against other sensors in the occupant compartment for clarity and all behaved in the same manner. This appears to be due to a slight bias error in the crash test accelerometer.

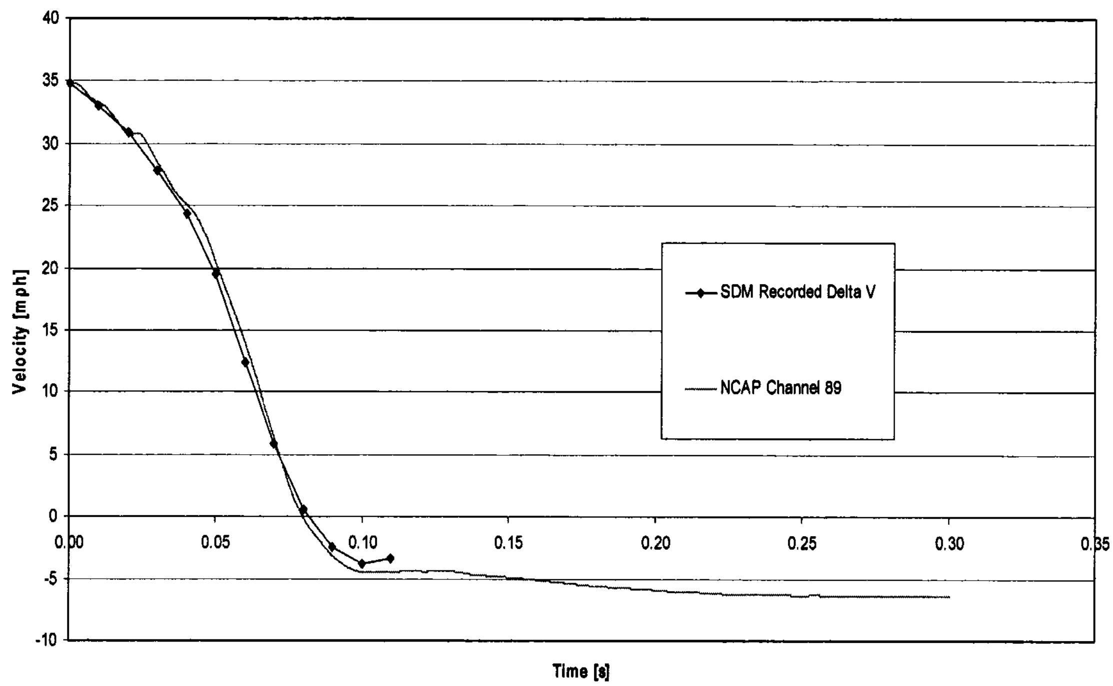

Figure 11. – NHTSA NCAP Test 4487 SDM vs. NCAP Delta V

Figure 11 shows the velocity profiles of NCAP sensor 89 and the SDM recorded delta-V. The curves match up very well throughout the entire deceleration profile, with every point recorded by the SDM falling approximately on the curve recorded by NCAP sensor 89 until the last two points. At 0.10 and 0.11 seconds, the SDM and the NCAP sensor deviate, with the SDM recording a smaller change in velocity that the NCAP sensor. This results in a slightly smaller maximum-recorded velocity change reported by the SDM. The SDM recorded a maximum velocity change of 38.61 mph, while the NCAP accelerometer recorded a maximum velocity change of 39.34 mph, resulting a 1.86 % difference.

NHTSA Test Comparison Summary

After completing the comparisons of the EDR velocity profiles versus the NCAP recorded velocity profiles, we can see that the GM SDM accurately captures the data. Table 3 gives a summary of each test along with the maximum recorded velocity changes for each and the percent error. Although the values for percent error are included in the text for each case, Table 3 displays the data in summary format. Test 4472 shows a large error of 13.12 %, however the SDM failed to capture the entire event in this case.

Table 3. NHTSA Test Comparison Summary

NHTSA Test No.	NCAP Sensor / Channel No.	NCAP maximum recorded delta-V [mph]	GM SDM maximum recorded delta-V [mph]	% Error
3851	107	38.87	39.05	0.46 %
3952	107	41.63	41.39	0.58 %
4198	101	40.72	38.31	5.92 %
4244	98	37.92	35.96	5.17 %
4472	89	41.39	35.96	13.12 %
4487	89	39.34	38.61	1.86 %

GM SDM vs. NCAP Crash Parameters

Several of the parameters stored in SDMs are also reported in the NCAP test results. The following presents the results of the six test SDMs vs. NCAP test results in each of the respective categories.

GM SDM vs. NCAP Reported Seat Belt Usage

Since SDMs record the driver seat belt status, it is possible to evaluate their recorded status. All NCAP test dummies are fully belted into their seats prior to conducting the test, so NCAP driver seat belt status prior to impact will always be buckled in no uncertain terms. What we are interested in is finding if the SDM ever reports that the driver seat belt status is unbuckled. This would indicate a malfunction of the in car seat belt sensor detection circuit.

Table 4 shows the results from the six test vehicles. As would be expected all the SDMs correctly reported the status of the driver seat belt as buckled. Since the sample size is small, the results of the comparison do not make the SDM reported findings definitive, however they provides a good basis for comparison and a starting place for which a larger sample study should turn its attention.

Table 4. GM SDM vs. NCAP Driver Seat Belt Usage Status

NHTSA NCAP Test Number	SDM Reported Driver Seat Belt Status	NCAP Driver Seat Belt Status
3851	Buckled	Buckled
3952	Buckled	Buckled
4198	Buckled	Buckled
4244	Buckled	Buckled
4472	Buckled	Buckled
4487	Buckled	Buckled

GM SDM vs. NCAP Reported Airbag Deployment Status

Airbag deployment status can also be derived from the SDM when viewed with the Vetronix CDR tool. If the event is recorded as a deployment event, it will be available in the Vetronix CDR as a deployment event on the pull down viewing menu; otherwise the event is available as a non-deployment event on the pull down menu.

Because 35 mph full frontal fixed barrier tests are severe, the subject test vehicles airbags should all have deployed. Once again, all the vehicle airbags deployed as shown in Table 5. As stated above, due to the small sample size no definitive findings can be made though a larger study should definitely include a comparison such as this.

Table 5. GM SDM vs. NCAP Airbag Deployment Status

NHTSA NCAP Test Number	SDM Reported Airbag Deployment Status	NCAP Airbag Deployment Status
3851	Deployed	Deployed
3952	Deployed	Deployed
4198	Deployed	Deployed
4244	Deployed	Deployed
4472	Deployed	Deployed
4487	Deployed	Deployed

GM SDM vs. NCAP Initial Velocity – Pre-Crash Event

The test vehicle SDMs all had the capability of recording some pre-crash information such as vehicle speed, engine speed (in rpm), percent throttle, and brake switch status. NCAP tests require that the vehicles pre-crash speed be closely monitored to ensure that the vehicle contacted the barrier at the minimum appropriate speed without going too fast. This is accomplished with the use of a laser speed indicator accurate to within 0.01 mph. An interesting comparison is how well the SDM measured the pre-crash speed versus the actual pre-crash speed measured by the NCAP laser sensor. It is important to note that the SDM can only measure the pre-crash speed to within the nearest 1 mph.

Table 6. GM SDM vs. NCAP Initial Velocity – Pre-Crash Event

NHTSA NCAP Test Number	SDM Reported Initial Velocity Status [mph]	NCAP Measured Initial Velocity [mph]	% Error (Based on NCAP Velocity)
3851	35	35.17	0.48 %
3952	35	35.17	0.48 %
4198	35	34.98	0.06 %
4244	34	35.10	3.13 %
4472	35	34.73	0.78 %
4487	35	34.83	0.49 %

Table 6 shows the SDM reported initial velocity versus the NCAP measured initial velocity and the percent error with respect to the NCAP measurement. All of the test vehicles reported a pre-crash velocity of 35 mph with the exception of test 4244. The report of 34 mph, approximately 3% difference, is something of concern. This result does correspond however with the findings of another study where SDMs overestimated vehicle speed by up to 1.5 km/hr (0.9 mph) during low speed collisions and underestimated vehicle speeds by up to 3.7 km/hr (2.3 mph) during high speed collisions, which occurred in this particular case [29]. The fact that over / underestimates occur explains the incorrect report of initial velocity from the SDM in NCAP test 4244.

Presence of Non-Deployment Event

The vehicles used in the NCAP full frontal fixed barrier tests are new. Since they are new, they should not have anything recorded in their SDM. Therefore when the tests are completed, there should only be deployment data recorded in the SDM since the event was comprised of only a deployment event i.e. a collision significant enough to deploy the supplementary restraint system. Presence of a non-deployment event signifies that some other event must have occurred from the time the vehicle was purchased until the time that the testing was completed. Table 7 shows each test and its respective status as having recorded deployment / non-deployment as well as the corresponding ignition cycle times that go with each type of event recorded.

Table 7. GM SDM vs. NCAP Presence of Non-Deployment Event

NHTSA NCAP Test Number	SDM Reported Deployment Event	SDM Reported Non-Deployment Event	SDM Reported Ignition Cycles at Deployment	SDM Reported Ignition Cycles at Non-Deployment	SDM Reported Max Delta-V at Non-Deployment
3851	X		76		N/A
3952	X	X	171	171	-0.48
4198	X	X	74	19	-0.62
4244	X		67		N/A
4472	X	X	93	93	-0.33
4487	X	X	61	55	-0.12

Looking at individual events may help to explain what happened and why a new car would contain a non-deployment event. NCAP test 3851 reported a deployment event at 76 ignition cycles and no non-deployment event. This was also the case with NCAP test 4244, a deployment event occurred at 67 ignition cycles and no non-deployment was recorded, but what about the other cases?

NCAP test 3952 reports a deployment and non-deployment event both occurring at 171 ignition cycles. The same with NCAP test 4472, this time at 93 ignition cycles. This phenomenon of the deployment and non-deployment event occurring in the same ignition cycle is strange but could happen for several reasons. One possible reason could be that as the test vehicle was accelerated up to its 35 mph impact speed, it hit a bump or other such groove in the test track with a high enough change in velocity (delta-V) to cause the SDM to record the event as a non-deployment event. Another reason could be the engagement of the pusher sled to the vehicle after the ignition is turned on. The sled must fully engage the vehicle before the test can begin, and this is usually done after all the sensors are checked and the test vehicles ignition turned on. None of the events recorded as non-deployment events had a greater delta-V than –0.31 mph. The deployment events experienced much higher delta-Vs than this for the same ignition cycles.

NCAP tests 4198 and 4487 experienced a non-deployment event prior to the deployment event recorded by the SDM for the actual test. This could be for any number of reasons. The vehicle may have hit a small curb or even a pothole on its way from the dealer to the test facility. Its ignition may have been left on during transport on a vehicle car carrier, causing the SDM to record information as the vehicle bounced against its chain binders as it was carried down the highway at 65 mph. Cases where the SDM records a non-deployment event prior to the deployment event can happen for a number of different reasons.

Summary

The goal of this section was to compare the data retrieved from several EDRs with that from the lab instrumentation used in NCAP tests. The results of the comparison show that the GM SDMs used in the NCAP tests record the vehicle delta-V profile well. With the exception of a small time shift in one of the subject cases, the GM SDMs accurately portrayed the vehicles velocity profile during the collisions. They were also reliable in reporting the collision maximum velocity change to within about 5 percent. All the GM SDMs were able to correctly gather safety systems status such as driver seat belt and airbag deployment. Again with one exception, the GM SDMs were accurate in predicting pre-crash speeds to the best of their ability. Though the sample size of this particular study is small, the results give users of GM SDM data confidence that the data reported is both accurate and correct.

CHAPTER 3 – EVALUATION OF EDRS IN ACCIDENT INVESTIGATIONS

Objective

Over 6 million police recorded collisions occur on United States highways each year [30]. Several thousand of these collisions are investigated each year in painstaking detail by NHTSA accident investigation teams, automobile manufacturers, and insurance companies. Reports on the investigated accidents include various parameters relating to the crash such as detailed photographs of the crash scene, presence of skid marks, collision debris left behind from the vehicles, make, model, and year of each vehicle, and injuries sustained by the occupants.

Several parameters determined by the accident investigation teams visually are also recorded by the vehicle event data recorder (EDR) electronically if the vehicle involved in the collision is so equipped. With the information downloaded from the EDR, there is a means of comparison between the EDR recorded information and the accident investigation team recorded information.

This section provides a statistical analysis of an EDR database developed at Rowan University. The database contains information from both the accident investigation teams and the information downloaded from the corresponding EDR. Comparisons are made and conclusions are drawn based on those comparisons.

Collection of Case Data

NHTSA collects EDR records from several hundred crashes every year. These cases are investigated as part of NHTSA's Special Crash Investigations (SCI), National Automotive Sampling System / Crashworthiness Data System (NASS / CDS) and Crash Injury Research and Engineering Network (CIREN) studies [5]. The data collected under these databases is used to help accident investigators better understand collisions so that they can improve highway safety. This is accomplished by allowing researchers to find specific information in an orderly manner and draw conclusions based on this information.

In order for a case to qualify for entry into any of the databases mentioned above, a police accident report (PAR) must be completed. The case must include at least one motor vehicle and have resulted in property damage, injury, or death. Cases files are then collected via detailed reports and entered into their respective databases.

National Automotive Sampling System (NASS)

The NASS database is comprised of two separate databases, the Crashworthiness Data System (CDS) and the General Estimates System (GES). NASS was established in 1979 as part of an effort to improve on our nation's highway systems through research and development. The NASS database contains detailed information on a random sample of hundreds of thousands of crashes ranging from minor to fatal involving vehicles from cars and light trucks to large trucks and vans. Primary users of the database include scientists and engineers who attempt to analyze and quantify vehicle collisions and their associated injuries. [31]

Crashworthiness Data System (CDS)

NASS crash research teams across the country, known as Primarily Sampling Units (PSUs), gather detailed information on about 5,000 crashes each year. Cases are selected at random from those entered with valid PARs. The accident investigation teams are trained to obtain crash site data such as vehicle skid marks, fluid spills, glass or broken vehicle debris left behind from the collision, and guard rail damage. The vehicles themselves are located, photographed, measured for damage as a result of the crash, and the interiors searched for locations stuck by the occupants. Figure 12 shows a vehicle being measured for crash damage / deflection with a typical gauge used by the PSU teams. [32]

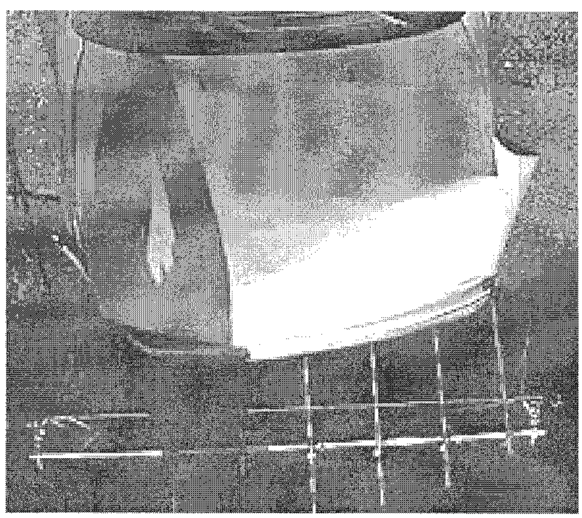

Figure 12. Vehicle with Gage in Place for Crash Damage Measurement

Crash victims are interviewed and medical records reviewed to quantify the extent of the victims' injuries. PSU teams are interested only in information that will help them to understand the nature of the crash. Personal information about those involved in the crash are not included in any NASS file. [32]

Currently there are 27 PSUs located across the country. These 27 PSUs are quality controlled by 2 NASS Zone Centers. The Zone Centers coordinate and supervise the PSUs, checking all cases to ensure completeness and quality of data, as well as keep the PSUs informed of any changes to functional and administrative procedures. The Zone Centers are responsible for keeping the PSUs up to date on the latest techniques, procedures, vehicle components, hardware and software. [32]

General Estimates System (GES)

The General Estimates System, or GES, was created in 1988. Its primary purpose was threefold:

1. Identify traffic safety problem areas.
2. Provide a basis for regulatory and consumer initiatives.
3. Form the basis for cost and benefit analyses of traffic safety initiatives.

The information is then used to estimate how many different kinds of motor vehicle crashes take place and what results from their occurrence. Though only about one half of the motor vehicle crashes that take place in a given year are reported to the police, most of the unreported crashes are minor often resulting in little to no property damage or personal injury. By limiting GES cases to those that have PARs, the GES database focuses on collisions that are of the greatest concern to highway safety. [33]

Special Crash Investigations (SCI)

The National Center for Statistics and Analysis (NCSA) Special Crash Investigations (SCI) program has been providing the most detailed level of crash investigations for NHTSA since 1972. Hundreds of data elements pertaining to the vehicle, occupants, roadway, and safety systems are collected for each study. Over 200 crashes are designated for the study each year; its data ranging from police accident reports and insurance reports to special reports put together by trained accident investigation teams [34]. These investigations include detailed crash scene information such as debris, skid marks, and existence of roadside barriers.

The intent of the SCI cases is to provide supplemental and special crash information for examining the outcomes of a crash from an engineering perspective. The main benefit of SCI is its ability to provide extremely detailed crash information on crashes almost anywhere in the country to investigators in a timely fashion. [34]

Crash Injury Research & Engineering Network (CIREN)

The Crash Injury Research and Engineering Network (CIREN) was started in 1996 and is exactly what its name implies; a computer network based on a collaboration of research on crash injuries taken at ten Level 1 trauma centers across the country. Level 1 Trauma Centers are "teaching" institutions usually associated with a university. By using this network, researchers can review data and share expertise. Funding for the trauma centers come from several sources. Seven are funded by NHTSA, one by Mercedes-Benz, one by Ford, and one is self-funded (The Froedtert Hospital & Medical College of Wisconsin). [35]

CIREN collects information from about 400 cases per year. It contains many parameters from severe crashes, including crash reconstruction and detailed medical injury profiles. Discriminating information such as personal and location identifiers have been removed from the CIREN files to preserve patient confidentiality. All CIREN cases that have undergone quality control and coding are available for public viewing, and additional cases are released as they become available. [35]

Description of the Rowan University GM SDM Database

Prior to March 2003 the only NASS cases with EDR data were those cases involving General Motors (GM) vehicles. GM signed an agreement with Vetronix Corporation allowing Vetronix to decode, download, and display all data recorded within the GM Sensing and Diagnostics Module (SDM), the GM version of the EDR. This is done using the Vetronix Crash Data Retrieval System (CDR). The Vetronix CDR tool provides no option to export the data in electronic format. All data viewable via the Vetronix CDR tool must be entered into some other form of database by hand for analysis (a tedious and error prone process).

In March 2003, Ford Motor Company set-up a similar agreement with Vetronix Corporation allowing the complete decoding, downloading, and displaying of all the data contained within their Restraint Control Module (RCM), Ford's version of the EDR. Similar to the GM version, this is done using the Vetronix CDR tool and must again be entered by hand into some other form of database for analysis.

Due to confidentiality agreements with NHTSA, none of the EDR data associated with SCI have been made publicly available at of the time of this writing. CIREN teams have successfully downloaded some EDR cases but like SCI, no cases were available for analysis at the time of this writing. This study utilizes the findings from NASS / CDS teams exclusively. It is based on a previous study completed on a similar dataset from NASS / CDS 1999-2001 by Gabler et al. [36].

In 2002, NASS / CDS accident investigation teams were able to successfully gather EDR information from 315 GM vehicles involved in collisions as shown in Table 8. These cases represent a sampling of collisions across the country.

Table 8. Contents of Rowan University GM SDM Database

Source	Total Number Of Cases
NASS / CDS 2002	315

Database Format

All of the contents of the General Motors' SDMs were downloaded by the NASS / CDS accident investigation teams using the Vetronix Crash Data Retrieval (CDR) tool in CDR file format during the investigation of the vehicle. When Rowan University obtained the data, individual files were opened using Vetronix CDR v.2.0. An example of the data provided by the Vetronix software can be found in the appendices. The data was entered into a separate database set up in Microsoft® Excel and analyzed using a format similar to that previously developed by Rowan University for NASS / CDS 1999-2001 [36]. The database developed for the NASS / CDS 2002 data contains the following five tables, their formats also available in the appendices:

1. NASS case description – Contains pertinent NASS data for each case.
2. Deployment Event – Crash Parameters
3. Deployment Event – Pre-Crash Parameters
4. Non-Deployment Event – Crash Parameters
5. Non-Deployment Event – Pre-Crash Parameters

The information for the NASS / CDS cases were obtained through a SAS code extraction, where the case number e.g. 200202014, and the 10 character vehicle identification number (VIN) are sent to the SAS code and a set of predetermined CDS parameters are returned. The output of the SAS code is in text format and must be imported into Microsoft® Excel for analysis.

Multiple vehicle crashes posed a problem as all the vehicles were assigned the same case number by convention, their VINs being the only distinguishing factor. In some cases, the vehicle number assigned to a vehicle by the NASS investigation teams was not the same vehicle number assigned to that vehicle in the NASS public database and served only as a temporary identifier. This problem was overcome by matching the EDR file VIN to the NASS / CDS database VIN [36]. Keep in mind that the EDR contains the full 17 digit VIN, whereas the NASS / CDS file contains only the first 10 digits of the VIN for privacy purposes. If a multi-vehicle crash occurred, the vehicle NASS information / EDR information could be matched based on the VIN. Only vehicles that could be matched based on both their case number and a 10 digit VIN were included in this study.

Quality Issues

As with any analysis, a percentage of the EDR files could not be matched to a NASS / CDS case or be viewed using the Vetronix software. In total, there were 349 cases; 315 of which were kept and used in the analysis. Nineteen (19) EDR cases contained no matching NASS VIN and nine (9) cases that contained hexadecimal data only, and could not be viewed with the Vetronix software. Other minor problems with 6 other EDR cases included some duplicate cases, cases that were listed out of year (a 2001 EDR case was sent along with the 2002 EDR cases), empty cases or cases missing certain data. These 34 cases were not included in the 315 cases shown in Table 8 nor were they included in the analysis that follows. They are listed however by case, VIN, and reason for exclusion in the appendices.

Description of the GM SDM Cases

General Motors has been recording event data since 1994 via their Sensing and Diagnostic Module (SDM), the GM version of the EDR. Several types of SDMs have been used in GM vehicles since their inception; though the two main units that have been used are the SDM-R found on vehicles model year (MY) 1996 to MY 1999 and the SDM-G found on vehicles MY 2000 and newer. Other types of SDMs include the SDM-A, SDM-B, and SDM-E models. The SDM-A/B/E air bag modules share a common connector and similar embedded software. Data from these modules are similar to the SDM-R. Vetronix now offers software and cable updates that allow interface with the SDM - A/B/E modules, equipped on select 1994 - 1996 GM vehicles. [37] Figure 13 shows the two most common types of the GM SDM: the SDM-R and the SDM-G.

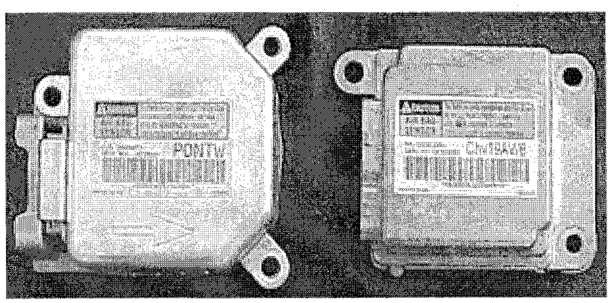

Figure 13. General Motors' Sensing & Diagnostic Modules: SDM-R (Left), SDM-G (Right)

Event Storage

The GM SDM records three different types of events. The first type of event recorded is a "Non-Deployment Event." In this type of event, the vehicle experiences a deceleration strong enough to set the SDM into "Algorithm Enable" mode but not strong enough to deploy the airbags. The second type of event is a "Deployment Event" i.e. one in which the airbags are deployed. The third type of event is known as a "Deployment

Level Event" in which there is a strong enough deceleration for airbag deployment but the airbags have already been deployed.

Storage of these events is an important parameter to consider. Deployment events are permanently stored in the SDMs internal memory and cannot be erased or overwritten. The SDM can store up to two different deployment "type" events if they occur within 5 seconds of each other, a deployment event and a deployment level event. Once the SDM has deployed the airbag, the SDM must be replaced. Non-deployment data files are permanently locked into the SDMs memory once a deployment event occurs [38].

All non-deployment events however, are not permanently stored. They can be overwritten by subsequent non-deployment events of greater severity or they will be erased after 250 ignition cycles, as long as a deployment event has not occurred within this timeframe. A non-deployment event may also be overwritten if the non-deployment event occurs within 5 seconds before the deployment event or a deployment level event occurs within 5 seconds after the deployment event. The SDM can store up to one non-deployment *type* event, be it a non-deployment or a deployment level event [38].

In some module types, time between events is recorded and reported in seconds. If the time between the two events is greater than 5 seconds, the SDM reports time between events as "N/A." The SDM-R can record up to 300 milliseconds of the vehicle forward velocity after "Algorithm Enable", the SDM-G can record up to 150 milliseconds. The maximum forward velocity change that can be recorded by the SDM is 56 mph [38]. In the 315 cases used in this analysis, the maximum-recorded velocity change of any of the cases was found to be 55.95 mph.

In general, various modules types of the General Motors SDM are capable of storing the following parameters: warning lamp status, driver seat belt status, passenger airbag suppression status, ignition cycles at deployment / non-deployment, ignition cycles at investigation, time between events (sec), driver time from "algorithm enable" to airbag deployment (first and second stage as well as passenger airbag deployment times in certain models), maximum SDM recorded velocity change (mph), algorithm enable to maximum SDM recorded velocity change (ms) and longitudinal velocity (mph) vs. time (msec) history as primary deployment and non-deployment crash parameters. There are some SDM model versions that store other information, but all the cases reported in 2002 contained the parameters listed above as a minimum data set. All the SDMs recorded the following pre-crash deployment and non-deployment parameters: vehicle speed (mph), engine speed (rpm), percent throttle (%), brake switch status (on/off). A detailed listing of all recorded parameters and their respective units can be found in the appendices.

Table 9 gives a summary of the NASS / CDS 2002 cases by type of event recorded by the SDM. This information was extracted using Vetronix v.2.0., showing that approximately 50% of the cases involved the deployment of the driver airbag.

Table 9. 2002 NASS / CDS GM SDM Deployment Status

Source	Total
Cases with Non-Deployment Events Only	151
Cases with Non-Deployment & Deployment Events	110
Cases with Deployment Events Only	44
Cases with Deployment and Deployment Level Events	10
Total	315

Computing GM SDM Delta-V

The GM SDM records the change in longitudinal (the front to rear axis of the vehicle) velocity every ten (10) milliseconds for 150 to 300 milliseconds depending on model year of the vehicle. The GM SDM does not record the change in lateral (side-to-side) velocity.

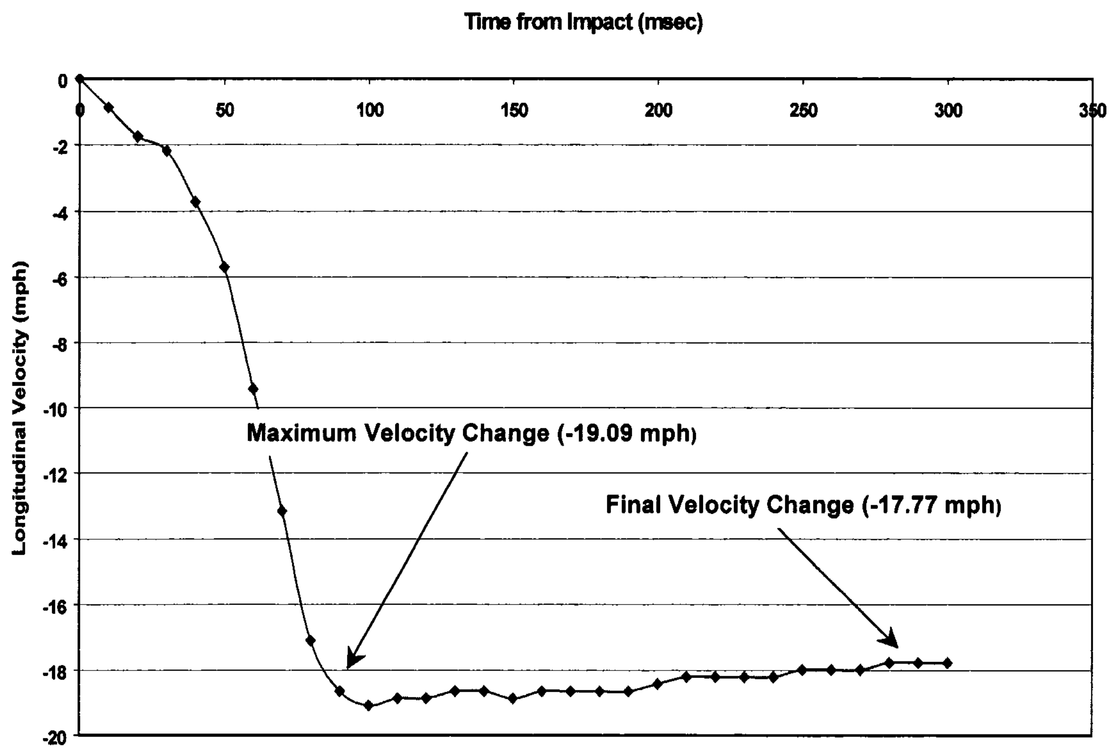

Figure 14. SDM record of Longitudinal Velocity vs. Time for a 1997 Chevrolet Cavalier Involved in a Frontal Collision with Another Vehicle.

Figure 14 shows the longitudinal velocity profile for a 1997 Chevrolet Cavalier involved in a frontal collision with another vehicle. This study uses this record to find the maximum velocity change recorded by the SDM for each case. The maximum-recorded velocity change shown in Figure 14 corresponds to the delta-V computed by Winsmash, the computer program used by NASS for estimating the delta-V experience by a vehicle based on vehicle deformation measurements. One of the major limitations of Winsmash and similar programs is that they assume a completely plastic deformation

[39]. This assumption means that the vehicles do not separate after the collision. In reality, the vehicles do separate and some of the energy that crushed the vehicle to its maximum point is returned, forcing the vehicles away from each other. The separation of the vehicles due to this return of crash energy is known as the rebound phase of the collision. As a result of this, vehicle deformation measurements alone may lead to an under-reported delta-V.

Vehicles that experience collisions behave like a spring . During compression, the kinetic energy of motion is converted into potential energy stored in the spring. Upon release, the stored potential energy is returned from the spring as kinetic energy. To a lesser extent, this is exactly what happens to a vehicle body during a collision. This can be observed in Figure 14 where the final recorded velocity is 1.32 mph less than the maximum EDR recorded velocity crash. 17.77 mph is only 93% of the maximum velocity change, 19.09 mph.

Characterization of the GM SDM Dataset

This section describes the composition of the 2002 NASS / CDS dataset. As shown in Table 10, 30% of the 2002 NASS / CDS cases (93 of the 315) are single vehicle crashes only. These types of crashes usually involve interaction between the roadside and the vehicle. The remaining 70% of the cases (222 of the 315) are vehicle-to-vehicle collisions.

Table 10. 2002 NASS / CDS GM SDM Cases by Number of Vehicles Involved

Number of Vehicles Involved in Collision	Total Cases	Percent
1	93	30 %
2	181	57 %
3	35	11 %
More than 3	6	2 %
Total	315	100 %

Analysis of Table 11 shows that 45% of the 2002 NASS / CDS cases involved multiple events. 16% of the cases involved more than two events. Since GM SDMs can only store a maximum of two events, it is likely that some event data was lost in these 52 cases (16%).

Table 11. 2002 NASS / CDS GM SDM Cases by Number of Events Experienced

Number of Events Experienced by Vehicle	Total Vehicles	Percent
1	172	55 %
2	91	29 %
3	32	10 %
More than 3	20	6 %
Total	315	100 %

Passenger cars accounted for 64% of the cases in the 2002 NASS / CDS dataset as shown in Table 12. The remaining 36% of the vehicles were light trucks and vans. This corresponds to the passenger car population that comprises approximately two thirds of the total registered vehicles in the United States as measured by vehicle registrations [36]. The remaining third of the vehicles were light trucks and vans, again shown in Table 12.

Table 12. 2002 NASS / CDS GM SDM Cases by Vehicle Body Type

Vehicle Body Type Class	Vehicle Body Type	Body Type Total	Body Type Class Total	Body Type Class Total %
Car	Sub-Compact Car	3	202	64 %
	Compact Car	83		
	Intermediate Car	69		
	Full Size Car	45		
	Largest Size Car	2		
LTV	Compact Utility	24	113	36 %
	Large Utility	14		
	Minivan	8		
	Large Van	15		
	Compact Pickup	14		
	Large Pickup	32		
	Utility Station Wagon	6		
Total		315	315	100 %

The NASS database scores the severity of occupant injuries using the Abbreviated Injury Scale (AIS) for both the driver and passenger (when applicable). AIS is a numerical value from zero (0) through six (6), zero being no injury, six being a fatal injury as shown in Table 13. An AIS of seven (7) means that the severity of the injury sustained by the occupant was unknown, AIS "N" means that injury data was not collected, and AIS "U" means that it was unknown as to whether or not the occupant(s) was injured. [40]

Table 13. The Abbreviated Injury Scale

AIS Value	Injury Characterization
0	No Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum/Fatal

The maximum AIS sustained by the driver for the NASS / CDS 2002 cases is presented in Table 14. Of the total number of cases, 264 had known values for maximum driver AIS. Almost 30% of the cases (78 of the 264) resulted in an AIS assignment of 0 or no sustained injuries. Nearly 50% of the cases (126 of the 264) resulted in an AIS assignment of 1, or minor injuries sustained.

For cases where the airbag did not deploy, an AIS value of 2 was reported in 4% (5 of 119) of cases. AIS values ranging from 3 to 6 (serious to fatal injuries) were observed in 11% (13 of 119) of cases. Of these thirteen cases, five were side impacts, four were top impacts with no horizontal force, and one was an undercarriage impact with no horizontal force. The remaining two of thirteen included an AIS 5 rear impact and an AIS 4 frontal impact. This means that in only 1.7% (2 out of 119) of the cases with insufficiently high longitudinal velocity change to trigger airbag deployment did the units fail to protect the occupants (where an AIS value was known). The remaining cases did not have high enough longitudinal velocity change to trigger bag deployment based on the direction of the impact.

For the deployment cases, AIS values of 0 and 1 comprised 72% (102 of 143) of the cases where AIS values were known. An AIS value of 2 was reported in 14% (20 of 143) of cases. AIS values ranging from 3 to 6 were observed in 15% (21 of 143) of deployment cases.

Table 14. 2002 NASS / CDS GM SDM Cases by Maximum Driver AIS

AIS	Airbag Did Not Deploy	Airbag Deployed	Airbag Deployment Status Unknown or Not Available	Total	Percent of Total
0	51	27		78	24.8 %
1	50	75	1	126	40.0 %
2	5	20	1	26	8.3 %
3	5	13		18	5.7 %
4	5	5		10	3.2 %
5	3	2		5	1.6 %
6		1		1	0.3 %
Subtotal	119	143	2	264	83.8 %
7 = Unknown Severity	6	13		19	6.0 %
N = Not Collected			24	24	7.6 %
U = Injuries Unknown	4	4		8	2.5 %
Total	129	160	26	315	100 %

In Table 15, the GM SDM cases are presented by most harmful object struck. For 67% of the cases (211 of 315), the most harmful object struck was another vehicle. For 25% of the cases (80 of 315), the most harmful object struck was a fixed object. In this analysis, fixed objects included trees, embankments, poles, barriers, walls, ditches and culverts, curbs, bridges, and the category "other fixed object." A rollover was the most harmful event in 5% of the cases (16 of 315). Estimation of delta-V is particularly difficult in cases where the vehicle collides with a fixed object due to the nature of inelastic collisions i.e. collisions where crash rebound energy is not entirely returned to the vehicle during the rebound phase of the collision. It is in these instances that an EDR velocity profile may be most reliable measure of crash severity.

Table 15. 2002 NASS / CDS GM SDM Cases by Most Harmful Object Struck

Object Struck	Total	Percent
Vehicle In Transit	211	66.98 %
Rollover	16	5.08 %
Small Tree	2	0.63 %
Large Tree	23	7.30 %
Embankment	2	0.63 %
Breakaway Pole	2	0.63 %
Medium Pole	7	2.22 %
Large Pole	11	3.49 %
Unknown Size Pole	1	0.32 %
Concrete Barrier	6	1.90 %
Other Barrier	10	3.17 %
Wall	7	2.22 %
Ditch / Culvert	3	0.95 %
Curb	1	0.32 %
Bridge	4	1.27 %
Other Fixed Object	1	0.32 %
Object Fell From Vehicle	1	0.32 %
Vehicle Not In Transit	3	0.95 %
Animal	4	1.27 %
Total	315	100 %

Availability of GM SDM Delta-V Data

Though all the events stored in the GM SDM triggered recording as either a deployment or non-deployment event, not all of them captured the velocity profile. For the non-deployment events database, only 46% (79 of 151) of the cases captured a non-zero velocity vs. time profile as shown in Table 16. In 38% (57 of 151) of the non-deployment cases, the delta-V vs. time data was missing. While the fact that the GM SDM only recorded the non-zero velocity vs. time in 46% of the cases is discouraging, it is certainly an improvement over the 37% recorded in the NASS / CDS 1999-2001 cases due to a problem associated with the GM 2000 and 2001 SDM boxes where the SDM would occasionally fail to record non-deployment data. This was corrected in newer versions of the SDM and is reflected by the increase non-zero velocity vs. time percentage [36].

Table 17 shows that for deployment events, only one case did not record velocity profile. Case number 200248212 recorded a deployment and non-deployment event, athough no velocity profile was recorded for either event. The vehicle experienced a distributed 30-degree frontal collision with airbag deployment. The occupants received an AIS of 1. A possible reason for the SDM recording failure was that the vehicles electrical system had been compromised during the collision and the unit continued operating on reserve power to operate the airbags, but was unable to record the velocity profile. This is part of the SDM design. With only this one exception, it can be said that the GM SDM recorded velocity profile every time a deployment event was experienced.

Table 16. Non-Deployment Events: Availability of GM SDM Velocity Data

Type of Event	Cases containing Velocity vs. Time	Cases containing zero Velocity vs. Time	Cases Missing Velocity vs. Time	Total
Non-Deployment Only	79	15	57	151
Non-Deployment & Deployment	43	32	35	110
Total	122	47	92	262

Table 17. Deployment & Deployment Level Events: Availability of GM SDM Velocity Data

Type of Event	Cases Containing Velocity vs. Time	Cases Containing Zero Velocity vs. Time	Cases Missing Velocity vs. Time	Total
Deployment Only	44	-	-	44
Deployment & Non-Deployment	105	4	1	110
Deployment & Deployment Level	10	-	-	10
Total	159	4	1	164

A new feature found in some of the GM SDMs when viewed with the Vetronix software is the field "Event Recording Complete." This field contains the Boolean expressions yes or no and is an indication of the data completeness. In the 315 GM SDM cases sampled, eight of the cases contained this field as shown in Table 18. The cases were all in model years 2001 and newer vehicles, and all cases that contained this field reported a "Yes." It is unclear what determines the inclusion of this field in the SDM, as vehicle make, model, and model year seemed to have no effect e.g. there were other vehicles of the same vehicle make, model, and model year that did not include this field. While not imperative to this analysis, a field containing information on data completeness will prove useful in future analyses on GM vehicles when all the vehicles are equipped SDMs that record this field.

Table 18. GM SDM Cases with "Event Recording Complete" Field

NASS / CDS Case Number	SDM Reported "Event Recording Complete"	Vehicle Model Year	Vehicle Make	Vehicle Model
200206107	Yes	2002	Chevrolet	Trail Blazer
200209166	Yes	2001	Saturn	LS
200212108	Yes	2002	Chevrolet	Monte Carlo (FWD)
200212132	Yes	2002	Pontiac	Bonneville / Catalina
200212150	Yes	2003	Chevrolet	Suburban
200212166	Yes	2001	Saturn	LS
200242116	Yes	2002	Buick	LeSabre / Wildcat / Centurion
200248185	Yes	2001	Chevrolet	Caprice / Impala

Delta-V Distribution

The most common measure of crash severity is the maximum change in velocity, or delta-V, experienced by the vehicle. The GM SDM records the vehicle longitudinal delta-V time profile during the collision. Maximum delta-V can be computed by searching for the largest deviation from 0 mph in the velocity time profile. Once these values have been computed, the GM SDM distribution of longitudinal delta-V can be plotted for non-deployment, deployment level, and deployment events as shown in Figure 15, Figure 16, and Figure 17.

As shown in Table 16 and Table 17, non-zero velocity vs. time data was captured for 122 non-deployment cases and 159 deployment (and deployment level) cases. The fact that non-deployment events are of lower severity e.g. lower values for longitudinal delta-V than deployment (and deployment level) events is shown by the fact that Figure 15 has more cases in the lower longitudinal delta-V range than does Figure 16. For non-deployments, the majority of the cases fall under the 15 mph mark.

The most harmful event in the three cases with a delta-V above 15 mph included a rear impact with no deployment (200243117) and two frontal impacts, one with deployment (200247134), one without (200249165). These vehicles collided with another vehicle, a bridge abutment, and another vehicle, respectively.

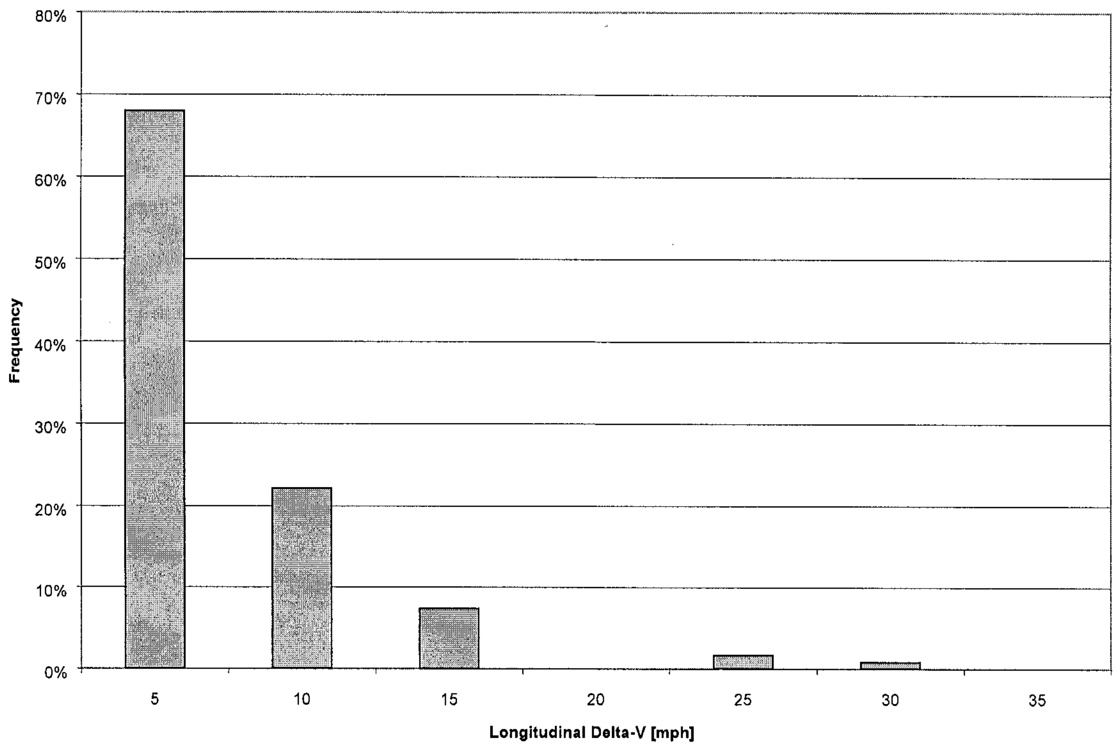

Figure 15. Non-Deployment Events: Distribution of GM SDM Longitudinal Delta-V (122 Cases, GM SDMs)

Again, Figure 16 shows the distribution of GM SDM longitudinal delta-V for the 10 deployment level events in the 315 case sample. Note that nine of the ten cases (90%) are at or above the 10 mph mark. The case that falls below the 10 mph mark (case 200206019) was a Chevrolet Malibu involved in a side impact. The SDM in this case recorded only the longitudinal delta-V, not the lateral delta-V, which is most likely to cause injury in a side impact.

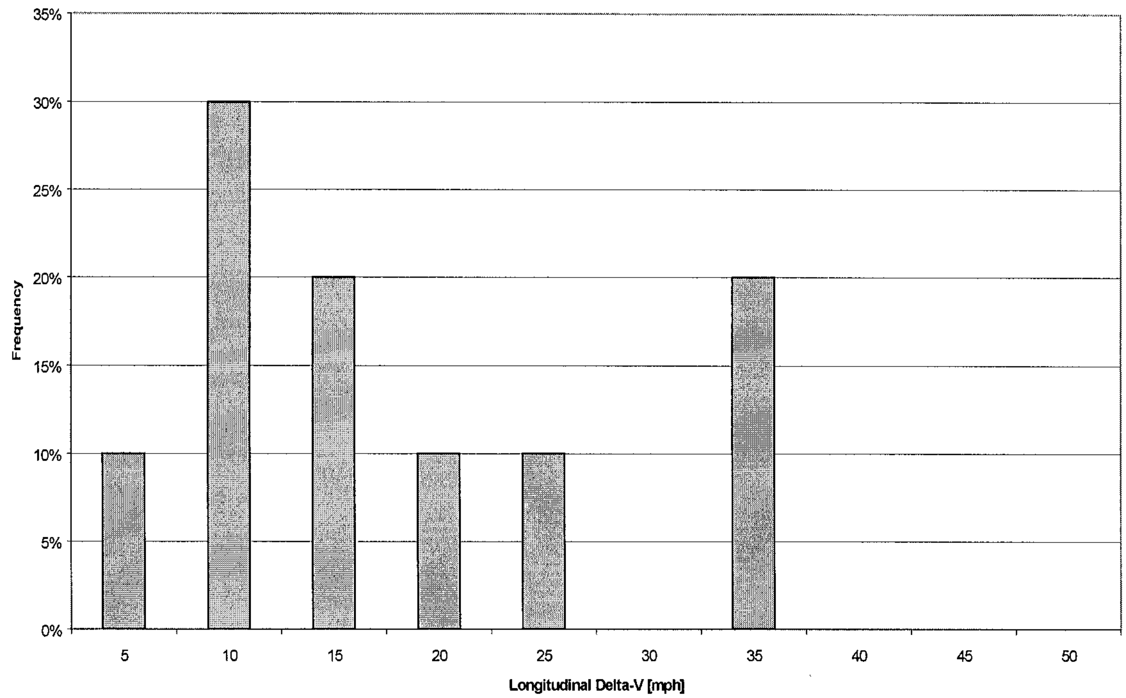

Figure 16. Deployment Level Events: Distribution of GM SDM Longitudinal Delta-V (10 Cases, GM SDMs)

Note that in Figure 17, 7% of the deployment events fall below a delta-V of 5 mph. This is an unexpected, as this delta-V falls well below the usual threshold of 10-15 mph for deployment. The cases that fall in this regime involved side impacts or collisions with fixed objects e.g. curbs and trees. These results are similar to those found on the NASS / CDS 1999-2001 cases [36]. Also note that the longitudinal delta-V axis ends with delta-V values of 55, 56, and 60 mph. This is because the GM SDM does not record delta-V above 56 mph. As mentioned earlier, one case in the 315 case sample recorded a maximum delta-V of 55.95 mph.

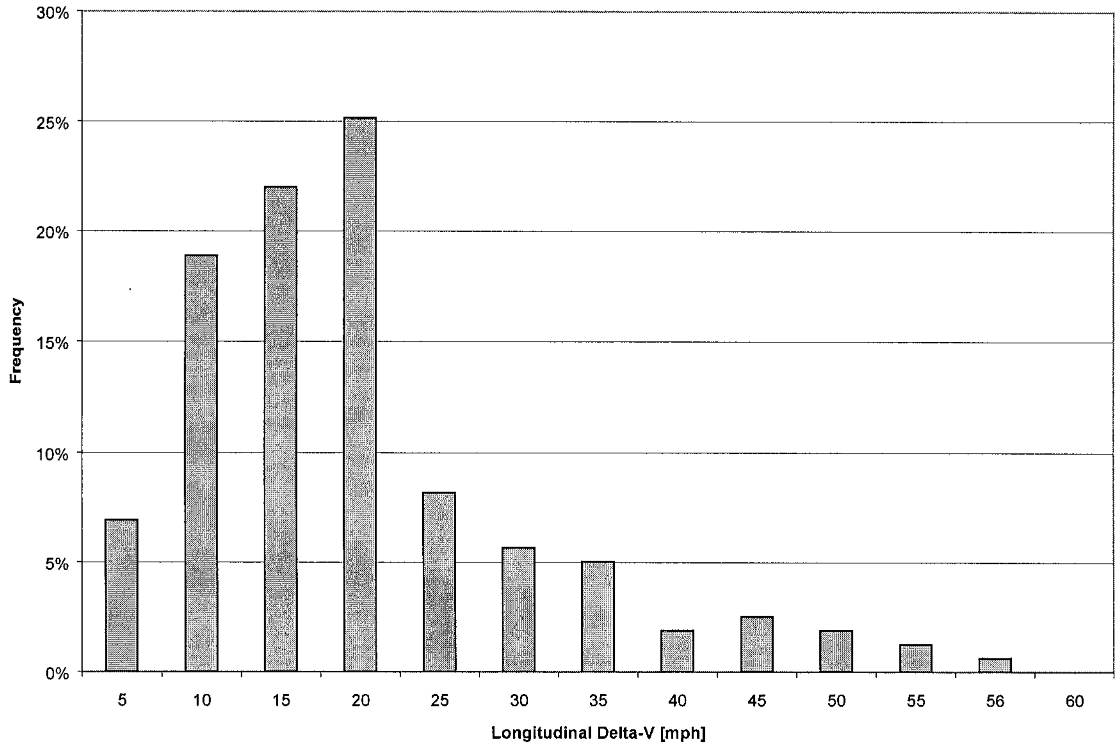

Figure 17. Deployment Events: Distribution of GM SDM Longitudinal Delta-V (159 Cases, GM SDMs)

Winsmash vs. GM SDM Delta-V

The measure of crash severity, delta-V, can be obtained in two different ways. It can be obtained by integrating vehicle deceleration or estimated based on post-crash vehicle deformation. Before the introduction of EDRs, the only way that a crash investigator could obtain a value for delta-V was from vehicle deformation. Using knowledge about the crush characteristics of vehicles, crash investigators are able to derive an estimate of the delta-V by measuring the vehicles permanent deformation after a collision. These measurements are input into computer codes such as WinSmash [39] and CRASH3 [41] that are used to compute corresponding estimates of longitudinal and lateral delta-V as output.

Codes such as WinSmash and CRASH3 were designed for frontal crashes with full engagement. As we know, real accidents occur in many other configurations, and when a configuration deviates from full frontal engagement, the estimate of both longitudinal and lateral delta-V become increasingly less accurate [39][42]. Crash configurations that prove particularly difficult to estimate delta-V values include sideswipes, fixed narrow objects such as poles and trees, side impacts, and rollovers. This becomes more apparent upon review of the NASS / CDS 2002 data where 41% (128 of 315) of WinSmash delta-V estimates are reported as unknown [36].

With the advent of the EDR comes the benefit of avoiding the difficulties associated with delta-V estimation using crash reconstruction techniques. EDRs provide a “snap-shot” of the vehicle velocity profile as the collision occurred, leaving little room for speculation as to what the vehicle “felt” upon impact. Since EDRs measure the actual velocity profile of the vehicle, crash researchers now have an accurate tool for estimating crash severity without having to worry about derivation problems associated with computer codes e.g. the incollision collision assumption.

The GM SDM measures the vehicle longitudinal velocity profile. Other manufacturers such as Ford record both the lateral and longitudinal velocity profiles. Ford EDRs will be discussed in greater detail in sections to follow.

Objective

This study attempts to evaluate the possibility of supplementing or replacing the WinSmash estimated delta-V reported in the NASS / CDS 2002 dataset with the delta-V recorded in EDRs. The analysis includes those cases for which there exists both a WinSmash delta-V estimate and a corresponding GM SDM reported delta-V.

Availability

For this analysis, known SDM delta-V values refer to any instance where the SDM was able to record a value for delta-V in a deployment, non-deplyment, or deployment level event. As tabulated in Table 19 and shown in Figure 18, both the SDMs and WinSmash were able to recover a value for delta-V 47% (149 of 315) of the time, while neither source was able to recover a value for delta-V in 12% (37 of 315) of the cases. In 12% of the cases (38 of 315), NASS / CDS values for delta-V were available when SDM values were either unknown or missing. In 29% of the cases (91 of 315) SDMs were able to recover delta-V values when NASS / CDS delta-V values were unavailable. This means that for 29% of the cases, an SDM delta-V measurement could replace an unknown NASS / CDS value.

Table 19. GM SDM vs. NASS / CDS 2002: Delta-V Availability

GM SDM Velocity Status	NASS/CDS Delta-V Known	NASS/CDS Delta-V Unknown	Total
Known Delta-V	149	91	240
Zero Delta-V	9	9	18
Missing Delta-V	29	28	57
Total	187	128	315

EDRs clearly provide an effective alternative for obtaining delta-V values when NASS investigators are unable to obtain a value using conventional methods. Though EDRs were able to obtain delta-V values in 91 cases of 128 (71%) where NASS / CDS was unable to obtain a value, NASS / CDS delta-V was available in 38 cases of 187 (20%) were EDRs reported a value of zero or failed to report anything at all.

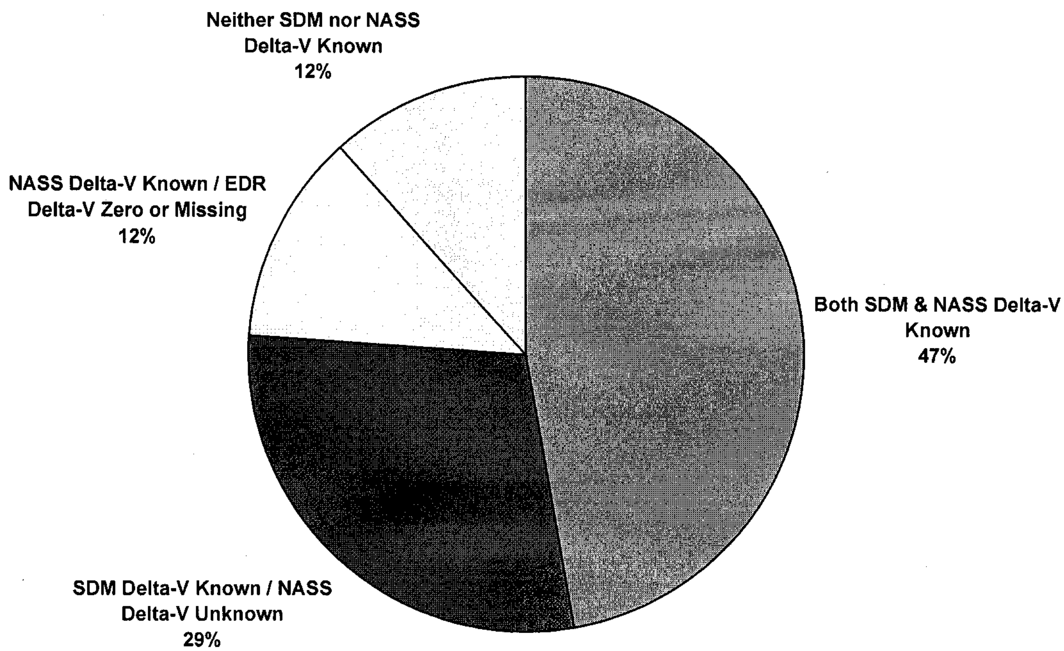

Figure 18. GM SDM vs. NASS / CDS 2002: Delta-V Availability

Delta-V Comparison

As previously mentioned, NASS / CDS delta-V estimates are derived from measurements taken from vehicles after a collision. These deflection measurements are then entered into WinSmash and estimates of the delta-V are output. EDRs measure the acceleration of a vehicle directly as they are mounted in the vehicle occupant compartment. This gives the EDR a better opportunity to correctly report the delta-V experienced by the vehicle. This analysis attempts to evaluate how well the NASS / CDS 2002 delta-V values match the recorded GM SDM delta-V values. Of the 315 NASS / CDS 2002 GM cases, 149 have WinSmash estimates of longitudinal delta-V and corresponding GM SDM reported longitudinal delta-V.

Figure 19 compares the estimated delta-V from WinSmash to the recorded delta-V from the GMs SDM by crash mode. Figure 20 compares the estimated delta-V from WinSmash to the recorded delta-V from the SDM by the type of event e.g. deployment or non-deployment. The diagonal line on the graph represents a perfect match of reported delta-V, thus symbols falling along this line represent an exact match. In a perfect world, all the symbols would fall along this line. Though exact matches are rare, both graphs show the symbols falling roughly around the diagonal.

As can be seen in Figure 19, there is no evidence that delta-V values from WinSmash differ from those reported by the SDM according to crash mode. Figure 20 suggests that WinSmash may overestimate delta-V for low-speed, non-deployment events and underestimate delta-V for high-speed, deployment events when compared to the GM SDM. Both of these results are similar to those found in the NASS / CDS 1999-2001 EDR cases [36]. Since the sample size is small at 315 total cases, only 149 of those cases with corresponding delta-V data, a study based on a much larger sample size would be advantageous in finding correlation between overestimates / underestimates based on both crash mode and event type.

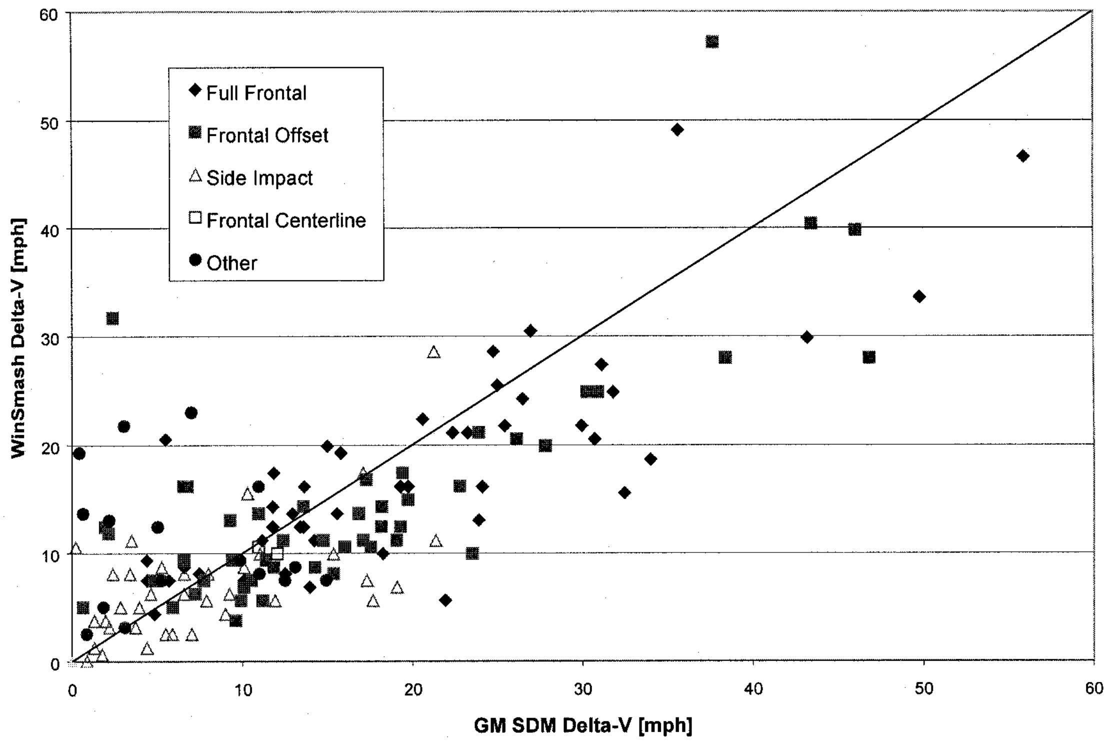

Figure 19. Longitudinal Delta-V Comparison by Crash Mode

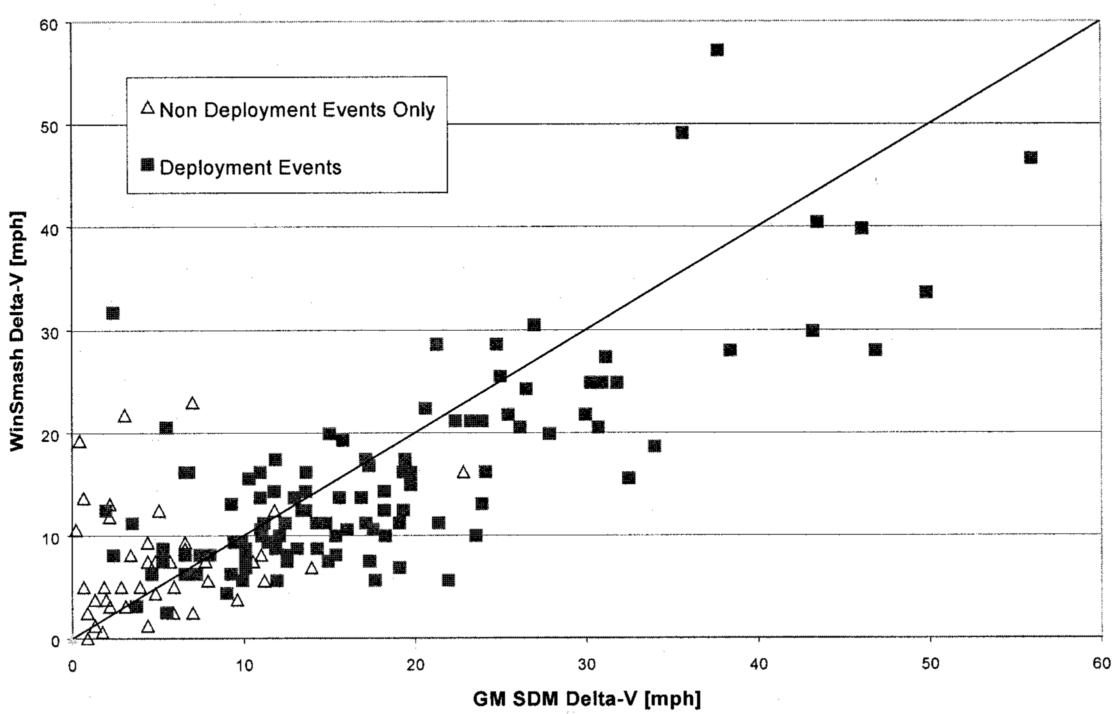

Figure 20. Longitudinal Delta-V Comparison by Event Type (Deployment or Non-Deployment)

Description of the Rowan University Ford RCM Database

As previously mentioned, the Ford Motor Company version of the EDR is their Restraint Control Module (RCM). Much like the GM SDM, the Ford RCM records in the event of a deployment of the supplementary restraint systems. Prior to March 2003, viewing the data stored in the Ford RCM required a proprietary tool. In March 2003, Ford set-up an agreement with Vetronix Corporation allowing the complete decoding, downloading, and displaying of all the data stored in their RCM. Similar to the GM SDM, this is done using the Vetronix Crash Data Retrieval (CDR) tool. Data displayed by the Vetronix software must be entered by hand into some other form of database for analysis.

Since the agreement made between Ford and Vetronix is recent, there exists almost no literature on their RCM or its data as of this writing. Others have described the data to the best of their knowledge at the time [1][4], though only a limited amount was made publicly available. With the agreement between Ford and Vetronix complete, the stored data in the Ford RCM can be accessed and viewed using the Vetronix v.2.0 software. Much of the information for the sections that follow comes directly from the literature available in the Vetronix CDR software help files.

Similar to the GM SDM cases, confidentiality agreements with NHTSA prevented any SCI cases containing EDR information from being made publicly available at the time of this writing. Again, CIREN teams have successfully downloaded some EDR cases but like SCI, no cases were available for analysis at the time of this writing. This study utilizes NASS / CDS data exclusively. The NASS / CDS accident investigators were able to successfully gather EDR information from 10 Ford vehicles in 2002 as seen in Table 20.

Table 20. Contents of Rowan University Ford GM Database

Source	Total Number Of Cases
NASS / CDS 2002	10

Database Format

Similar to the GM SDM cases, the contents of the Ford SDMs were downloaded by the NASS / CDS accident investigation teams using the Vetronix CDR tool in CDR file format during the investigation of the vehicle post crash. When the data arrived at Rowan University for analysis, the individual CDR file were opened using Vetronix v.2.0. An example of the data provided by the Vetronix software can be found in the appendices. The Ford data was entered into Microsoft® Excel for analysis.

Since the Ford data has only recently been made publicly available, the database structure is a first-of-a-kind. Due to the limited number of cases, the database only contains two different RCM types: that of a Ford Taurus and that of a Ford Crown Victoria. Because the two types of RCMs store data differently, two separate data sheets were constructed for each type based on the first three characters of the vehicle identification number (VIN). The first sheet contains all the RCMs system information e.g. airbag deployment status (deployed or not deployed), seat belt status (engaged, not engaged). The second sheet contains the RCM recorded crash pulse including longitudinal and lateral acceleration vs. time and delta-V vs. time. In summary, the database contains the following tables, the formats of which are available in the appendices:

1. NASS case description – Contains pertinent NASS data for each case.
2. 1FA - Taurus Sys Info – System information
3. 1FA - Taurus Crash Pulse – Longitudinal and lateral acceleration and delta-V vs. time.
4. 2FA - Crown Vic Sys Info – System information
5. 2FA - Crown Vic Crash Pulse – Longitudinal and lateral acceleration and delta-V vs. time.

The information for the NASS / CDS 2002 data were obtained through SAS code extraction. This was done in the same fashion as the GM cases; the SAS code was given the case number e.g. 200209111, and the 10 character VIN. The SAS code then returns a set of predetermined CDS parameters in text format that must be imported into Microsoft® Excel for analysis.

Quality Issues

An advantage of having such a limited number of cases in the Ford analysis was that no problems were experienced when trying to match NASS / CDS data to corresponding Ford RCM data. All Ford cases were viewable in the Vetronix v.2.0. viewer and none had to be excluded from the analysis.

Description of the Ford RCM Cases

Ford has been recording event data since 1998 via their Restraint Control Module (RCM). The RCM is a computer located under at the front of the occupant compartment under the instrument panel. It receives signals from the electronic crash severity sensor located at the front of the vehicle providing early indication of impact severity. The RCM uses this information to calculate crash severity and determine airbag inflation pressure. This information is also used to activate the safety belt pretensioners. [43]

Ford's agreement with Vetronix has allowed researchers to obtain access to the deceleration profiles and other crash related metrics stored in their RCM. Because the agreement went public so recently, there are a very limited number of cases that can be analyzed as is evident in Table 20. The following section outlines the information stored in the Ford RCM that has been made publicly available at the time of this writing.

Event Storage and Delta-V Records

Much of the information about the Ford RCM comes directly from the module information contained in the Vetronix CDR file. The information provided in this section comes from a 2000 Ford Taurus CDR file, NASS / CDS case number 200211063.

Unlike the GM SDM, the Ford Restraint Control Module (RCM) records crash data only and does *not* record pre-crash parameters such as vehicle speed, throttle position, brake on or off. Ford clearly states that sole purpose of the recorded deceleration is for determining if the RCM deployed the restraint devices correctly. The recorded deceleration data can be mathematically integrated into delta-V, which is the change in velocity during the recording time and is *not* the vehicle speed or the vehicle / barrier equivalent.

Recording time is often an issue when investigating a crash pulse. To capture a crash pulse in its entirety, usually a minimum of 300 milliseconds of data needs to be recorded. The 2000 Ford Taurus records 40 acceleration points at 2 millisecond intervals totaling 80 milliseconds of recording time. Since most real-world crashes have a duration that is longer than 80 milliseconds, they exceed the memory capacity of which the RCM has the ability to record. This being said, the delta-V calculated and displayed from the RCM may be lower than the actual delta-V that the vehicle experienced during the event. Ford recommends reviewing the deceleration pulse and checking to see that it has settled to zero before accepting the reported delta-V as the actual delta-V experienced by the vehicle. If the deceleration has not settled to zero, then the delta-V reported by the RCM is likely understated.

Ford states its RCM is limited in its ability to capture events such as angular collisions, side impacts, and vehicle rotation due to the dual-axis accelerometer setup. No reason for this limitation is given. Ford recommends that any delta-V reported by the RCM should be verified by crash scene investigation such as vehicle crush profile and skid marks on the road as well as assumed event sequence.

The Ford RCM has a backup power supply contained within the module that contains sufficient power to continue monitoring and analyzing the deceleration data for deployment of the restraint devices. This backup power is reserved strictly for the case where there is a loss of power to the RCM due to a cut wire and therefore may not record any deceleration data if this were to occur. Also, if the deceleration input does not exceed a delta-V above 4 mph for 100 milliseconds, there may be no data recorded. If power is interrupted during recording, or if the module resets itself during an event, a partial recording may occur. This is reported as "no data" in the data table and not plotted on the acceleration graph.

Storing Multiple Crash Events

For crashes that involve multiple impacts, only one of the events will be stored in the RCM. If the restraint devices have not been deployed, then the event that has been recorded is not "locked" and may be overwritten. This is similar to the GM SDM where a more severe event i.e. greater delta-V value can overwrite a less severe event and again, the investigator must decide which event has been stored.

The deceleration data stored in the RCM may be from a previous event other than the subject event in certain situations. For example, the module records data from some non-deployment events, so if after the RCM has recorded data from a non-deployment event, a subsequent event occurs in which there is a loss of power, the last event stored (the non-deployment event in this case) is the event that is stored in the RCM memory for download. If this new, subsequent, event is a deployment event and recording has occurred, the deployment times should be recorded. If there are no deployment times recorded, but the restraint devices have fired, the recorded data are most likely from a prior event. However, deployment events are "locked" permanently into the RCM memory and cannot be erased or altered in any way, so it is up to the investigator to decide which event has been stored.

Of the ten cases NASS / CDS cases used for this analysis, four (40%) were deployment events and six (60%) were non-deployment events as shown in Table 21.

Table 21. Deployment Status of Ford EDR Cases for NASS / CDS 2002

Case Number	Deployment Status
200209111	Deployed
200211063	Not Deployed
200211168	Not Deployed
200243109	Not Deployed
200245201	Deployed
200247075	Not Deployed
200247111	Deployed
200248079	Not Deployed
200276081	Not Deployed
200281118	Deployed

Computing Ford RCM Delta-V

As previously mentioned, the Ford RCM records the longitudinal and lateral acceleration vs. time and delta-V vs. time. The Ford Taurus recorded this information every two (2) milliseconds for 80 milliseconds upon impact in the cases used for this analysis. The Ford Crown Victoria recorded this information every one (1) millisecond for 57 milliseconds prior to algorithm "wake-up" and every eight-tenths (0.8) of a millisecond for up to eighty-eight (88) milliseconds upon impact in the cases used for this analysis.

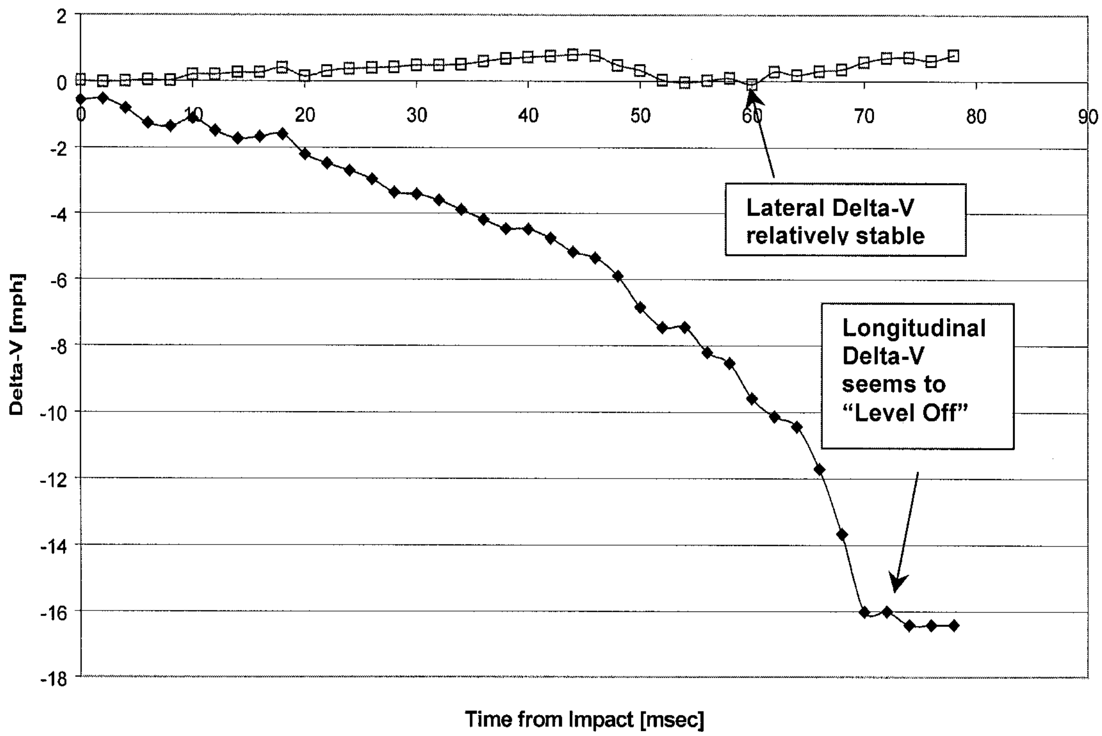

Figure 21. Ford RCM record of Delta-V vs. Time for a 2000 Ford Taurus Involved in a Frontal Collision with a Tree

Most real world crash pulses have a longer duration than eighty to eighty-eight milliseconds. This is evident after plotting all ten delta-V vs. time histories in both the longitudinal and lateral directions. Figure 21 shows the Ford RCM record of delta-V vs. time for a 2000 Ford Taurus involved in a frontal collision with a tree. In this particular instance, the longitudinal delta-V seems to "level off" with respect to time. This leveling off is important as it indicates that the entire crash pulse has been captured in that direction. All Ford crash pulses however do not level off however.

Figure 22 show a Ford RCM record of delta-V vs. time for a 2000 Ford Taurus involved in a frontal collision with another vehicle. In this case, the delta-V record has not reached equilibrium i.e. "leveled off" in both the longitudinal and lateral directions resulting in an incorrect value for maximum delta-V e.g. the delta-V value is still changing with respect to time. In cases like this, it is up to the investigator to determine if the reported value for maximum delta-V is accurate based on comparison with crash scene evidence and vehicle crush profile.

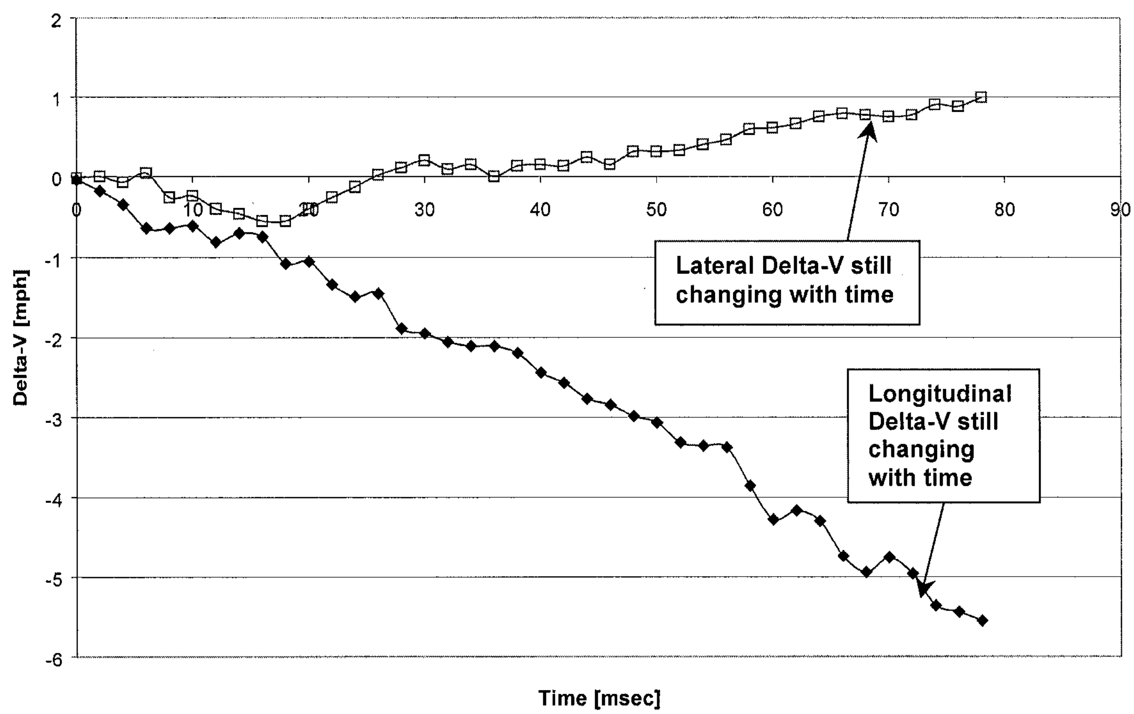

Figure 22. Ford RCM record of a Delta-V vs. Time for a 2000 Ford Taurus Involved in a Frontal Collision with another Vehicle.

Plots similar to Figure 22 show that the Ford RCM does not record a sufficient amount of time to capture all directional delta-V events in their entirety. This is evident in Table 22, where three of seven matching NASS / CDS - Ford RCM longitudinal delta-V graphs had not settled to steady state i.e. not "leveled off", and three of five matching NASS / CDS - Ford RCM lateral delta-V graphs had not settled to steady state. These two combined to make three of five matching NASS / CDS - Ford RCM resultants incomplete.

Incomplete capture of the maximum delta-V by the Ford RCM results in WinSmash overestimates delta-V. In reality, the Ford RCM is most likely under-reporting the maximum value of delta-V because it has not recorded enough delta-V vs. time data. When a delta-V plot reaches steady state, the change in delta-V is no longer increasing. This can be seen in Figure 21 as the part of the plot that flattens at approximately 75 milliseconds. Not until a delta-V vs. time graph "levels off" can a maximum value for delta-V be assumed because delta-V is still changing with time. If the data are cut off while delta-V is still changing with time as is the case shown in Figure 22, the value at the end of the data may or may not be the value for maximum delta-V.

Table 22 shows all of the maximum delta-V values recorded by the Ford RCM in both the longitudinal (Long.) and lateral (Lat.) directions for each case in this study. The NASS / CDS values for longitudinal and lateral delta-V are also included for their respective cases in an attempt to quantify the difference between the two data sources. The percent differences (% Diff.) are tabulated and show that the Ford RCM is indeed limited in its ability to estimate delta-V. In cases where the Ford RCM captures the delta-V vs. time history in its entirety, the same phenomena experienced by the GM SDM exists when a comparison between the Ford RCM and WinSmash is made. WinSmash estimates the delta-V based on vehicle deformation measurements; one of its major limitations as mentioned previously [39]. Since WinSmash assumes an entirely plastic deformation, the delta-V reported by WinSmash may be less than that actually experienced by the vehicle.

Table 22. Tabulation of Maximum Recorded Delta-V: Ford RCM & NASS / CDS

NASS / CDS Case	Vehicle Type	Long. Ford RCM Max Delta-V	Long. NASS / CDS Delta-V	% Diff.	Long. Graph Leveled Off?	Lat. Ford RCM Max Delta-V	Lat. NASS / CDS Delta-V	% Diff.	Lat. Graph Leveled Off?
200209111	Taurus	10.1	7	31 %	Yes	22.99	12	48 %	Yes
200211063	Taurus	16.42	34	107 %	Yes	0.79	0	100 %	Yes
200211168	Taurus	4.17	10	140 %	No	2.72	12	341 %	Yes
200243109	Taurus	1.03	Unknown	N/A	No	0.59	Unknown	N/A	No
200247075	Taurus	5.55	Unknown	N/A	No	0.99	Unknown	N/A	No
200248079	Taurus	5.95	15	152 %	No	6.39	18	182 %	No
200276081	Taurus	31.46	Unknown	N/A	No	25.18	Unknown	N/A	No
200281118	Taurus	9.9	12	21 %	No	1.01	0	100 %	No
200245201	Crown Victoria	11.76	14	19 %	No	Unavailable	8	N/A	N/A
200247111	Crown Victoria	1.88	7	272 %	Yes	Unavailable	20	N/A	N/A

Characterization of the Ford RCM Dataset

This section describes the composition of the 2002 NASS / CDS Ford dataset. Table 23 shows the ten 2002 NASS / CDS cases by the number of vehicles involved. Though the dataset is small, 30% of the cases were single vehicle collisions while 70% of the cases involved multiple vehicles. These percentages match those of the 315 GM cases shown in Table 10.

Table 23. 2002 NASS / CDS Ford RCM Cases by Number of Vehicles Involved

Number of Vehicles Involved in Collision	Total
1	3
2	5
3	2
More than 3	0
Total	10

Table 24 breaks down the Ford RCM cases by the number of events experienced by the vehicle. Six of the ten cases involved multiple events (two or more), the remaining 40% were single event collisions. Again, since the Ford RCM only stores information for one event, it is likely that some of the crash information was not captured in 60% of the cases.

Table 24. 2002 NASS / CDS Ford RCM Cases by Number of Events

Number of Events Experienced by Vehicle	Total Vehicles
1	4
2	4
3	1
More than 3	1
Total	10

All of the cases in the NASS / CDS 2002 dataset for Ford were passenger cars as shown in Table 25. Along with the announcement from Vetronix in March 2003 about their ability to decode Ford's RCM came a list of the Ford vehicle coverage included in the software. All of these vehicles were intermediate to large size cars or vans (Ford Windstar). This is the reason for no trucks appearing in Table 25.

Table 25. 2002 NASS / CDS Ford RCM Cases by Vehicle Body Type

Vehicle Body Type Class	Vehicle Body Type	Body Type Total	Body Type Class Total	Body Type Class Total %
Car	Intermediate Car	8	10	100 %
	Largest Size Car	2		
Total		10	10	100 %

The maximum driver AIS sustained by the driver for the NASS / CDS 2002 Ford cases is presented in Table 26 (See Table 13 for details on AIS). Nine of the ten cases had known values for maximum driver AIS. Two of these nine cases (22%) resulted in an AIS assignment of 0, no sustained injuries. Five of the nine cases (55%) with known AIS values resulted in AIS 1, or only minor injuries sustained. An AIS value of 2 and 3 were assigned to one case each (11% each). There were no cases with AIS values of 4,5, or 6, serious to fatal injuries. In the four total cases where the airbag deployed, only three of these cases had known AIS values. All three of these cases were AIS 1. This means that in all of the Ford deployment events where AIS values were known, the driver sustained only minor injuries.

Table 26. 2002 NASS / CDS Ford RCM Cases by Maximum Driver AIS

AIS	Airbag Did Not Deploy	Airbag Deployed	Airbag Deployment Status Unknown or Not Available	Total
0	2			2
1	2	3		5
2	1			1
3	1			1
4				0
5				0
6				0
Subtotal	6	3	0	9
7 = Unknown Severity		1		1
N = Not Collected				0
U = Unknown if injured				0
Total	6	4	0	10

Table 27 presents the 10 2002 NASS / CDS Ford cases by most harmful object struck. Of these ten cases, seven of the vehicles hit other vehicles, one hit a large tree and the remaining two struck an embankment. In short, 70% of the vehicles hit other vehicles while 30% of the vehicles hit fixed objects. While the lot size is small, the percentages are remarkably close to those of the much larger GM SDM lot of 315 cases, 67%, and 25% respectively. Though none of the Ford cases used in this analysis experienced rollovers, these events tend to be the most difficult for EDRs to contend with, since current EDRs do not measure or record vertical acceleration or roll. The Ford RCM does record lateral acceleration and delta-V, however, and this should prove particularly useful in crash severity estimation in fixed object collisions as these collisions tend to be offset.

Table 27. 2002 NASS / CDS Ford RCM Cases by Most Harmful Object Struck

Object Struck	Total
Vehicle	7
Large Tree	1
Embankment	2
Total	10

Availability Ford RCM Delta-V Data

Due to the fact that the Ford RCM stores only one event in memory, every Ford RCM that was downloaded by a NASS investigation team had stored some value for either the longitudinal and/or lateral acceleration vs. time and delta-V vs. time histories. Table 28 shows that all ten Ford RCM cases contained longitudinal delta-V vs. time data, with eight cases containing lateral delta-V-time histories. It should be noted that all eight cases involving a Ford Taurus contained both longitudinal and lateral acceleration-time and delta-V-time histories. The two Ford Crown Victoria cases contained longitudinal acceleration-time and delta-V-time histories, with the lateral histories missing in both instances. This is due to the module type and is not a system malfunction.

Table 28. Availability of Ford RCM Velocity Data: Longitudinal and Lateral

Case Number	Vehicle Model Year	Vehicle Model	RCM Recorded Longitudinal Delta-V vs. Time	RCM Recorded Lateral Delta-V vs. Time
200209111	2000	Taurus	✓	✓
200211063	2000	Taurus	✓	✓
200211168	2000	Taurus	✓	✓
200243109	2000	Taurus	✓	✓
200247075	2000	Taurus	✓	✓
200248079	2000	Taurus	✓	✓
200276081	2000	Taurus	✓	✓
200281118	2001	Taurus	✓	✓
200245201	2001	Crown Victoria	✓	No
200247111	2003	Crown Victoria	✓	No

Delta-V Distribution

As previously mentioned the Ford Taurus captures delta-V in both longitudinal and lateral directions, while the Ford Crown Victoria captures delta-V on the longitudinal direction only. Using the data from both types of modules, the maximum delta-V distributions can be plotted. Figure 23 shows all ten Ford cases containing longitudinal delta-V data, while Figure 24 shows the eight Ford Taurus cases containing lateral delta-V information.

Figure 23 shows that most of the collisions involving the ten Ford cases were relatively low severity i.e. delta-V under 15 mph in the longitudinal direction. Only two cases breached a delta-V value of 20 mph. Both of these cases involved collisions with fixed objects. The delta-V 20 mph vehicle collided with a large tree and the delta-V 35 mph vehicle hit an embankment. The remaining cases involved one very low severity crash with a small tree and the rest were collisions with other vehicles.

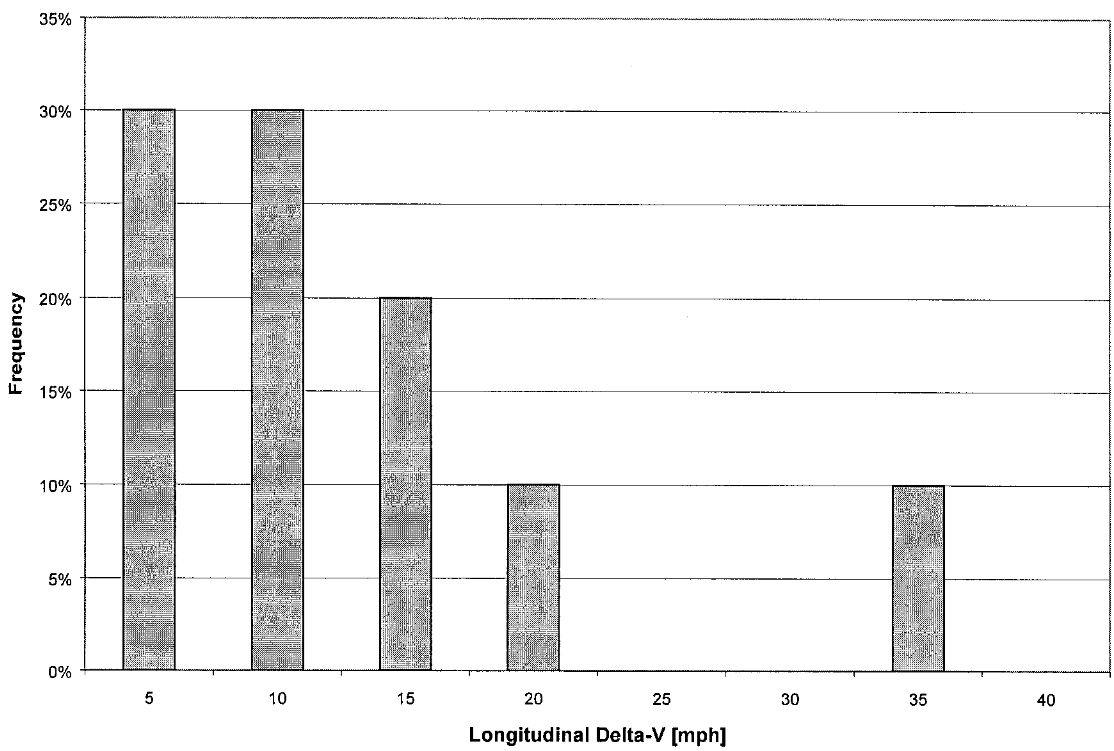

Figure 23. Distribution of Resultant Longitudinal Delta-V (10 Cases, Ford RCM)

Six of the eight Ford Taurus cases containing lateral delta-V data were low severity cases i.e. delta-V under 15 mph, as shown in Figure 24. In the two cases with lateral delta-V values above 10 mph, one involved a vehicle hitting an embankment, and several invloved a vehicle getting hit directly in the side by another vehicle. The principal direction of force was reported as unknown for the delta-V 30 mph vehicle that hit the embankment, while the delta-V 25 mph vehicle that was hit by another vehicle was confirmed as hit directly in the driver side door. Strangely enough, the lateral delta-V 30 mph case resulted in a maximum driver AIS value of 0 and the delta-V 25 mph case resulted in a maximum driver AIS value of 1, meaning that both drivers suffered only minor injuries.

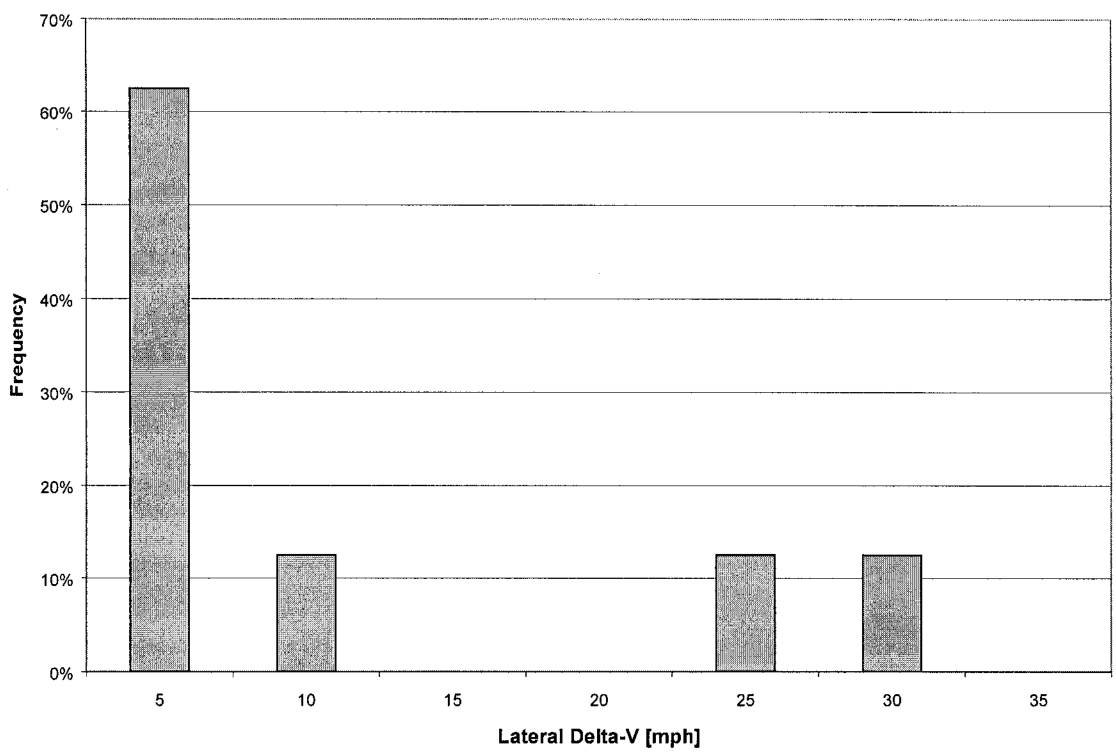

Figure 24. Distribution of Resultant Lateral Delta-V (8 Cases, Ford RCM)

Winsmash vs. Ford RCM Delta-V

This section completes an analysis of the 10 Ford SDM cases similar to that completed for the 315 GM SDM cases; see the section titled "Winsmash vs. GM SDM Delta-V" for a description.

Objective

This study attempts to evaluate the possibility of supplementing or replacing the WinSmash estimated delta-V reported in the NASS / CDS 2002 dataset with the delta-V recorded in EDRs. The analysis includes those cases for which there exists both a WinSmash delta-V estimate and a corresponding Ford RCM reported delta-V.

Availability

NASS / CDS can record both longitudinal and lateral delta-V for each vehicle in the database, though this information was unavailable for some cases. It may also have been reported as insignificant by NASS / CDS, indicated by a zero as shown in

Table 22. For example, a NASS / CDS value of lateral delta-V of 0 would most often mean that the vehicle was involved in a frontal collision only. The same would hold true for a vehicle with a NASS / CDS reported longitudinal delta-V of 0, the vehicle probably experienced a side impact only. Because the Ford RCM and NASS / CDS record delta-V values in both the longitudinal and lateral directions, comparison is a matter of matching the two delta-V types for each case. Table 29 breaks down the Ford RCM cases and the NASS / CDS cases in terms of what was recorded and estimated, respectively. The data are displayed graphically in Figure 25 and Figure 26.

Table 29. Ford RCM vs. NASS / CDS 2002: Delta-V Availability

NASS / CDS Case Number	Ford RCM Recorded Longitudinal Delta-V	NASS / CDS 2002 Winsmash Estimated Longitudinal Delta-V	Ford RCM Recorded Lateral Delta-V	NASS / CDS 2002 Winsmash Estimated Lateral Delta-V
200209111	✓	✓	✓	✓
200211063	✓	✓	✓	Zero
200211168	✓	✓	✓	✓
200243109	✓	Unknown	✓	Unknown
200247075	✓	Unknown	✓	Unknown
200248079	✓	✓	✓	✓
200276081	✓	Unknown	✓	Unknown
200281118	✓	✓	✓	Zero
200245201	✓	✓	Unavailable	✓
200247111	✓	✓	Unavailable	✓

All ten Ford SDM cases recorded longitudinal delta-V vs. time and eight of ten recorded lateral delta-V vs. time. As mentioned in earlier, lateral delta-V was unavailable for both Ford Crown Victoria cases. All the other Ford vehicles were Ford Taurus.

Longitudinally, the 2002 NASS / CDS database contained seven cases with known delta-V vs. time, three cases with unknown delta-V vs. time. Laterally, the 2002 NASS / CDS database contained five cases with known delta-V versus time, three cases with unknown delta-V vs. time, and two cases where the delta-V versus time was reported as zero.

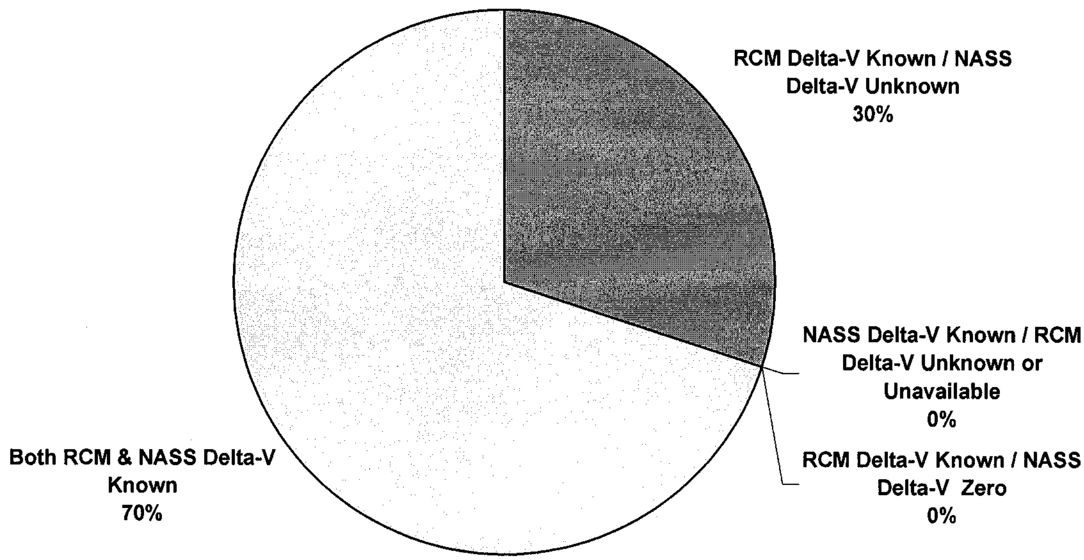

Figure 25. Ford RCM vs. NASS / CDS 2002: Longitudinal Delta-V Availability

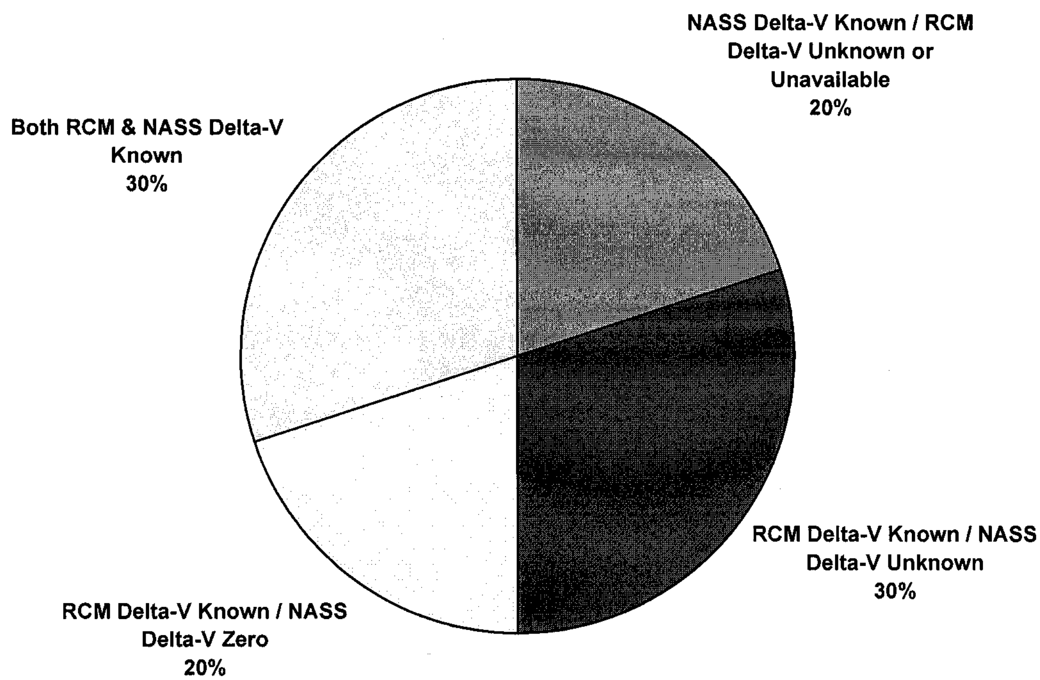

Figure 26. Ford RCM vs. NASS / CDS 2002: Lateral Delta-V Availability

A comparison such as this seems mundane based on such a small number of cases, however the fact that the Ford RCM captures delta-V vs. time for every case is very significant. Since the point of this analysis is to evaluate the possibility of supplementing or replacing the WinSmash estimated delta-V reported in the NASS / CDS 2002 dataset with the delta-V recorded in EDRs, this comparison provides valuable insight for comparison involving a larger dataset. Based on the limited number of cases presented in Table 29, the Ford RCM appears to be better at providing crash severity measures than conventional accident reconstruction methods as far as data availability is concerned.

Delta-V Comparison

NASS / CDS derives its values for delta-V from post-crash measurements taken from the subject vehicle. These measurements are entered into WinSmash and the longitudinal, lateral, and resultant delta-V components are output and entered into the NASS / CDS database. EDRs are mounted in the vehicles occupant compartment and measure the delta-V of a vehicle directly, giving them a better opportunity to correctly report the delta-V experienced by the vehicle.

This analysis attempts to evaluate how well the NASS / CDS 2002 delta-V values match the delta-V values reported by the Ford RCM. The analysis was completed for the longitudinal, lateral, and resultant components of delta-V. The NASS / CDS database reports delta-V in the three directions mentioned: longitudinal, lateral, and resultant, while the Ford RCM only records delta-V in the longitudinal and lateral directions. The resultant delta-V value for the Ford RCM cases is computed from the longitudinal and lateral components.

Of the ten Ford cases, seven had corresponding Ford RCM – NASS / CDS values in the longitudinal directions. Five had corresponding values in the lateral direction. Since resultant delta-V components are computed using both the longitudinal and lateral delta-V values, only those five were available in the resultant direction.

Figure 27 shows the longitudinal delta-V comparison for the seven cases where corresponding Ford RCM – NASS / CDS delta-V values were available. Figure 28 shows the same comparison for the five cases where corresponding Ford RCM – NASS / CDS delta-V values were available in the lateral direction. In both cases, the diagonal line represents an exact match betweenWinsmash delta-V and Ford RCM reported delta-V. Figure 29 repeats the analysis for the five cases for which resultant components were available. All three figures show a tendency of WinSmash to overestimate Delta-V when compared to the Ford RCM. As previously mentioned however, the Ford RCM tends to underestimate the value of delta-V in both the longitudinal and lateral directions (and thus the resultant direction) due to its short recording duration.

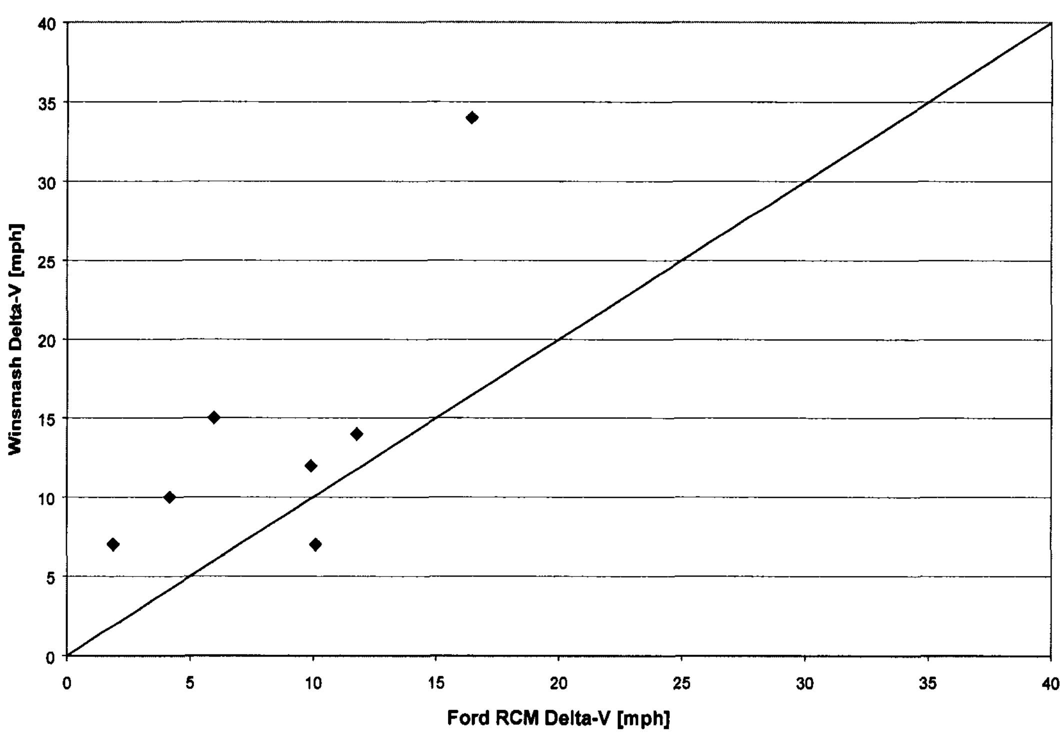

Figure 27. Ford RCM vs. NASS / CDS 2002 Winsmash Estimate: Longitudinal Delta-V Comparison (7 Cases)

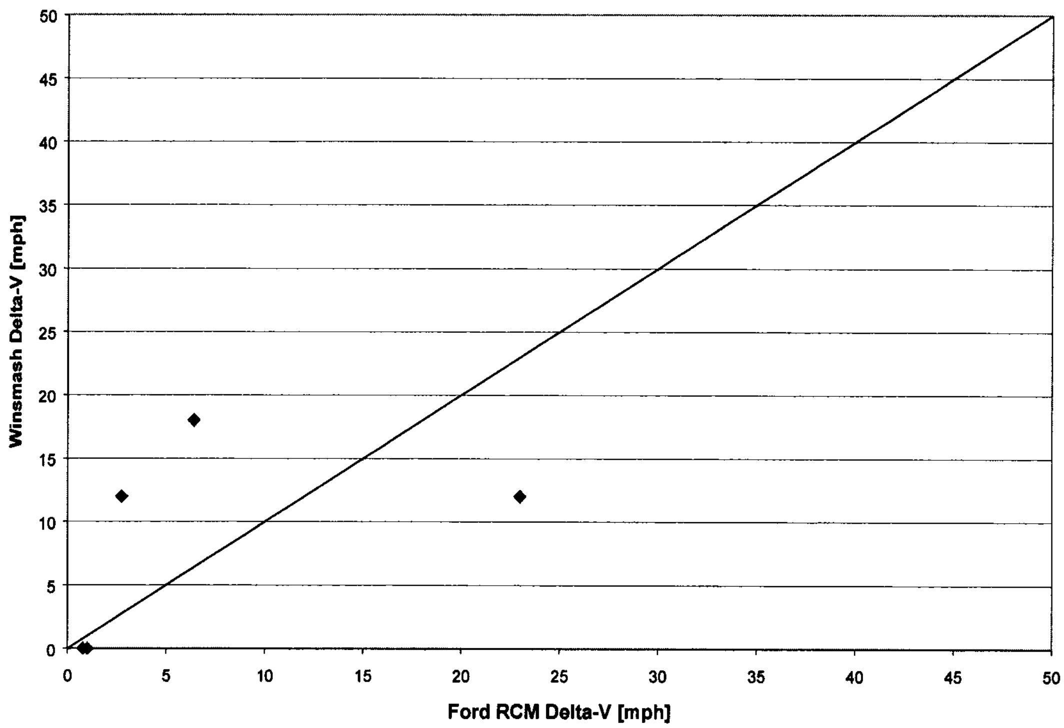

Figure 28. Ford RCM vs. NASS / CDS 2002 Winsmash Estimate: Lateral Delta-V Comparison (5 Cases)

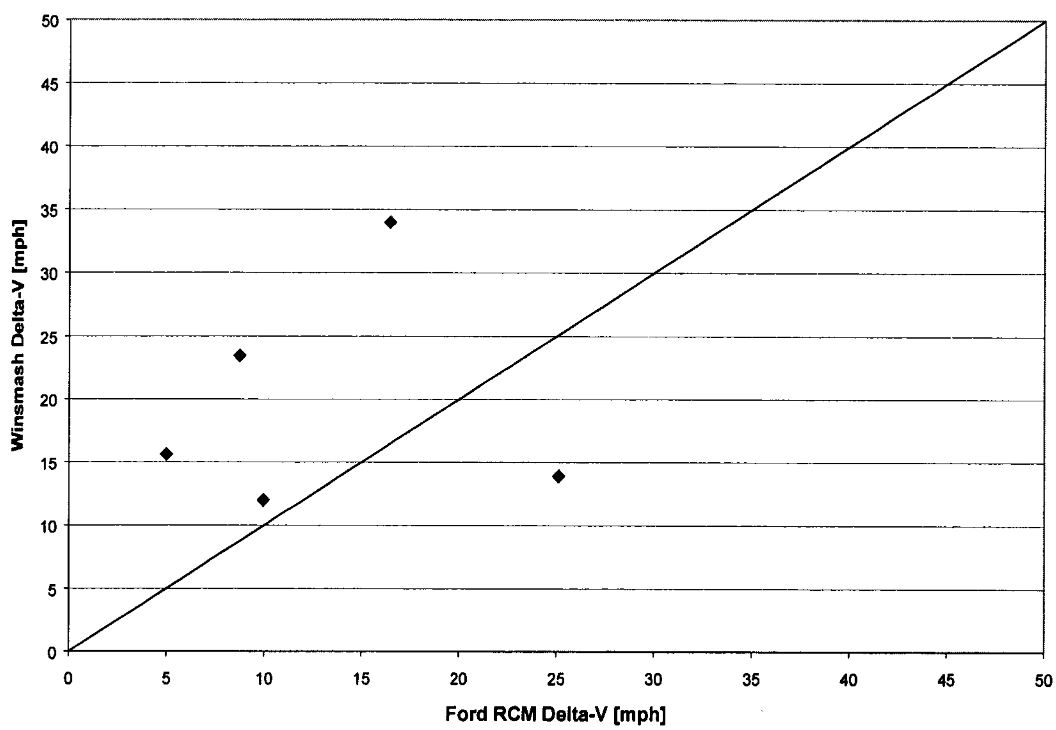

Figure 29. Ford RCM vs. NASS / CDS 2002 Winsmash Estimate: Resultant Delta-V Comparison (5 Cases)

Summary

The purpose of this study was to statistically analyze an EDR database developed by Rowan University. The database was developed for two different automobile manufacturers: General Motors (GM) and Ford Motor Company. The GM database contained 315 cases. The Ford database had only 10 cases due to the limited availability of their data. All cases from both manufacturers were gathered by accident investigations teams across the country and put together in the NASS / CDS 2002 database.

Although each manufacturer stores different parameters in their EDR, both were consistent in reporting common crash research items such as seat belt status and delta-V vs. time histories. Since previous GM data has already been collected and entered into a database at Rowan University for NASS / CDS 1999-2001, a merge of the two datasets will allow for conclusions based on the data to be more definitive. Due to the limited number of cases in the NASS CDS 2002 Ford dataset, a much larger sample needs to be compiled before any real conclusions can be drawn.

CHAPTER 4 – CONCLUSIONS

The goal of this study was to provide a direct comparison between EDR recorded data and that of full-scale crash tests and accident investigations. After completing both analyses, it becomes clear that EDRs are powerful tools for both automakers and researchers alike. The conclusions are as follows:

Evaluation of EDRs in Crash Tests

This analysis compared data retrieved from several EDRs with that from the lab instrumentation used in six (6) NHTSA New Car Assessment Program (NCAP) tests of General Motors (GM) vehicles. There were two primary points of interest for each case. They were:

- **Vehicle Safety Systems Status and Recording Status.** All the EDRs were able to correctly gather safety systems status such as driver seat belt and airbag deployment. EDRs were accurate in predicting pre-crash speeds to the best of their ability in five of the six (83 %) of the tests.
- **Delta-V vs. Time Profile.** The GM SDM accurately portrayed the vehicle velocity profile during the collisions in five of the six (83 %) of the tests. It was also reliable in reporting the maximum longitudinal velocity change to within approximately five percent.

Overall, the results of the comparison show that the EDRs used in the NCAP tests record the vehicle delta-V profile well. Though the sample size of this particular study is small, the results should give users of EDR data confidence that the data reported is both accurate and correct.

Evaluation of EDRs in Accident Investigations

An EDR database developed by Rowan University was statistically analyzed. Each case in the database contains information from both NASS / CDS and the information downloaded from the corresponding EDR. The database was developed for two automobile manufacturers exclusively, GM and Ford, as these were the only two manufacturers whose EDR information was publicly available at the time. Conclusions for each manufacturer follow, as well as an overall EDR limitations section.

General Motors

- **Database Development.** Rowan University has developed an EDR database for the GM Sensing and Diagnostic Module (SDM) based on 315 cases from 2002 NASS / CDS in which SDM data was recovered during the crash investigation. The vehicles range from model year 1996 to 2003.
- **Availability of GM SDM Delta-V Data.** Not all GM SDMs captured the velocity profile. For non-deployment events, only 46% of the cases captured a delta-V vs. time profile. In 35% of these cases, the delta-V vs. time data was missing. Deployment events recorded delta-V vs. time in 96% of the cases.
- **Winsmash vs. GM SDM Delta-V Values.** A comparison between NASS / CDS and GM SDM delta-V values was made when both sources of data were available. In the 149 cases compared, there was

no evidence of deviation between NASS / CDS delta-V and GM SDM delta-V based on crash mode. WinSmash does show the tendency to overestimate delta-V for low speed non-deployment events and underestimate delta-V for high-speed deployment events when compared to the GM SDM.

- **Winsmash vs. GM SDM Delta-V Availability.** The GM SDM has the potential to provide a delta-V value where NASS / CDS delta-V is reported as unknown. In the 315 case sample, the GM SDM was able to capture a delta-V value in 29% of cases where NASS / CDS had failed.

Ford Motor Company

- **Database Development.** Rowan University has developed an EDR database for the Ford Restraint Control Module (RCM) based on 10 cases from 2002 NASS / CDS in which RCM data was recovered during the crash investigation. The database includes eight Ford Tauruses and two Ford Crown Victorias between model years 2000 and 2003.
- **Winsmash vs. Ford RCM Delta-V Values.** A comparison between NASS / CDS and Ford RCM longitudinal delta-V values was made for seven Ford cases and a lateral comparison was made for five of the cases due to data availability problems. As quantified in the analysis, the Ford RCMs often underestimate delta-V due to their short (eighty

millisecond) recording duration. This led to a mismatch of delta-V values between NASS / CDS and the Ford RCM.

- **Winsmash vs. Ford RCM Delta-V Availability.** The Ford RCM has the potential to provide a delta-V value where NASS / CDS delta-V is reported as unknown. In the ten case sample, the Ford RCM was able to capture a delta-V value in every case in both directions (where applicable). NASS / CDS failed to return a delta-V value in three of these ten instances.

Limitations

Though the technology of the both manufacturers version of the EDR is continually evolving, they are not perfect and experience several limitations. Overall, these limitations include:

- The recording times are too short to capture the entire event in most cases, especially the Ford RCM.
- Both the GM SDM and the Ford RCM experience difficulty recording multiple events. The GM SDM stores up to two events, the Ford RCM records only one event.
- The GM SDM had some missing delta-V histories for non-deployment events.
- The GM SDM does not record lateral delta-V which is required for total delta-V calculation.
- Both the GM SDM and the Ford RCM experience difficulty in matching the EDR event with the event recorded by NASS / CDS.

This study provides a direct comparison between EDR recorded data and that of full-scale crash tests and accident investigations. Although EDRs in their current state experience limitations and will certainly be improved as technology advances, the results show that EDRs are powerful tools for both automakers and researchers alike.

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[24] *Fincham, W.F; Kast. A.; Lambourn, R.F. Feb. 1995. The Use of a High Resolution Accident Data Recorder in the Field; SAE Paper No. 950351.*

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[36] *Gabler, H., Hampton, C. Event Data Recorders: Engineering Evaluation of Initial Field Data. Final Report. A Letter Report Prepared for National Highway Traffic Safety Administration, Washington, DC 20590*

[37] *Kerr, James. JKerr@Vetronix.com "RE: Question about SDM Modules" Friday, February 14, 2003.*

[38] *SDM Data Limitations. NASS Case No. 20020925, Viewable via Vetronix v.2.0. Viewed June 3, 2003. Note: SDM Data Limitations sheet varies depending on SDM version, make, model, and model year of vehicle.*

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[40] *Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale, 1990 Revision, Update 98.*

[41] *CRASH3 User's Guide and Technical Manual, National Highway Traffic Safety Administration, Final Report. 1981, Revised 1982.*

[42] *O'Neil,B., Preuss, C.A., and Nolan, J.M. "Relationships between computed delta-V and Impact Speeds for Offset Crashes", Paper No. 96-S9-O-11, Proceedings of the Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia. May 1996.*

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APPENDIX A – ANNOTATED BIBLIOGRAPHY

This section provides an annotated bibliography of articles that describe current Event Data Recorder (EDR) engineered products. The bibliography is divided into sections by application topic area. This bibliography includes an extensive set of references compiled by NHTSA's Working Group Final Report, August 2001, which was the starting point for this literature survey.

Review Articles

R.L. Phen, Dowdy, M.W., Ebbeler, D.H., Kim, E.H., Moore, N.R., VanZandt, T.R.,. National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), Advanced Airbag Technology Assessment. Final Report. April 1998.

In this report by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), the need for further research and data collection on Event Data Recorders was identified. The two key issues that were identified as priorities for further research by the National Highway Traffic Safety Administration (NHTSA), they included: the need for a better understanding of restraint system performance and the need for better real world data.

Event Data Recorders - Summary of Finding by the NHTSA EDR Working Group. Final Report. August 2001.

Starting in 1997, the National Transportation Safety Board (NTSB) issued a recommendation to pursue vehicle crash information. During that same year, the National Aeronautics and Space Administration (NASA) recommended the study of "...the feasibility if installing and obtaining crash data for safety analyses from crash recorders on vehicles." By 1998, the NHTSA Office of Research and Development launched a working group comprised of industry, academia, and government organizations. Members of the working group set out to study the state-of-the art Event Data Recorders (EDR). Research was limited to fact finding only and not making any recommendations. Their objective: *To facilitate the collection & utilization of collision avoidance and crashworthiness data from on board Event Data Recorders.* The report presents an overview of EDR history and the different modes of transportation that currently use EDR technology. Current EDR manufacturer systems are examined and reviewed, classified as either original equipment manufacturer (OEM) or aftermarket. Benefits and problems with EDR technology are then discussed as well.

Matsumoto, K. 1998. Trends and Priorities in Motor Vehicle Safety for the 21st century: Japan. Japan Ministry of International Trade and Industry, Tokyo. 3 p. International Technical Conference on Experimental Safety Vehicles. Sixteenth. Proceedings. Volume I. Washington, D.C., NHTSA, 1998. Pp. 85-87. UMTRI-92420 A15

The author explains that as motor vehicle usage increases across the globe, vehicle safety features become an even more important issue then it is today. The idea of "smart vehicles" is presented, in which the vehicles are equipped with Central Processing Units (CPU) that integrate various sensors and actuators, process data, communicate outside the vehicle, and control the vehicle. Among the systems that the CPU controls and obtains data from is the drive recorder. This recorder saves data from the various sensors and overwrites old data with new data once a certain threshold is breached. The author specifies that the driver recorder will determine the movements of the vehicle, the actions of the various systems during those movements, and the action of the driver during those movements. Issues identified as left to be resolved include driver's privacy, who should be responsible for the extra expense of the recorder, and who will have access to the data and to what extent once a particular incident has been recorded.

Event Data Recorders-Summary of Finding by the NHTSA EDR Working Group-Volume II: Supplemental Findings for Trucks, Motorcoaches, and School Buses. May 2002 (DOT HS 809 432)

This supplemental report outlines the objective findings of the Truck and Bus Event Data Recorder Working Group (T&B EDR WG) and serves as an extension to the findings of the EDR Working Group (EDR WG). Due to the inherent differences in weight, load, geometry, and size, NHTSA recognized the need to address the application of EDRs in mass transit/transport vehicles separately from applications in typical passenger vehicles. The T&B EDR WG focused on the generation of data elements to be collected, during what events data should be collected as well as the survivability issues of the devices. A total of twenty-eight (28) data elements for possible inclusion in the EDR parameter collection set for large vehicles have been identified and prioritized based on need and current technology. For each data element, the report provides a brief discussion identifying possible measurement parameters (unit, range, sampling rate, and accuracy) as well as issues involved with its collection. Survivability issues and trade-offs of these devices are discussed and a need for additional research is identified prior to the adaptation of a minimum standard. Also, a discussion of the events for which data should be recorded is presented. Although a significant amount of research is required due to the lack of intrusion of EDR technology into this vehicle classification, the WG concludes that the EDR technology has the potential to greatly improve safety.

Deering, Darrel; Fay, Richard; Robinette, Ric; Scott, John. Using event Data Recorders in Collision Reconstruction. Fay Engineering Corp. Copyright © 2002 Society of Automotive Engineers. Paper number 2002-01-0535, Book number SP- 1666.

This article discusses the latest publicly released information several event data recorders. The EDR systems included are aftermarket systems DriveCam, MACBox, and BUS-WATCH, as well as the OEM systems SDM by GM and the Ford RCM. The article lists out parameters for the BUS-WATCH system only, as others have been published previously. The BUS-WATCH parameters included: vehicle speed, brake application times, turn indicator actuation, temperature and battery voltage on a time indexed scale. The authors mention that the BUS-WATCH system needs proper calibration to ensure accurate information is provided. Discussion about newer diesel engines, including those from Detroit Diesel, Cummins, Caterpillar, Mack, and others follows. These diesel engines are standardized under SAE 1587 for information download. The information contained within the Electronic Modules (ECMs) can be downloaded to handheld computers and printed later. It is interesting to note that the data from one manufacturers computer can be downloaded by any of the other manufacturers' computer link under the standardization. Similar standardization may prove useful for passenger vehicles as the technology emerges. Methods for downloading data from the EDR post event are discussed. The authors provide a list of data elements that include pre-crash, crash, and post-crash data.

Lawerence, M. Jonathan. Wilkinson, C. Craig. King, J. David. Heinriches, E. Bradley. Sigmund, P. Gunter. The Accuracy and Sensitivity of Event Data Recorders in Low Speed Collisions. MacInnis Engineering Associates. Society of Automotive Engineers, Inc. 2002.

With the inception of the Vetronix Crash Data Retrieval System, the collision data stored in airbag sensing and diagnostic modules (SDM) found on all 1996 or newer General Motors vehicles has become available to accident investigators. This study performs two experiments to investigate the accuracy and sensitivity of the speed change reported by the SDM in low speed collisions. The first test subjected two SDM equipped vehicles to 260 staged frontal collisions with speed changes below 11 km/hr. The second test involved the removal of the SDMs from the vehicles and subjecting them to a wide variety of collision pulses via a linear motion sled. In all vehicle tests, the SDM underestimated the actual speed change of the vehicle. The sled testing results showed that the shape, duration, and peak acceleration of the collision pulse affected the accuracy of the speed change reported by the SDM. This sled test data was then used to evaluate how the SDM reported speed change was computed. A threshold trigger model that ignored a section of the collision pulse explained the difference between the actual and the SDM-reported speed change. The report concludes that accident investigators that use SDM collision data to determine the severity of low speed collisions must account for the error present in the SDM-reported speed change.

Lawerence, J., Wilkinson, C., Heinrichs, B., Siegmund, G. The Accuracy of Pre-Crash Speed Captured by Event Data Recorders. MacInnis Engineering Associates. 2003 SAE World Congress, Detroit, Michigan March 3-6, 2003. Paper 2003-01-0889

General Motors Sensing and Diagnostic (SDM) reported Pre-Crash speeds were compared to speeds reported by a 5th wheel of known accuracy. A total of 118 tests were run at various speeds on three different 2002 GM vehicles including a Pontiac Sunfire, a Chevrolet Malibu, and a Chevrolet Impala. A circuit that replaced the accelerometer and caused a deployment level event to be recorded triggered the SDMs. The data from the SDM was then downloaded using Vetronix Crash Data Retrieval System v.1.60. This data was then compared to the 5th wheel speed value at the respective time intervals. Results showed that SDM-reported speeds ranged between an overestimate of 1.5 km/hr at low speeds to an underestimate of 3.7 km/hr at high speeds. The authors believe that the consistency of these results reasonably allow for accident reconstructionists to incorporated the SDM reported Pre-Crash speeds into their analysis.

Steiner, John. EDR Pre-Crash Sources for General Motors Vehicles. Roger Clark Associates. 2002, 13 pages.

This article looks into General Motors Sensing and Diagnostic Modules (SDM) in a vehicle systems overview, explaining how the EDR is tied into the In – Vehicle Network (IVN). The author explains how the EDR gets the pre-crash data from other systems on the IVN including the on-board diagnostics system (OBD), the powertrain control module (PCM), the electronic brake and traction control module (EBTCM). After the systems have been laid out and explained, the author discusses how different environments and crash scenarios that effect vehicle operation with regard to driver input effect pre-crash data recorded by the EDR prior to collision. Several examples are given.

Original Equipment Manufacturer Articles

Andersson, U.; Koch, M.; Norin, H. 1997. The Volvo Digital Accident Research Recorder (DARR) Converting Accident DARR-Pulses Into Different Impact Severity Measures. Volvo Car Corporation, Automotive Safety Centre, Goeteborg (Sweden) 20 p. International IRCOBI conference on the biomechanics of impact. 1997. Proceedings. Hannover, IRCOBI, 1997. Pp. 301-320. UMTRI-92418 A19

The first experiences from the Digital Accident Research Recorder (DARR) are presented. This Digital Accident Research Recorder is Volvo's version of a crash recorder and is used on all Volvo models equipped with airbags. Information on the crash recorder itself was limited to direction, magnitude and time-span for the recorded data. They were longitudinal only, 400 m/s^2, and 180 ms respectively. This research describes the validation tests of DARR, and the collection as well as the quality control of incoming DARR data. Volvo's accident team received approximately 250 cases and from those, 32 cases were selected for further research. Relevant results include DARR data being reported as still being too limited for reliable analysis (due to the nature of the single axis accelerometer).

Correia, J.T.; Iliadis, K.A.; McCarron, E.S.; Smole, M.A. June 2001. Utilizing Data From Automotive Event Data Recorders. Hastings, Bouldong, Correia Consulting Engineers. Proceedings of the Canadian Multidisciplinary Road Safety Conference XII; June 10-13, 2001; London, Ontario. 16 pgs.

Vertronix products are investigated in detail. An Abstract and a historical summary of EDRs are given. Different types of Automotive EDRs are described as well as an in-depth look at how the Vertronix Sensing and Diagnostic Module (SDM) works.

Since 1994, GM vehicles have been using electronic sensors called Sensing and Diagnostic Modules (SDM) that have the capability of recording event data. In March of 2000, Vertronix Corporation unveiled its Crash Data Retrieval (CDR) system that allows its users to download the data contained within certain GM SDMs. The event data recorded in the GM SDM for both deployment and non deployment events that is available for download using the CDR system includes: driver seat belt, SIR warning lamp, RF airbag suppression, ignition cycles @ event(s), ignition cycles @ investigation(s). The following crash parameters are recorded for both deployment and non deployment events: forward ΔV, time to deployment, time between events, and the time to maximum ΔV. Pre-Crash Parameters recorded in the latest SDM-G include: vehicle speed, engine RPM, percent throttle, brake status, and data validity information.

This information thus far has outlines the parameters recorded for GM vehicles only, however in November 2000, Ford agreed to let Vertronix develop software to enable CDR users to download crash data from Restraint Control Modules (RCM) found on selected Ford vehicles. Software updates and cables were expected before the end of 2001. The article identifies the following as potential uses and benefits from airbag sensing modules in this article: real time, law enforcement, government, vehicle design, highway design, insurance / legal, research, and owners / drivers.

Garthe, E.A.; Mango, N.K. 2001. Conflicting Uses of Data from Private Vehicle Data Systems. Garthe Associates, Marblehead, Mass. 15 p. Intelligent Vehicle Initiative (IVI): Technology and Navigation Systems. Warrendale: SAE, 2001, pp. 79-93. Report No. SAE 2001-01-0804. UMTRI-94222 A10.

Challenges and opportunities presented by the introduction of crash event data recorded from private vehicles are the focus of this article. Broad descriptions of some of the different types of systems that are available, specifically how they work and the types of information that they store are given. Specifically, the two types of system categories that the author mentions are streaming data systems (record a given parameter versus time) and point data systems (record Boolean or point information such as seat belt – buckled or unbuckled). Three manufacturers', GM, Ford, and Mercedes – Benz, systems are mentioned. The GM SDM EDR and OnStar Crash notification systems, Mercedes – Benz TeleAid crash notification system, and the Ford Wingcast traveling internet access and entertainment service are mentioned without getting into any serious detail. A list of GM vehicles whose streaming data recorder (SDM crash info) can be downloaded as of March 2000 is included in the paper. Data ownership issues are discussed in detail as well as a description of the NHTSA working group research is summarized.

German, A.; Comeau, J.L.; Monk, B.; McClafferty, K.; Tiessen, P.F.; Chan, J. June 2001. The Use of Event Data Recorders in the Analysis of Real-World Crashes, Proceedings of the Canadian Multidisciplinary Road Safety Conference XII; June 10-13, 2001; London, Ontario. 15 pgs.

While it is understood that the Ford Motor Company is in the process of developing a similar CDR system, currently, a proprietary tool is required to interface with their restraint control module (RCM). The use of this tool is limited to certain vehicle models that are equipped with advanced airbag systems. These systems include such features as seat belt pretensioners, occupant proximity sensing, and air bags with dual threshold deployment and dual-stage inflators. The sophisticated nature of these systems, particularily the higher deployment threshold for belted occupants, and the low output level in the first-stage inflator, offers the potential for significantly enhanced protection for belted occupants. Such developments are quite consistant with the findings of Canadian research into first-generation airbag systems. Transport Canada and Ford Motor Company of Canada are therefore, conducting a joint research project to help evaluate the real-world performance of these advanced restraint systems and, as part of this study, data from the on-board recorders are being obtained. To date, information has been obtained from crash recorders installed in vehicles that have been part of Transport Canada's on-going research and regulatory development programs, and from real-world crashes.

Engstrom, Anders. Methods and tools for evaluation of the Volvo Pre Crash Recorder. Masters Thesis performed in Vehicular Systems at Linkopings Institute of Technology. Reg nr: LiTH-ISY-EX-3181.

Volvos Pre Crash Recorder (PCR) is an addition to the existing Digital Accident Data Recorder (DARR) and meant to function in tandem with it. The DARR has been in use in Volvo vehicles since 1994 and records deceleration values upon airbag deployment. The PCR function is to record 31 predetermined parameters in 500 ms starting 5 seconds prior to a crash and store them in memory. Those parameters include: outdoor temp, global time, time from ignition on, steering wheel angle, lateral acceleration, roll rate, vehicle speed, longitudinal acceleration, driver requested torque, engine torque, actual yaw rate, engine speed, engine speed quality factor, BCM voltage, engine torque quality factor, BCM functions enabled / disabled, stability traction control / dynamic stability and traction control switch manually on / off, driving direction (PRNDL), brake pedal position, clutch pedal position, BCM functions active / inactive. Though the mentioned items are only 21 in sum, the parameters that make up this data group are 31 in number as listed in the source article.

Menig, Paul and Cary Coverdill. Transportation Recorders on Commercial Vehicles. International Symposium of Transportation Recorders. May 3-5, 1999. Arlington, Virginia.

A history of data recorders in commercial vehicles and overview of current technology and a projection regarding future recoding capabilities is presented in this article. Several aftermarket and OEM systems and their capabilities are discussed; the main purpose of each device appears to be in regard to fleet management and collision warning rather than the obtainment of crash related parameters. Caterpillar engines, for instance, record extensive data ranging from ambient air temperature to the instantaneous fuel rate. The only elements, however, that appear to apply to vehicular crashes are engine RPM, vehicle speed, and hard braking warning. The Tacholink system is discussed along with its extensive "high definition" speed recording capabilities of the last 1000 meters before an accident. Although this recording capacity is similar to an EDR, the author mentions that these devices, in general, are not constructed to survive a crash and in most cases are "not even of sufficient design to last the life of the vehicle in normal service."

Aftermarket Manufacturer Systems

Delphi Automotive Systems Accident Recorder 2 (ADR 2)
Information from: http://www.delphiauto.com/motorsports/products/

Delphi's product was developed with the racing crowd in mind. The recorded event parameters include: Wheel Speed, Throttle Position, Steering Angle, Lap Indicator, X-Axis Acceleration (up to 500 g), Y-Axis Acceleration (up to 500 g), Z-Axis Acceleration (up to 500 g), Yaw Rate, Internal Real Time Clock, 7 General purpose analog inputs, and finally 3 General Purpose Timer inputs. The unit senses and records these parameters at 1000 Hz before, during and after an event. Upon trigger, the data are stored in the units internal memory to be accessed later via a high speed data link to a PC. The necessary suite of Windows™ compatible data analysis software is included with the unit. Since this particular unit was designed for racing applications, the casing features a highly rugged design and has an internal uninterruptible power supply that allows the ADR – 2 to continue operating should vehicle power become unavailable.

I-Witness Incorporated DriveCam I
Rayner, Gary & Sophia, November 2001. Innovations Deserving Exploratory Analysis Programs (IDEA) – Intelligent Transportation Systems Program. I-Witness Black Box Recorder Final Report for ITS Project 84. Available at: **http://gulliver.trb.org/publications/sp/its-idea_84.pdf**

I-Witness Incorporated's first product is a digital video event data recorder called DriveCam I. When triggered by a collision, erratic driving, or the units manual push button, DriveCam I digitally saves 20 seconds of information. The EDR records from 10 seconds prior to trigger to 10 seconds following the event. It is then possible to replay the event showing video, audio, and acceleration forces (g forces) experienced during the event. Data captured includes the date and time for the event. All of the information can then be downloaded to a computer or VCR for viewing and / or long-term storage. Events can be displayed immediately on a television or camcorder, and DriveCam I has the same features and functions as a VCR i.e. play, fast forward, rewind, etc. DriveCam I includes a sensitive black and white CMOS camera, microphone, 4-direction accelerometer, a real-time clock, and other electronic components all controlled by software. G forces are sampled at a rate of 60 Hz in each of the 4 directions. The accelerometers can measure up to 50 G's with a resolution of 0.1 G. Video resolution is 256 x 200 effective pixels. The unit is slightly larger than a pager and installs behind the rear-view mirror yielding a 120-degree field of view out of the front windshield. DriveCam I continuously records Video, Audio, and 4 directions of g forces in a circulating digital memory buffer of 16 MB. It retails for about $800.00.

VDO-Kienzle and Siemens UDS 2156 Accident Data Recorder
Lehmann, G.; Reynolds, T. Printed March 2002. The Contribution of Onboard Recording Systems to Road Safety and Accident Analysis.
Available at: http://www.ntsb.gov/events/symp_rec/proceedings/authors/lehmann.pdf

VDO-Kienzle and Siemens manufactured what they have called an Accident Data Recorder. This Accident Data Recorder, the UDS 2156 was specifically developed for accident analysis and to be used in passenger cars, trucks, and buses. The Accident Data Recorder is mainly composed of sensors measuring the transverse and longitudinal acceleration of the vehicle as well as its change of direction and road speed. The Accident Data Recorder detects when and how long the ignition, lamps, turn signals, and brakes have been activated. In the case of an accident, the unit automatically triggers data recording at a rate of 500 Hz 30 seconds prior to and 15 seconds after, for a total of 45 seconds of recorded data. The system also has the ability to record special functions such as the use of sirens and flashing lights on emergency vehicles. There is enough memory in the Accident Data Recorder to allow for three accidents to be stored.

Information download for the UDS 2156: http://forensicaccident.com/UDS_page1.htm

Graduated software programs [for the UDS 2156], tailored to the user, are available to access the event data. The UDS Software (32-bit) runs generally on the

Windows™ 95, Windows™ 98 and Windows™ NT 4.0 operating systems. Using UDShow, the person responsible for the vehicle fleet can read out the stored events and statistics data and can display or print them out in a variey of ways, including graphically.

Independent Witness Incorporated Witness Black Box
Information available at: http://www.iwiwitness.com/witness.html

The Witness Black Box monitors the vehicles motion and in the event of an impact it records the date, time, direction, impact severity (G-forces) and acceleration profiles. The data stored in the Witness can be accessed immediately for verification at the scene of an accident with a laptop computer or removed and downloaded at a desk. IWI uses SAE – J211 guidelines for collecting data. The Witness is self-contained, operates on patented battery consumption technology that allows the device to operate for over two years without maintenance. Installation can be done in approximately four minutes, as the unit does not connect to any of the vehicle electrical systems.

Carroll, Joseph and Michael Fennell. An Autonomous Data Recorder for Field Testing. International Symposium of Transportation Recorders. May 3-5, 1999. Arlington, Virginia.

This article details the efforts of the Tether Applications Company to develop the Small Intelligent Datalogger (SID), which is a miniature and autonomous data recorder. Although the device was designed to be the core of a low-cost, low-power spacecraft, it appears to be useful in situations where development of data recording specifications are required, connection to or development of sensors is not economical or feasible, or a backup data collection system is required. Pertinent features of this device include the customization option for sensors, extensive memory capabilities, and expansion possibilities with commercial "off the shelf" parts. Currently, the design and testing process is 90% complete and the anticipated cost of the device is approximately $3,000. The authors mention briefly the possibility of an application in the automobile industry but the only useful on-board sensing capabilities appear to be the 3-axis acceleration measurements, 2-axis angular rotation measurements and the possibility of four external "on-off" type event recorders.

Fincham, W.F; Kast. A.; Lambourn, R.F. Feb. 1995. The Use of a High Resolution Accident Data Recorder in the Field; SAE Paper No. 950351

The Event Data Recorder (EDR) that was under discussion was the Mannesmann Kieinzel UDS2156. Details specifications about the UDS system are given in the paper as well.

The review of the above article comes directly from the following
Husher, Stein. Noble Engineering. Feb. 1995. pg 138 SAE Paper No. 950351

This paper presents original data and analysis on the performance of a self contained on-board data acquisition package. The research demonstrates that the recorded data can accurately reconstruct the trajectory of a vehicle. Additionally, this device can give a very detailed picture of the operational status of the vehicle and of the external forces experienced by the occupants in that vehicle. This type of data could lead to refinements in accident reconstruction techniques and a better understanding of the real world collision environment.

Hook, P. 2001. "Skunk in the Trunk?: Journey and Collision Data Recorders: Asset or Liability?" Traffic Technology International Dec 2000 / Jan 2001.

Discussed here are the use of journey and collision recorders and their effects on reducing the number and severity of accidents that drivers are involved in. In both Europe and the USA, the use of such devices "are said to have resulted in dramatic falls in crash rates and general improvement in driver behavior." Currently, it seems as if implementation of such devices has only been completed on fleet vehicles. Two basic incident recorders exist on the market today, they include: Journey data recorders (JDR) that deal with and record driver behavior such as acceleration, harsh braking, excessive engine speed and engine idling times over an extended period as well as accident (or more properly, incident) data recorders (IDRs) that concentrate on the few seconds before and after an impact or other incident. Aftermarket companies that are mentioned to manufacture such devices include: VDO-Kienzle and Siemens of Germany, UK-based Leafield AVM and ITS Black Box, and the French company Simac Logiq.

Kullgren, A.; Lie, A.; Tingvall, C. 1994. The Use of Crash Recorders in Studying Real-Life Accidents. Chalmers Tekniska Hoegskola, Goeteborg, Sweden. 7 p. International Technical Conference on Enhanced Safety of Vehicles. Fourteenth. Proceedings, Volume 1. Washington, D.C., National Highway Traffic Safety Administration, 1994. Pp. 856-862. UMTRI-88120 A79

Low cost crash recorders used to obtain the crash pulse in frontal impacts have been installed in 30,000 cars in the Swedish market. The paper shows the crash pulses from real life accidents using this low cost Crash Pulse Recorder (CPR). Over 100 of the accidents have been recorded and used for the tests subjects of the study, however only 8 of them were picked out and studied in depth. The CPR unit itself is based on a spring mass system where the movements of the mass in a collision are measured. The displacements of the mass are measured on a photographic film using a light emitting diode (LED) to designate its location. The LED is driven by a crystal oscillator that yields a modified square pulse at a frequency of 1000 Hz. The circuit has its own power cell and uses no additional outside power. The trigger level for the unit has been preset at approximately 1 g. Detailed mathematical derivation of how the displacement of the spring mass is used to obtain the crash pulse is included along with a schematic of the unit itself.

Melvin, J. W.; Baron, K. J.; Little, W. C.; Gideon, T. W.; Pierce, J. 1998. Biomechanical Analysis of Indy Race Car Crashes. General Motors Corporation, Detroit, Mich./ Kestrel Advisors, Inc. 20 p. Stapp car crash conference. Forty-second. Proceedings. Warrendale, SAE, 1998. Pp. 247-266. Report No. SAE 983161. UMTRI-91882 A17

Beginning in 1992, GM Motor sports Safety Technology Research Program has turned its attention to the use of on board crash recorders in an ongoing effort to analyze Indy Car crashes. Melvin et al. discuss the development, specifications and implementation of the impact-recording device on the Indy Car race scene. The recorder that was decided on was an IST Model EDR-3 Environmental Shock and Vibration

Recorder by Instrumented Sensor Technology, Okemos, MI. The unit is rectangular (107 x 112 x 56 mm) and weighs 1.14 kg with the required eight 9-volt batteries. Internally, the unit is comprised of three piezoresistive accelerometers and a temperature sensor for any required temperature compensation of the accelerometer signals. The unit samples all three channels at 2000 Hz and upon trigger, digitally stores the data using 12 bit resolution with 412 Hz anti-aliasing filtering and then resets itself for the next impact. The unit records for a total time of 2.0 seconds (0.5 seconds prior to trigger and 1.5 seconds after trigger) and is capable of recording up to 10 separate impacts. The trigger mode requires that the deceleration be above 5 G for at least 5 msec, corresponding to a minimum velocity change of 0.25 m/sec. The EDR-3 offers a special serial communications port for standard or high speed serial data transfer to a host PC.

Raney, R.F., A Parental Black Box For Young Drivers. The New York Times. Thursday, August 22, 2002.

Road Safety International has introduced a system that allows parents to monitor the driving behavior of young drivers with their model RS-3000 On-Board Computer. The device monitors vehicle speed, steering input (for hard cornering), acceleration (or deceleration), and occupant compartment noise level emitting a loud beep if any of these parameters exceed a predetermined threshold set in the units internal memory. The beeping gets progressively louder if the exceeded parameters do not show improvement. The device plugs into the OBD II port to obtain its readings and is sold with a memory card that allows users to plug into a PC for data download. The included software compiles the data and gives drivers a single score from Level 1, the best, to Level 10, the worst. Level 5 is the recommended level to attain by emergency services agencies. The company has been selling similar devices to ambulance companies, police departments, and fire departments since 1992 that retail $3500, though the scaled down version for teenagers retails for $280. Road Safety International plans to incorporate a Global Positioning System in next years model that will allow parents to check the cars location via the Internet.

Automatic Collision Notification Systems

Buckeley, W. Taxis Soon May Get Black Boxes. The Wall Street Journal: Technology Journal. Thursday, March 14, 2003. Section B, Page 4.

International Business Machines (IBM) has designed an aftermarket EDR / ACN to be used in taxi cabs (fleet management). This EDR records pre-crash vehicle speed and with the advent of a crash, automatically reports data on speed, location, brake pressure and number of passengers to a crash-records depository run by IBM. The device, about the size of a cigarette box, will use other sensors such as those associated with seat-belts and airbags to monitor data and send five seconds worth of data about the car as a text message via cell phone to IBM's crash depository. Insurance companies are giving incentive to Taxi companies by offering insurance discounts based on the number of vehicles in the fleets with the devices installed.

Carter, A., Kanianthra, J., Preziotti, G.; June 2001. Enhancing Post-Crash Vehicle Safety Through an Automatic Collision Notification System. Proceedings of the 17th International Technical Conference on the

Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 175, 10 pgs. Review from ESV CD-ROM.

The National Highway Traffic Safety Administration (NHTSA), under the U.S. Department of Transportations Intelligent Transportation System (ITS) research program, designed and developed an ACN system in partnership with Veridian Inc. NHTSA conducted an operational test of the system by installing it in 850 volunteers' vehicles and collected data from vehicles involved in crashes. The data showed that it was technologically feasible for ACN systems to improve the timeliness and delivery of pre-hospital medical care of motor-vehicle crash victims.

Champion, Howard R. et al. Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Services Providers. International Symposium of Transportation Recorders. May 3-5, 1999. Arlington, Virginia.

A team consisting of trauma surgeons, emergency physicians, engineers and statisticians have developed software to automatically convert EDR data into an analogous crash severity rating that calculates the probability of serious injuries for a given crash. Termed URGENCY, the software is intended to utilize ACN technology to improve the response time of EMS teams and ultimately decrease the number of automobile crash related fatalities. The team related crash force (delta V), principal direction, rollover, vehicle weight, and seat belt use to the probability of a serious injury occurrence; these parameters were handled individually and in combination to provide a more realistic model. With additional data regarding the age, gender, entrapment, and ejection of the occupants (obtained by EMS dispatchers), the program displays the probability of a serious injury graphically as a percentage of 0 to 100. Currently, this software is being implemented in Buffalo, New York (a DOT contract with the Calspan Corporation) with a fleet of 1,000 vehicles equipped with ACN technology. Future versions are slated to include additional parameters such as pre-event speed, deceleration, air bag time and level of deployment, and seat belt forces. With significant research presented on the number of crash related deaths and the relation of the current response times, the team indicates that there is a strong need for the improvement of the highway environment.

Gabler, H.C.; DeFuria, J.; Schmalzel, J. L. June 2001. Automated Crash Notification Via The Wireless Web: System Design And Validation. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 71, 5 pgs.

The Rowan University research and development team presents the design of a low cost ACN System for the state of New Jersey. The research team successfully designed and constructed a working prototype of a low cost ACN, conducted a performance test that included a 10 mile drive around Rowan's campus area where the test apparatus was monitored and mapped from the base station. A durability test was also completed including a six-meter drop tower, subjecting the ACN casing and internal components to up to 10 G accelerations.

Galganski, R.A.; Donnelly, B.R.; Blatt, A..; Lombardo, L.V. June 2001. Crash Visualization Using Real-World Acceleration Data. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 357, 10 pgs.

Outlined here is information describing how actual motor vehicle acceleration data from real world collisions was used in conjunction with Articulated Total Body Control (ATB) computer analysis to generate animated images of simulation through mathematical modeling of occupants' motion inside the vehicle cabin. Data for the simulations was taken from Automatic Crash Notification systems (ACN) installed on a test lot of New York state vehicles. For the study, Veridian Engineering completed the testing of an advanced ACN system that it designed and built for the U.S. Department of Transportation (DOT) / NHTSA. The test vehicles were equipped with what was called an in-vehicle-module (IVM), a three- watt cellular phone package, and two antennas. Included in the IVM are a GPS unit, three orthogonal floor-plan-mounted accelerometers, a digital signal processor, a modem, and flash memory. Upon indication of a crash, the IVM detects the incident, opens a hands-free phone connection between the vehicle and a 9-1-1 emergency-message center. It then transmits to the center the location of the vehicle, the crash pulse, velocity change, and final rest position as well as the principal direction of the crash force. The paper then goes with a detailed discussion of how the information from the ACN was input into the software and used to create a dynamic occupant-positioning image for the entire duration of the crash pulse.

Use of Event Data Recorders in Fleet & Diagnostic Testing Articles

Arai, Y; Nishimoto, T;Ezak, Y; Yoshmoto, K. June 2001. Accidents and Near-Misses Analysis by Using Video Drive-Recorders in a Fleet Test. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 225, 6 pgs.

The author describes the use of video drive recorders (VDRs) in a fleet of 202 vehicles in central Tokyo, Japan. During the fleet test period a total of 30 collisions occurred and data was recorded. Two types of recorders were utilized: one that recorded accident data only, and the other that recorded both accident and near-miss data. Near-miss data compromises those incidents including rapid braking or steering without resulting in a collision. The VDRs were capable of recording such data as driving speed, acceleration / deceleration, yaw velocity, and several other "driving operations" (in the figures we are shown a turn signal chart). From these data, the crash researchers were able to plot out a course during the last minute before the collision (without the aid of Global Positioning System, GPS). According to the author, "drive-recorders record quantitatively the vehicle behavior and driving operation in time sequence *before and after* on accident. By combining data collected by the drive-recorder with the information on the traffic and road conditions surrounding an accident, it is possible to analyze the accident in greater detail in terms of people, vehicles and surrounding factors involved." The visual data provided by the VDR also shows evidence that it is possible to estimate the operator's behavior, surrounding traffic and road conditions. This data can then be used to verify the findings based on the stored electronic data. From what we can tell, all of the data are stored on-board in the VDR unit and then must be extracted after the event occurs.

Ueyama, M.; Ogawa, S.; Chikasue, H.; Muramatu, K. 1998. Relationship Between Driving Behavior and Traffic Accidents -- Accident Data Recorder and Driving Monitor Recorder. National Research Institute of Police Science, Tokyo (Japan)/ Yazaki Meter Corporation (Japan) 8 p. International Technical Conference on Experimental Safety Vehicles. Sixteenth. Proceedings. Volume I. Washington, D.C., NHTSA, 1998. Pp. 402-409. Report No. 98-S1-O-06. UMTRI-92420 A53

A field trial has been carried out using automatic recording systems. The systems included a Driving Monitoring Recorder (DMR) and an Accident Data Recorder (ADR) that were installed on a fleet of 20 vehicles in Tokyo, Japan for one year. Pre-and post crash data were recorded whenever accidents occurred, and the drivers that were using the vehicles were given driving aptitude tests prior to any use. The ADR that was used was the a Mannesmann Kieinzel ADR UDS2156 and the DMR that was used was the Yazaki Meter Co. DMR Yazac-5064. Once the data was collected, the general findings showed that the drivers that practiced hard acceleration and braking had a much higher tendency to have a collision. Also, there was a strong relationship between the driver awareness of the traffic situation at hand and the occurrence of an accident.

Ueyama, M. June 2001. Driver Characteristic Using Driver Monitoring Recorder. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 426, 10 pgs.

A field trial has been carried out using a set of automatic recording systems. The automatic recording systems that were used to conduct the testing were the Mannesmann Kieinzel ADR UDS2156, the Drive Monitoring Recorder (DMR) Yazak-5064 developed by Yazak Meter Co., and the Event Eye Camera (EEC). They were installed on total numbers of 105 vehicles in four fleets of taxi and truck in Tokyo area for 4 years in order to access the implications in driving characteristic and traffic conditions.

Wouters, P.I. J.; Bos, J. M. J. 2000. Traffic Accident Reduction by Monitoring Driver Behavior with In-Car Data Recorders. Institute for Road Safety Research SWOV, Leidschendam (Netherlands) 8 p. Accident Analysis and Prevention, Vol. 32, No.5, Sept 2000, pp. 643-650. UMTRI-61880.

This study aims at showing how monitoring driver behavior reduces traffic accidents. Vehicle data recorders were used to offer a means of providing drivers' behavioral tendencies, allowing them to be confronted with their recorded driving actions. A field trail was conducted using two types of commercially available vehicle data recorders, neither of which the manufacturers were given in the article. The first type was an Accident Data Recorder (ADR) and the second type was a Journey Data Recorder (JDR). The data recorded included time schedules, mean speed, rapid accelerations, fuel consumption, etc. as well as more detailed data 90 seconds prior to the point at which the vehicle came to rest. The data was collected from 11 different fleets and included over 840 vehicles, 270 of which were equipped with recorders. The results showed an average estimated accident reduction of about 20% when the operators were aware that the vehicles that they were driving were equipped with data recorders and would be confronted with their actions if an incident occurred.

Wright, P. G. 1998. The Role of Motorsport Safety. Federation Internationale de l'Automobile (England) 6 p. International Technical Conference on Experimental Safety Vehicles. Sixteenth. Proceedings. Volume II. Washington, D.C., NHTSA, 1998. Pp. 1263-1268. Report No. 98-S6-O-12. UMTRI-92421 A51

The history of safety and its role in the world of motorsports are described. The author argues that because motorsport accidents are caught on film, all of the cars are equipped with Accident Data Recorders, and detailed post accident reports are carried out, they provide an excellent arena for vehicle safety research. Racing organizations worldwide are beginning to use controlled systems to measure crash pulses. These crash pulses, coupled with the in depth accident film and reports make an almost perfect scenario for crash research.

Biomechanics Research Articles

Krafft, M.; Kullgren, A; Ydenius, A.; Tingvall, C. June 2001. The Correlation Between Crash Pulse Characteristics and Duration of Symptoms to the Neck – Crash Recordings in Real Life Rear Impacts. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 174, 7 pgs.

"Neck injuries have become the most common disabling injuries in vehicle crashes." This study focuses on the correlation between delta V measurements from Crash Pulse Recorders (CPR) and degree/time to recovery of neck injury sustained by vehicle occupants. "Since 1996 the crash recorder has been mounted under the driver seat to document rear impacts in 15,000 vehicles in four different Toyota car models. ... The CPR has a trigger level of approximately 3g. The CPR is based on a spring mass system where the movements of the mass in a rear impact are measured. The displacement of the mass is registered on a photographic film. The circuit has its own power cell and does not need an external power unit....When the characteristic parameters for each CPR have been measured, such as spring coefficient and frictional drag, and with a knowledge of the displacement time history, the acceleration time history can be calculated. The crash pulses were filtered at approximately 100 Hz. Change of velocity and mean and peak accelerations were calculated from the crash pulse." There was no mention of whether or not the CRPs were OEM or aftermarket parts nor what other types of data were recorded other then those discussed above.

Krafft, M.; Kullgren, A.; Tingvall, C. Bostroem, O.; Fredriksson, R. 2000. How Crash Severity in Rear Impacts Influences Short and Long-Term Consequences to the Neck. Folksam Research and Development, Stockholm (Sweden)/ Monash University, Accident Research Centre, Clayton, Victoria (Australia)/ Autoliv AB, Vaargaarda (Sweden) 9 p. Accident Analysis and Prevention, Vol. 32, No. 2, Mar 2000, p.187-195. UMTRI-61502.

Crash Pulse Recorders (CPR) were installed in 10,000 vehicles and used to measure the change in velocity as well as the acceleration in vehicles involved in <u>rear</u> impacts. Data from these recorders was then gathered after a collision occurred, however only 28 rear impacts were evaluated due to uncertain reporting procedures. Tests were also conducted on vehicles equipped with a tow-bar hinge outfitted with similar acceleration measuring devices. The data was then compared and used in a study to determine the influence of crash severity in rear impacts leading to long-term and short-term consequences to the neck.

Krafft, M.; Kullgren, A.; Lie,A.; Tinggvall, C. June 2001. Injury Risk Functions for Individual Car Models. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 168, 8 pgs.

"The relation between impact severity and risk of injury is a fundamental issue in terms of comparing vehicles and occupant protection systems.... In this study, an alternative way to derive risk functions was developed and used. In the present method, risk functions were derived using matched pairs of crashes, varying mass relations in a controlled way, and generating risk versus relative change in velocity. " In the new derivation, principles of conservation of momentum were used.

Kullgren, A.; Kraft, M.; N. Gryen, AA.; Tingvall, C. 2000. Neck Injuries in Frontal Impacts: Influence of Crash Pulse Characteristics on Injury Risk. Folksam Research and Development, Stockholm (Sweden) / Karolinska Institutet, Department of Clinical Neuroscience and Family Medicine, Stockholm (Sweden) / Monash University, Accident Research Centre, Clayton, Victroia (Australia) 9 p. Accident Analysis and Prevention, Vol. 32, No. 2, Mar 2000, pp. 197-205. UMTRI-61503.

Crash Pulse Recorders (CPR) were installed in 100,000 vehicles and used to measure the change in velocity as well as the acceleration in vehicles involved in <u>frontal</u> impacts. The study focuses on the 143 frontal impacts with overlap exceeding 25%. Overlap data under 25% was not included in the study. Data from these recorders was then gathered after a collision occurred in which damages that amounted to 7000 USD or more. The data was then used to study and predict injury risk associated with frontal impacts.

Kullgren, A.; Ydenius, A.; Tingvall, C. 1998. Frontal Impacts with Small Partial Overlap: Real Life Data from Crash Recorders. Folksam Research (Sweden) Karolinska Institutet, Department of Clinical Neuroscience and Family Medicine, Stockholm (Sweden) Swedish National Road Administration. 10 p. International Technical Conference on Experimental Safety Vehicles. Sixteenth. Proceedings. Volume I. Washington, D.C., NHTSA, 1998. Pp. 259-268. Report No. 98-S1-O-13. UMTRI-92420 A38

Crash Pulse Recorders (CPR) were installed in approximately 100,000 vehicles since 1992 and about 300 crash pulses were recorded. These recorders measure the acceleration time history in one direction and were filtered at roughly 100 Hz. The acceleration time history was then used to calculate change of velocity as well as mean and peak accelerations. Using the results from the 300 crash pulses recorded, conclusions were drawn about the severity of impacts with small overlap sometimes referred to as narrow offset. These types of collisions are generally characterized by high closing velocities, fairly low change of velocities with major intrusions and high intrusion velocities, often resulting in severe injuries to the occupants. The significance of the study is that most crash tests do not address this type of impact where the main part of the vehicles energy absorbing frontal structure is not engaged. Conclusions were that impacts of this nature do in fact produce severe injuries due to the fact the frontal structure that absorbs the greatest portion of the energy of the collision were missed.

Krafft, M.; Kullgren, A.; Tingvall, C. 1998. Crash Pulse Recorder in Rear Impacts -- Real Life Data. Folksam Research Foundation, Stockholm (Sweden)/ Karolinska Institutet, Stockholm (Sweden) Statens Vaeg- och Trafikinstitut, Linkoeping (Sweden) 7 p. International Technical Conference on Experimental Safety Vehicles. Sixteenth. Proceedings. Volume II. Washington, D.C., NHTSA, 1998. Pp. 1256-1262. Report No. 98-S6-O-10. UMTRI-92421 A50

This paper presents results from real-life rear impacts with vehicles equipped with a low-cost one-dimensional crash recorder known as the Crash Pulse Recorder (CPR). Since 1996 the CPR has been mounted in 10,000 vehicles in two different car models under the driver seat. Its purpose is to present crash pulse and change in velocity measured in real-life rear impacts related to short and long term consequences from AIS 1 neck injuries. Conclusions from the data were vague. The data showed that crash pulses where occupants sustained significant injuries varied widely and that peak accelerations of 14.7g caused the greatest chances of sustaining AIS 1 neck injuries.

Linder, A.; Avery, M; Krafft, M.; Kullgren, A.; Swenson, M.Y.; June 2001. Acceleration Pulses and Crash Severity in Low Velocity Rear Impacts – Real World Data and Barrier Tests. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 216, 10 pgs.

This study aimed at collecting and categorizing acceleration pulses in three different types of rear collisions. "The acceleration pulse from a solid, 1000 kg, mobile barrier test (MBT) at 40% overlap and an impact velocity of 15 km/h was studied for 33 different cars… Acceleration pulses from two different car types in real-world collisions producing a similar change of velocity were also analyzed… The Risk of AIS 1 neck injuries in rear impacts was found to be related to both delta-v and acceleration (pulse) produced on impact (Krafft et al., 2001). The first aim of this study was to show and quantify the variety of acceleration pulses and mean accelerations that can occur in different cars impacted in the same way. The second aim was to demonstrate the variety of crash pulses and levels of acceleration in the same car model from real-world crashes producing similar delta-v." This data could then be used to correlate between crash pulse and occupant injury sustained. For the mobile barrier tests, "The acceleration signals were filtered in accordance with SAE CFC60 and the velocity was calculated by integrating the acceleration." No mention was made of the type of device that was used to collect the acceleration data. In the comparison using the data from the real world rear impacts, one dimensional crash-pulse recorders were used. These recorders were mounted under the driver or passenger seats of various new (1996) car models in Sweden by Folksam. "The crash-pulse recorder is based on a spring mass system where the movement of the mass is registered on photographic film."

Mooi, H.G.; Galliano, F. June 2001. Dutch In-Depth Accident Investigation: First Experiences and Analysis Results for Motorcycles and Mopeds. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 236, 10 pgs.

"In September 1999 the Dutch Accident Research Team (DART) within TNO Automotive started an in-depth investigation of traffic accidents. In this paper, the methodology, working procedures and experiences of the team are described and explained in detail... Results on accident configurations, accident causes, injuries, collision speeds and helmet damages are presented... Two main goals for in-depth research can be distinguished: first to propose measures for the improvement of traffic safety and second to monitor measures in general once they are introduced for their actual benefit." The effect of velocity and helmet-use are discussed in detail. "For passenger car-to-car collisions the delta V is mostly used. For PTWs (Powered Two Wheelers), however, this does not always make sense. In case of a head to tail collision for example, the delta V is almost zero but in case the PTW falls as a consequence of the collision the severity of the accident is more severe than this delta V suggests."

Crash Studies and Rating Systems Articles

Carra, J.S.; Stern,S.D. June 2001. Large Truck Crash Data Collection. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 247, 11 pgs.

NHTSA is collecting data pertaining to large trucks involved in crashes. Two collection programs have been specified, one that deals with the causation of fatal and serious large truck crashes over the last two years, and the other an effort to collect data on large truck motor carrier crashes in each state. These data are entered in to one of 24 of the databases in the National Automotive Sampling Systems Sites (NASS) around the country. Data collection from the data recorders began in Spring 2001. So far the, only preliminary analysis from the electronic data has begun (as of Fall 2002).

Gabler, H., Hampton, C. Estimating Crash Severity: Can Event Data Recorders Replace Crash Reconstruction? U.S. National Highway Traffic Safety Administration. Paper 490. February 2003.

Gabler, H., Hampton, C. Event Data Recorders: Engineering Evaluation of Initial Field Data. Final Report. A Letter Report Prepared for National Highway Traffic Safety Administration, Washington, DC 20590

This paper examines the possibility of replacing the delta-V estimates obtained via crash reconstruction with the delta-V measurements computed in EDRs. The basis for the comparison is 225 NASS/CDS cases from 1999 – 2001 and their corresponding EDR datasets. The study was limited to the use of General Motors cases due to confidentiality agreements associated with other automakers at the time of the study. The delta-V estimates from post-crash investigations for basis of comparison were obtained from a program called WinSmash. A seat-belt usage comparison study was also examined for both the NASS/CDS and the reported EDR seat belt status. Since EDRs in their current state are not perfect, a discussion pertaining to the limitations of EDR data use follows. The discussion includes the problems EDRs have with multiple events, the difficulty of correlating the EDR event with post-crash investigations, the need for longer recording times, the need for additional crash sensors, missing velocity vs. time data, the need for additional event triggers, and field data collection issues associated with EDRs.

Hill, J; Thomas, P.; Smith, M.; Byard, N.;Rillie, I. June 2001. The Methodology of on the Spot Accident Investigation in the UK. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 350, 10 pgs.

A research project that is underway in the United Kingdom considers on the spot accident investigation. This project allows for expert accident investigators to attend the scene of an accident with 15 minutes of the occurrence of the incident. These investigators will be gathering on the scene "perishable" data such as "trace marks on the highway, pedestrian contact marks on vehicles, the final resting position of the vehicles involved and weather, visibility, and traffic conditions. The data gathered by the project primarily focuses on four major items: types of vehicles, the roadway, any human factors, and the injuries sustained by the occupants. The on the spot (OTS) team is comprised of six members that include a Team Manager, a Senior Officer, and a serving Police Officer. Funding is provided by the UK Department of the Environment, Transport and the Regions (DETR) and the Highways Agency (HA) for two teams located in designated spots in the UK.

O'Neil,b., Preuss, C.A., and Nolan, J.M. "Relationships between computed delta-V and Impact Speeds for Offset Crashes", Paper No. 96-S9-O-11, Proceedings of the Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia. May 1996.

"A sample of real world frontal crashes in the United States was examined and the estimated crash severities were related to impact speeds for single-vehicle offset crashes into deformable barriers. For each of the vehicles in these tests, the postcrash vehicle deformation was measured using the procedures specified for CRASH3 and the delta-V was calculated. The results of this study suggest that a 40 percent offset into a deformable barrier at 64 km/h represents a real world crash severity below which about 75 percent of all MAIS 3 or greater injuries and slightly less than half of all fatal injuries to the passenger and occupants and frontal offset crashes in the United States. The fact that many deaths and serious injuries occur in higher severity crashes suggests that this test speed is not too high and that standards or crashworthiness evaluations in offset tests into deformable barriers at significantly lower speeds would be ignoring large numbers or real-world crashes with serious injuries."

Stewart, Gerald R. June 2001. The Role of Innovation and Statistical Methodology in Safety Assessment Projects. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 412, 7 pgs.

"In this paper the innovation of using one part of a Vehicle Identification Number (VIN – positions 1-10) to identify vehicles and their characteristics and the other part (positions 11-17) to capture crash event conditions at the time of the crash has been suggested as an advanced way to accurately and store important information from a crash." The events would then be stored in the EDR for later extraction, permanent storage and use by VIN interpretation software. Storing the information in a database in this VIN-like fashion allows " the potential for better quality data... and access to important vehicle characteristics" along with other important references.

Stucki, S.L., and Fessahaie, O. "Comparison of Measured velocity Change in Frontal Crash Tests to NASS Computed Velocity Change", SAE Paper 960649, February 1998.

"The purpose of this study is to quantify the differences between CRASH3 generated velocity change (delta-V) as used in the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) and measured velocities in actual frontal crash tests. An appropriate factor is then applied to delta-V in NASS to estimate an adjusted delta-V distribution based in these differences. A substantial change to the velocity distribution in NASS / CDS will have a significant bearing on the estimates of lives and injuries affected by any changes to the impact velocity for the frontal crash test in FMVSS No. 208 or other rulemaking decisions."

Government Recommendation & Proposed Regulation Articles

Childester, A.C.D; Hinch, J; Roston, T.A. June 2001. Real World Experiences With Event Data Recorders. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, June 4-7, 2001 at Amsterdam, The Netherlands. National Highway Traffic Safety Administration, Washington, DC. DOT HS 809 220, June 2001. Paper Number 247.

Technical aspects of EDR data are discussed; from what is currently out in the field to retrieving and storing the data. Included is a summary of the NHTSA WG findings. A brief but well detailed explanation of the two major players in EDR development thus far: GM and Ford. The 1999 GM-Vertronix relationship is explained as well as the development of the Vertronix Crash Data Retrieval (CDR) system that was developed for the GM Sensing and Diagnostic Module (SDM). Recommendations for future EDRs are laid out in detail in the report. Key issues addressed include: data collection, pre-crash data, at crash data, and crash pulse data. The article summarizes with the following: "The technology exists to provide detailed EDR data in all motor vehicles sold in the United States of America. The use of these EDR data can and had been used to improve occupant protection, thus saves lives. EDR data are critical in providing information relating to occupant status, severity assessment and deployment control in researching crashes with advanced occupant protection systems, and future applications are expected to result in more lives saved."

German, A.; Comeau, J.L.; Monk, B.; McClafferty, K.; Tiessen, P.F.; Chan, J. June 2001. The Use of Event Data Recorders in the Analysis of Real-World Crashes, Proceedings of the Canadian Multidisciplinary Road Safety Conference XII; June 10-13, 2001; London, Ontario. 15 pgs.

A series of test programs and pilot studies were conducted by the authors involving vehicles equipped with EDRs. The results from the crash tests were then compared to real world incidents with vehicles equipped with EDRs in which in-depth investigations were conducted. These investigations included interviews with the vehicle occupants and discussions of outside factors such as the weather conditions. Conclusions were then drawn upon comparison of the data. As pertains to the Event Data Recorders, "A lack of standardization as to the nature of the data which is recorded, the formats in which it is currently stored, the proprietary means by which data can be retrieved, and concerns relating to individual privacy, may provide substantial roadblocks to wide data accessibility." The authors' proposed several solutions to this that included:

manufacturers and suppliers working cooperatively to develop a common system; non-governmental agencies establishing recommended practices (such as SAE); or governments introducing regulations. The authors' agree however, that whatever the method of solution, developing standards and then implementing them in new on-board EDRs will take a considerable amount of time.

Kowalick, T.M. June 2001. Pros and Cons of Emerging Event Data Recorder (EDR) Technologies in the Highway Mode. Proceedings of The Institute of Electrical and Electronic Engineers (IEEE) VTS 53rd Vehicular Technical Conference, May 6-9, 2001 at Rhodes, Greece. IEEE catalog number 01CH37202C, ISBN: 0-7803-6730-8. 10 pgs.

"This research cites the recent efforts towards implementation of EDR Technologies in the United States highway mode of transportation. Initiatives of the National Transportation Safety Board (NTSB), the National Highway Traffic Safety Administration (NHTSA) are discussed, and independent research efforts are included." Between the years 1997 and 2001, the US NTSB made five recommendations the started research and development of EDR technology. The recommendations are listed on the NTSB Most Wanted List of Transportation Safety Improvements.

NTSB H-97-18. Reviewed by Kowalick June 2001.

Develop and implement, in conjunction with the domestic and international automobile manufacturers, a plan to gather better information on crash pulse, utilizing current or augmented crash sensing and recording devices.

NTSB H-98-23 available at http://www.ntsb.gov/Recs/letters/letters.htm

This safety recommendation advises members of the American Trucking Association (ATA), International Brotherhood of Teamsters, and Motor Freight Carrier Association to equip their vehicle fleets with automated and tamperproof onboard recording devices. This information will be used to identify information regarding driver and vehicle operating characteristics.

NTSB H-99-53 (NHTSA) available at **http://www.ntsb.gov/Recs/letters/letters.htm** *Reviewed by Kowalick June 2001.*

Require that all school buses and motor coaches manufactured after January 1, 2003 be equipped with on board recording systems that record vehicle parameters, including at a minimum, lateral and longitudinal acceleration, vertical acceleration, heading, vehicle speed, engine speed, driver seat belt status, braking input, steering input, gear selection, turn signal status (left / right), brake light status (on / off), Head / tail light status (on / off), passenger door status (open / close), emergency door status (open / close) hazard light status (on / off) brake system status (normal / warning), and flashing red light status (on / off) (school bus only). For those busses so equipped, the following should also be recorded: status of additional seat belts, air bag deployment criteria, air bag deployment time, air bag deployment energy. The on board recording system should record data at a sampling rate that is sufficient to define vehicle dynamics and should be capable of preserving data in the event of a vehicle crash or an electrical power loss. In addition, the on board recording system should be mounted to the bus body, not the chassis, to ensure that the data necessary for defining bus body motion are recorded.

NTSB H-99-54 (NHTSA) available at **http://www.ntsb.gov/Recs/letters/letters.htm** *Reviewed by Kowalick June 2001.*

Develop and implement, in cooperation with other government agencies and industry, standards for on board recording of bus crash data that address, at a minimum, parameters to be recorded, data sampling rates, duration of recording, interface configurations, data storage format, incorporation of fleet management tools, fluid immersion survivability, impact shock survivability, crush and penetration survivability, fire survivability, independent power supply, and ability to accommodate future requirements and technological advances.

Lehmann, G. 1996. The Features of the Accident Data Recorder and its Contribution to Road Safety. VDO Kienzle GmbH, Villingen-Schwenningen (Germany) 4 p. International Technical Conference on Enhanced Safety of Vehicles. Fifteenth Proceedings. Volume 2. Washington, D.C., National Highway Traffic Safety Administration, 1996. Pp. 1565-1568. Report No. 96-S9-W-34. UMTRI-91346 A54

This article describes the way in which the Accident Data Recorder (ADR) has contributed to highway safety. The recorder that was used in the study was the Mannesmann Kieinzel ADR UDS2156. Issues that were discussed included a brief discussion of legal issues (providing impartial and certain evidence about speeds and signals, etc.) and crash research issues (crash pulse and Delta-V). Other topics discussed included the benefit of fleet owners from the installation of an ADR in their fleet vehicles. The research states, "Experiences gained with the ADR during the last 3 years have shown that the UDS considerably influences the driving behavior and thus contributes to accident prevention.... It is the knowledge about the fact that the driving behavior can be objectively checked at any time that leads the driver to behave more attentively in critical accident-bound situations if an ACR is installed." The research concludes that installation of a ADR can be beneficial to fleet managers, crash researchers, and investigators.

O'Neill, B., Preuss, C., Nolan, J. Insurance Institute for Highway Safety. "Relationships Between Computed Delta-V and Impact Speeds For Offset Crashes." Paper Number 96-S9-O-11, Proceedings of the Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, May 1996.

This study examines a sample of U.S. frontal crashes and relates estimated crash severities to impact speeds for single vehicle offset crashes into offset barriers. Each of the vehicles used in the tests had its corresponding Delta-V computed using the specified vehicle deformation measurements set forth in CRASH3. Results showed that "a 40 percent offset test into a deformable barrier at 64 km/hr represents a real-world crash severity below which about 75 percent of all MAIS 3 or greater injuries and slightly less than half of all fatal injuries to passenger car occupants in frontal offset crashes occur in the United States." Also laid out was the fact that since the CRASH3 software package only calculates Delta-V up to the time of maximum crush, including no rebound velocity component, the Delta-V reported from the software are often underestimated.

Salomonsson, O.; Koch, M. 1991. Crash Recorder for Safety System Studies and as a Consumer's Product. Mannesmann Kienzle, Germany/ Volvo Car Corporation, Goeteborg, Sweden. 13 p. Frontal Crash Safety Technologies for the 90's. Warrendale, SAE, 1991. Pp. 21-33. Report No. SAE 910656. UMTRI-80924

This paper describes the development of the Mannesmann Kienzle (MK) Accident Data Recorder (ADR) UDS2156. Working along with Volvo Car Corporation in the late 1980s and early 1990s, MK and Volvo teamed up to design an ADR that would be suitable as a consumer product. The design process is discussed from the beginning, including what parameters Volvo wanted to see included for crash research data for their R&D department, as well as features that MK would include as part of the package. The only major difference between the original design parameters and the final design were that in the original parameters, the user of the ADR had access to it and was able to erase any events that the user felt could later be incriminating. The final design of the ADR phased this feature out and would eventually become the UDS2156.

Stucki, S., Fessahaie, O. "Comparison of Measured Velocity Change in Frontal Crash Tests to NASS Computed Velocity Change" Society of Automotive Engineers Paper Number 980649 (February 1998).

This study attempts to quantify the differences between the CRASH3 generated velocity change (Delta-V) and measured velocities in actual frontal crash tests. This Delta-V is used in the National Automotive Sampling System – Crashworthiness Data System (NASS- CDS) to give a crash severity measure based on the CRASH3 generated Delta-V. The study "concluded that the CRASH3 Delta-V cannot be assumed to give reasonable estimates of velocity change in" deformable fixed barrier (DFB) tests due to the soft impact surfaces. This is of significance because many real world objects such as other vehicles moving in the same relative direction or pedestrians struck by subject vehicles resemble a DFB. Since the Delta-V reported by CRASH3 is often underestimated, an adjustment factor was computed and incorporated in a later program called WinSmash.

APPENDIX B – PROBLEM EDR CASES

Case / VIN / Problem

The following EDR files could not be used for the reasons listed below.

Number	Case ID on EDR File	VIN on EDR File	Problem
1	200202140	2G4WS52M9X	No Matching NASS VIN for this case
2	200208125	1G2NF52T51	No Matching NASS VIN for this case
3	200209053	1GHDT13W5W	No Matching NASS VIN for this case
4	200211041	2G1WL52J6Y	No Matching NASS VIN for this case
5	200211065	1G1JC1245Y	No Matching NASS VIN for this case
6	200211084	2G1WL52M4V	No Matching NASS VIN for this case
7	200211227	1G2JB1241X	No Matching NASS VIN for this case
8	200212115	2G1WH55KXY	No Matching NASS VIN for this case
9	200212117	1GMDX03E11	No Matching NASS VIN for this case
10	200213093	1G8ZK5276W	No Matching NASS VIN for this case
11	200213147	1G2WP52K6X	No Matching NASS VIN for this case
12	200213157	2G4WB52K5X	No Matching NASS VIN for this case
13	200243041	1G2NF52F72	No Matching NASS VIN for this case
14	200243041	1G8ZF52892	No Matching NASS VIN for this case
15	200245041	1G2WP12K0V	No Matching NASS VIN for this case
16	200272001	1G2JB52472	No Matching NASS VIN for this case
17	200276084	1GCHK29U32	No Matching NASS VIN for this case
18	200276084	3GNFK16T41	No Matching NASS VIN for this case
19	200282084	1GKEK13RXY	No Matching NASS VIN for this case

Number	Case ID on EDR File	VIN on EDR File	Problem
1	200208085	1G2JB1240X	Hexadecimal Data Only
2	200208103	1G4NJ52M6V	Hexadecimal Data Only
3	200211092	2G1WX15K62	Hexadecimal Data Only
4	200212131	1G2HX52K7X	Hexadecimal Data Only
5	200243186	1G8JU52F7Y	Hexadecimal Data Only
6	200245113	1G2JB1248X	Hexadecimal Data Only
7	200247100	1G8JW82R7Y	Hexadecimal Data Only
8	200275114	1G3GR62C2W	Hexadecimal Data Only
9	200278124	1G8JU52F0Y	Hexadecimal Data Only

Problem EDR Case Notes

- Case 200208103 contains hexadecimal data only, and also has no matching VIN for this case number in the NASS database.

- Case 200113091 in with the 2002 batch. This case contained the same information that was found in case 200213091. This may have been a simple mistake in the year. It was an identical case however, as indicated by all downloaded parameters as well as the VIN number. For this reason it was not included in the analysis

- Case 200213198 (VIN 2G4WB52K5X) was a duplicate download of case 200213157. Due to this, case 200213198 (VIN 2G4WB52K5X) was discarded and case 200213157 was kept.

- Case 200241062 contained no case file (xxxx-xx-xxx.cdr) to be opened (i.e. Empty folder) with Vetronix v.2.0. and was not included in the analysis.

- Case 200245044 (VIN 1G2WP12K0V) was a duplicate download of case 200245041. Due to this, case 200245044 (VIN 1G2WP12K0V) was discarded and case 200245041 was kept.

- The case with VIN 2G1FP32K8W has all the data but has no Case # associated with it. It was the very last case in the 2002 NHTSA data. Due to it having no case number, it was not included in the analysis.

APPENDIX C – GM SDM DATABASE DATA ELEMENTS

The database of NASS / CDS data elements developed for the NHTSA GM SDM cases contains the following five tables:

1. NASS case description – Contains pertinent NASS data for each case.
2. Deployment Event – Crash Parameters
3. Deployment Event – Pre-Crash Parameters
4. Non Deployment Event – Crash Parameters
5. Non Deployment Event – Pre-Crash Parameters

The data elements contained in each of these tables are presented below:

Table 30. NASS Case Descriptions

Data Element	Notes
NASS Case ID	Ex. 200202014
NASS Vehicle No.	Ex. 1,2,3
Model Year	
Make	
Model	
NASS Driver Seat Belt Use	
NASS Driver Airbag Deployment	Ex. Lap and Shoulder or None Used
NASS Driver MAIS	
NASS RF Passenger Seat Belt Status	Ex. Lap and Shoulder or None Used
NASS RF Passenger Airbag Deployment	Ex. Bag Deployed or Non Deployed
NASS GAD Most Harmful Event	Ex. F,B,R,L
NASS Principle Direction of Force (Degrees)	Ex. 10
NASS Specific Longitudinal Location	Ex. P,B,D,Y,Z
NASS Longitudinal Delta-V (km/hr)	Estimated from WinSmash
NASS Lateral Delta-V (km/hr)	Estimated from WinSmash
NASS Total Delta-V (km/hr)	Estimated from WinSmash
NASS Number of Events This Accident	
NASS Number of Events This Vehicle	
NASS Number of Vehicles Involved	
NASS Object Contacted Most Harmful Event	Ex. Vehicle No. 1
NASS Body Type	Ex. Full Size Car
NASS Other Body Type Most Harmful Event	Ex. Large Pickup
NASS Driver Airbag Deployment Event	Coded Numbers
NASS RF Passenger Airbag Deployment Even	Coded Numbers
EDR VIN Number (17 Character)	

Abbreviations:

- RF = Right Front
- MAIS = Maximum Abbreviated Injury Scale
- GAD = General Area of Damage

Table 31. Deployment Event – Crash Parameters

Data Element	Data Type	Comments
NASS Case ID		Ex. 200202014
Vehicle No. From EDR File Name		
Non Dep / Dep / Dep Level		Ex. D, N/D, D/DL, N
Injury Criteria		Assigned by NASS
Warning Lamp Status		
Seat Belt Status	Boolean	Ex. Unbuckled
Passenger Air Bag	Boolean	Ex. Not Suppressed
Ignition Cycles at Deployment	Integer	
Ignition Cycles at Investigation	Integer	
Time (s) between N or DL and D	Floating Point	
Driver Alg Enable to 1st Stage Dep (ms)	Floating Point	
Max EDR V Change (mph)	Floating Point	
Alg Enable To Max V Change (ms)	Floating Point	
VIN from EDR [17 Characters]		
Brake Switch State @ Alg Enable	Boolean	Ex. Applied / Not Applied
Brake Switch State Validity Status	Boolean	Ex. Valid / Invalid
Driver Alg Enable to 2nd Stage Dep (ms)	Floating Point	
Frontal Dep Level Event Counter	Integer	
Event Recording Complete	Boolean	Ex. Yes / No
Multiple Events	Boolean	Ex. Yes / No
>= 1 Events not recorded	Boolean	Ex. Yes / No
Pass Alg Enable to 1st Stage Dep (ms)	Floating Point	
Pass Alg Enable to 2nd Stage Dep (ms)	Floating Point	
Velocity Data?	Integer	Derived
Velocity Change	Floating Point	1 Sample per 10 ms
Max delta-V [mph]	Floating Point	Derived

Table 32. Deployment Event – Pre-Crash Parameters

Data Element	Data Type	Sampling Rate	Comments
NASS Case ID			Ex. 200202014
Vehicle no. From EDR file name			
Non Dep / Dep / Dep Level			Ex. D, N/D, D/DL, N
Vehicle Speed (MPH)	5 Element Array	1 Sample per sec	
Engine Speed (RPM)	5 Element Array	1 Sample per sec	
Percent Throttle (%)	5 Element Array	1 Sample per sec	0 to 100
Brake Switch Status	5 Element Array	1 Sample per sec	On / Off

Table 33. Non–Deployment Event – Crash Parameters

Data Element	Data Type	Comments
NASS Case ID		Ex. 200202014
Vehicle No. From EDR File Name		
Non-Dep / Dep / Dep Level		
Prior Deployment	Boolean	Ex. Yes / No
Warning Lamp Status		
Seat Belt Status	Boolean	Ex. Unbuckled
Passenger Air Bag	Boolean	Ex. Not Suppressed
Ignition Cycles at Non Dep or Dep Level	Integer	
Ignition Cycles at Investigation	Integer	
Time (s) between N or DL and D	Floating Point	
Max EDR V Change (mph)	Floating Point	
Alg Enable to Max V Change (ms)	Floating Point	
Alg Enable to Dep command criteria met (ms)	Floating Point	
Brake Switch State @ Alg Enable	Boolean	Ex. Applied / Not Applied
Brake Switch State Validity Status	Boolean	Ex. Valid / Invalid
Frontal Dep Level Event Counter	Integer	
Event Recording Complete	Boolean	Ex. Yes / No
Multiple Events	Boolean	Ex. Yes / No
>= 1 Events not recorded	Boolean	Ex. Yes / No
Velocity Data?	Integer	Derived
Velocity Change	Floating Point	1 Sample per 10 ms
Max delta-V [mph]	Floating Point	Derived

Table 34. Non-Deployment Event – Pre-Crash Parameters

Data Element	Data Type	Sampling Rate	Comments
NASS Case ID			Ex. 200202014
Vehicle no. From EDR file name			
Non Dep / Dep / Dep Level			Ex. D, N/D, D/DL, N
Vehicle Speed (MPH)	5 Element Array	1 Sample per sec	
Engine Speed (RPM)	5 Element Array	1 Sample per sec	
Percent Throttle (%)	5 Element Array	1 Sample per sec	0 to 100
Brake Switch Status	5 Element Array	1 Sample per sec	On / Off

APPENDIX D – FORD RCM DATABASE DATA ELEMENTS

The database of NASS / CDS data elements developed for the NHTSA Ford RCM cases contains the following tables:

1. NASS case description – Contains the pertinent NASS data for each case.
2. 1FA - Taurus Sys Info – System information
3. 1FA - Taurus Crash Pulse – Longitudinal and lateral acceleration and delta-V vs. time.
4. 2FA - Crown Vic Sys Info – System information
5. 2FA - Crown Vic Crash Pulse – Longitudinal and lateral acceleration and delta-V vs. time.

The data elements contained in each of these tables are presented below:

Table 35. NASS Case Description

Data Element	Notes
NASS Case ID	Ex. 200202014
NASS Vehicle No.	Ex. 1,2,3
Model Year	
Make	
Model	
NASS Driver Seat Belt Status	
NASS Driver Airbag Deployment	Ex. Lap and Shoulder or None Used
NASS Driver MAIS	
NASS RF Passenger Seat Belt Status	Ex. Lap and Shoulder or None Used
NASS RF Passenger Airbag Deployment	Ex. Bag Deployed or Non Deployed
NASS RF Passenger MAIS	
NASS GAD Most Harmful Event	Ex. F,B,R,L
NASS Principle Direction of Force (Degrees)	Ex. 10
NASS Specific Longitudinal Location	Ex. P,B,D,Y,Z
NASS Longitudinal Delta-V (km/hr)	Estimated from WinSmash
NASS Lateral Delta-V (km/hr)	Estimated from WinSmash
NASS Total Delta-V (km/hr)	Estimated from WinSmash
NASS Number of Events This Accident	
NASS Number of Events This Vehicle	
NASS Number of Vehicles Involved	
NASS Object Contacted Most Harmful Event	Ex. Vehicle No. 1
NASS Body Type	Ex. Full Size Car
NASS Other Body Type Most Harmful Event	Ex. Large Pickup
NASS Driver Airbag Deployment Event	Coded Numbers
NASS RF Passenger Airbag Deployment Event	Coded Numbers
EDR VIN Number (17 Character)	

Abbreviations:

- RF = Right Front
- MAIS = Maximum Abbreviated Injury Scale
- GAD = General Area of Damage

Table 36. 1FA – Taurus System Information

Data Element	Data Type	Comments
NASS Case ID		Ex. 200209111
Vehicle Type		Ex. Taurus or Crown Vic
Vehicle No. from File Name	Integer	
VIN		
Data Validity Check	Boolean	Ex Valid, Invalid
EDR Model Version	Integer	Ex. 141
Safing Decision to Left (Driver) Side Bag Deployment [msec]		Ex. Not Deployed or 15
Safing Decision to Right (Passenger) Side Bag Deployment [msec]		Ex. Not Deployed or 15
Diagnostic Codes Active When event Occurred	Integer	
Alg Wakeup to Pretensioner [msec]	Integer	
Alg Wakeup to 1st Stage - Unbelted [msec]	Integer	
Alg Wakeup to 1st Stage - Belted [msec]	Integer	
Alg Wakeup to 2nd Stage - Belted [msec]	Integer	
Driver Seat Belt	Boolean	Ex. Engaged
Passenger Seat Belt	Boolean	Ex. Engaged
Driver Seat Track in Forward Pos	Boolean	Ex. Yes / No
Runtime [msec]	Integer	
# Invalid Recording Times	Integer	
Driver - Alg Wakeup to Pretensioner Attempt [msec]	Various	Ex. Unbelted, Not Deployed, [Integer Value]
Driver - Alg Wakeup to 1st Stage Dep Attempt [msec]	Various	Ex. Not Deployed, [Integer Value]
Driver - Alg Wakeup to 2nd Stage Dep Attempt [msec]	Various	Ex. Not Deployed, Disposal, [Integer Value]
Passenger - Alg Wakeup to Pretensioner Attempt [msec]	Various	Ex. Unbelted, Not Deployed, [Integer Value]
Passenger - Alg Wakeup to 1st Stage Dep Attempt [msec]	Various	Ex. Not Deployed, [Integer Value]
Passenger - Alg Wakeup to 2nd Stage Dep Attempt [msec]	Various	Ex. Not Deployed, Disposal, [Integer Value]

Table 37. 1FA - Taurus Crash Pulse – Longitudinal & Lateral Acceleration vs. Time and Delta-V vs. Time.

Data Element	Data Type	Comments
NASS Case ID		Ex. 200209111
VIN		
Time [msec]	Integer	
Longitudinal Acceleration [G]	Floating Point	
Longitudinal Cumulative Delta V [MPH]	Floating Point	
Lateral Acceleration [G]	Floating Point	
Lateral Cumulative Delta V [MPH]	Floating Point	

Table 38. 2FA – Crown Victoria System Information

Data Element	Data Type	Comments
NASS Case ID		Ex. 200209111
Vehicle Type		Ex. Taurus or Crown Vic
Vehicle No. from File Name	Integer	
VIN		
Ford Part Number Prefix		Ex Valid, Invalid
Number of Active Faults	Integer	
Driver Seat Belt Buckle	Boolean	Ex. Buckled / Unbuckled
Passenger Seat Belt Buckle	Boolean	Ex. Buckled / Unbuckled
Driver Seat Track in Forward Pos	Boolean	Ex. Yes, No
Occupant Classification Status Value		Ex. Dual Stage, Empty
Unbelted Stage 1	Boolean	Ex. Fire, No Fire
Unbelted Stage 2	Boolean	Ex. Fire, No Fire
Belted Stage 1	Boolean	Ex. Fire, No Fire
Belted Stage 2	Boolean	Ex. Fire, No Fire
Driver Pretensioner	Boolean	Ex. Fire, No Fire
Passenger Pretensioner	Boolean	Ex. Fire, No Fire
Pretensioner Time [msec]	Various	Ex. [Floating point], None
1st Stage Time [msec]	Various	Ex. [Floating point], None
2nd Stage Time [msec]	Various	Ex. [Floating point], None
Pretensioner Time [msec]	Various	Ex. [Floating point], None
1st Stage Time [msec]	Various	Ex. [Floating point], None
2nd Stage Time [msec]	Various	Ex. [Floating point], None

Table 39. 2FA – Crown Victoria Crash Pulse – Longitudinal & Lateral Acceleration vs. Time and Delta-V vs. Time.

Data Element	Data Type	Comments
NASS Case ID		Ex. 200209111
VIN		
Time [msec]	Integer	
Longitudinal Acceleration [G]	Floating Point	
Longitudinal Cumulative Delta V [MPH]	Floating Point	
Lateral Acceleration [G]	Floating Point	
Lateral Cumulative Delta V [MPH]	Floating Point	

Appendix E – Example of Data Provided by Vetronix Crash Data Retrieval Software v.2.0.

General Motors Sensing & Diagnostic Module (SDM)

<u>Example of the Data Summary (Deployment, Deployment Level, Non-Deployment) extracted from a GM SDM:</u>

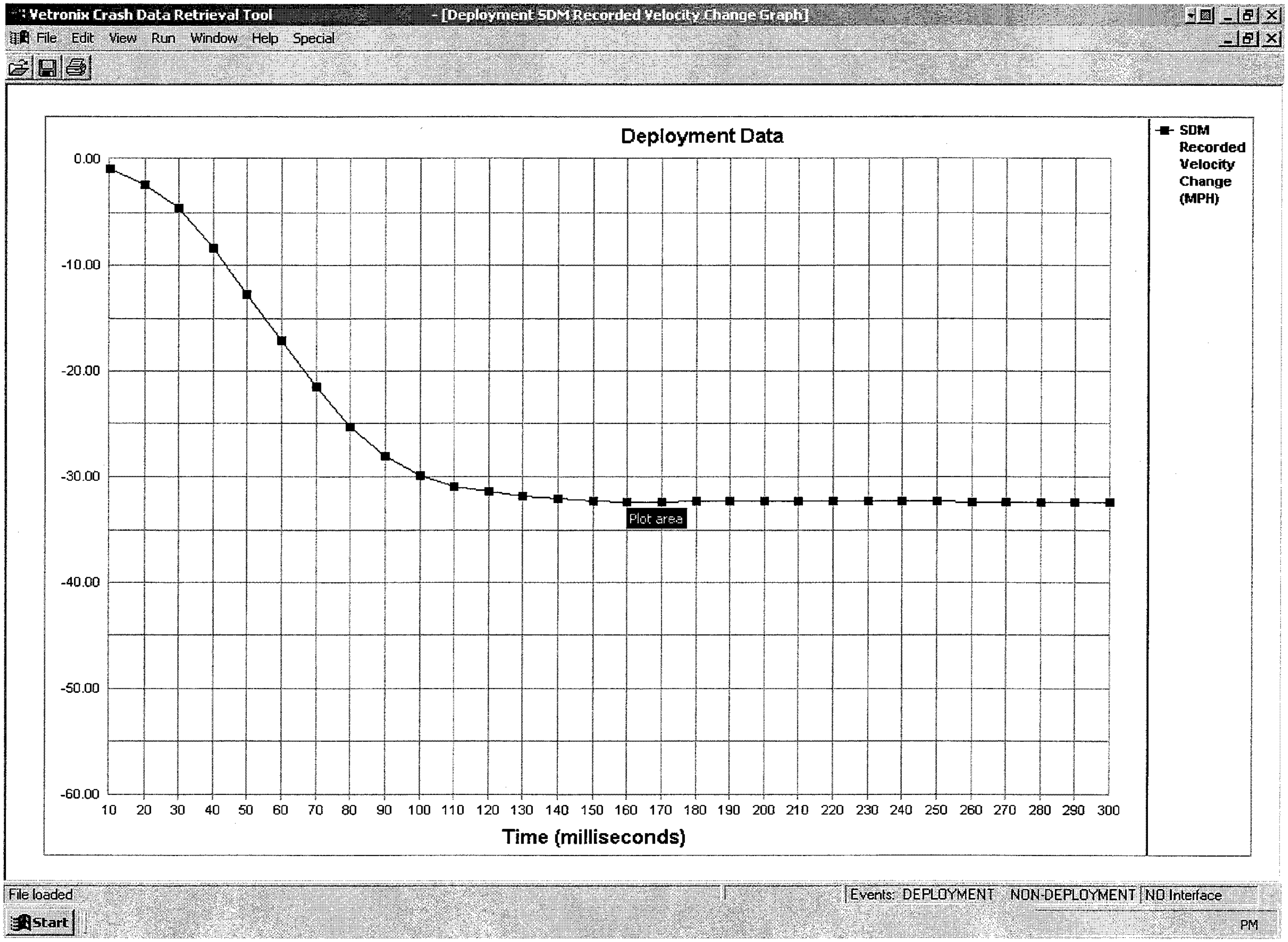
System Status At Deployment	
SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Ignition Cycles At Deployment	374
Ignition Cycles At Investigation	387
Maximum SDM Recorded Velocity Change (MPH)	-17.73
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	117.5
Driver First Stage Time Algorithm Enabled to Deployment Command Criteria Met (msec)	22.5
Driver Second Stage Time Algorithm Enabled to Deployment Command Criteria Met (msec)	N/A
Passenger First Stage Time Algorithm Enabled to Deployment Command Criteria Met (msec)	22.5
Passenger Second Stage Time Algorithm Enabled to Deployment Command Criteria Met (msec)	N/A
Time Between Non-Deployment And Deployment Events (sec)	1.4
Frontal Deployment Level Event Counter	1
Event Recording Complete	Yes
Multiple Events Associated With This Record	Yes
One Or More Associated Events Not Recorded	Yes

Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Recorded Velocity Change (MPH)	0.00	-0.62	-2.48	-4.65	-7.13	-9.92	-11.47	-13.95	-15.50	-16.43	-17.05	-17.67	N/A	N/A	N/A

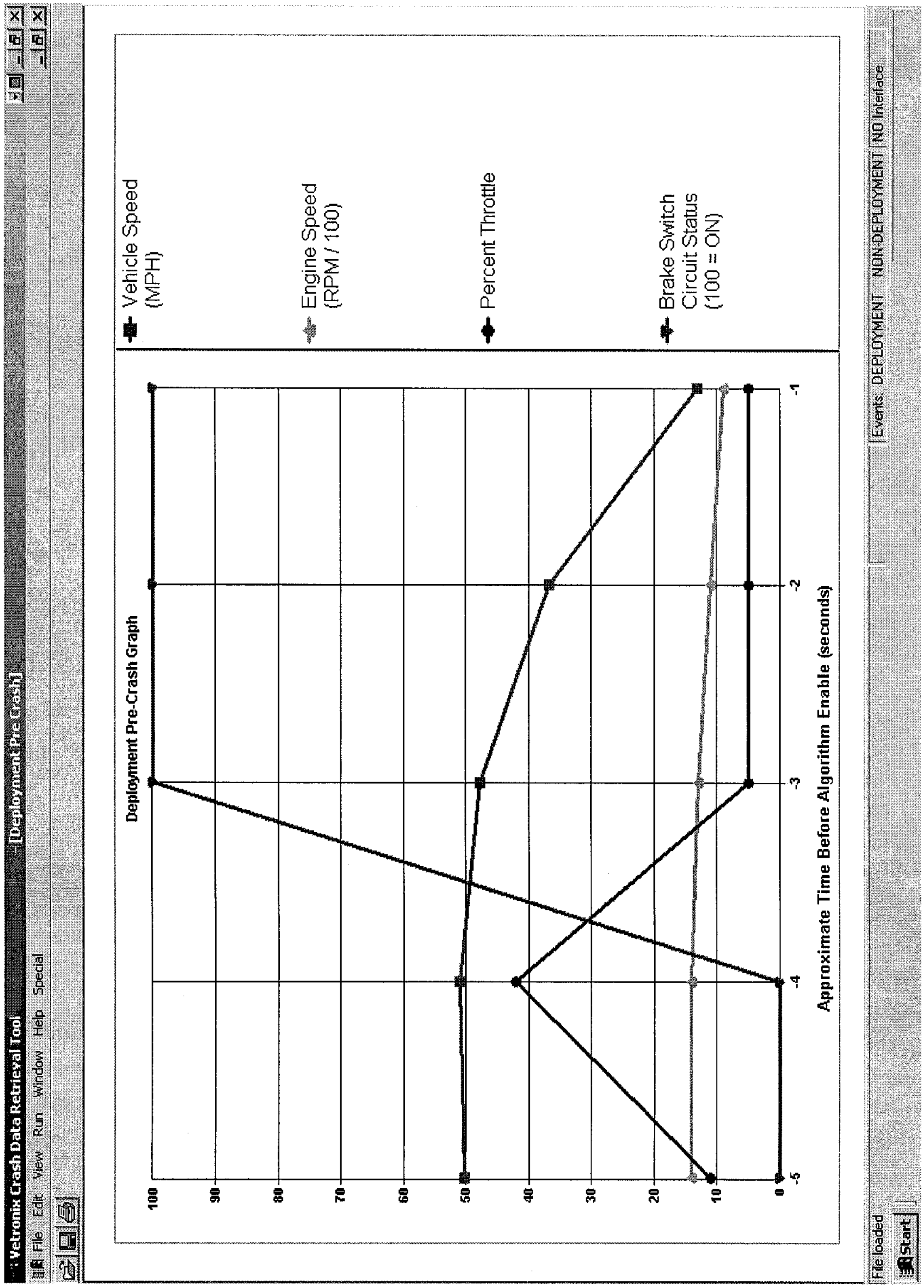
PRE-CRASH DATA

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	32	1344	0	OFF
-4	32	1408	0	OFF
-3	33	1408	10	OFF
-2	13	896	0	ON
-1	22	960	0	ON

Example of the SDM Recorded Velocity Change Graph:



Example of the Pre-Crash Graph extracted from a GM SDM:



Example of the Hexadecimal Data extracted from a GM SDM:

Vetronix Crash Data Retrieval Tool - [Hexadecimal Data]

File Edit View Run Window Help Special

```
1G6
$01   08 23 3A 3A
$02   99 D4
$03   41 53 31 30 35 33
$04   4B 30 4A 4D 58 33
$05   00
$06   25 72 57 40
$10   FD C9 E0
$11   83 03 83 D2 89 00
$14   3F 4C AC E0
$18   7D 7C 7D 82 81 82
$1C   36 FA 4B 53 59 59
$1D   59 36 FA 4B 53 59
$1E   59 59
$1F   FF 02 05 05 00
$20   A0 00 00 FF 7D 80
$21   FF FF FF FF FF FF
$22   FF FF FF FF FF FF
$23   FF 00 00 92 03 00
$24   00 01 01 01 02 02
$25   03 03 04 04 FF FF
$26   FF FF 0B 41 45 43
$27   42 41 00 80 00 08
$28   19 19 19 19 00 12
$29   19 1B 1C 16 00 FD
$2A   D3 80 FF 00 0C 00
$2B   0D 00 0F 00 00 00
$2C   00 00 00 00
$2D   00 0C 06 00
```

File loaded | Events: DEPLOYMENT NON-DEPLOYMENT | NO Interface

Start

Ford Restraint Control Module (RCM)

Example of Data extracted from the Ford RCM:

Vetronix Crash Data Retrieval Tool - [Data Summary]

File Edit View Run Window Help Special

System Status At Deployment	
Data Validity Check	Valid
EDR Model Version	141
Time From Side Safing Decision to Left (Driver) Side Bag Deployment (msec)	Not Deployed
Time From Side Safing Decision to Right (Passenger) Side Bag Deployment (msec)	Not Deployed
Diagnostic Codes Active When Event Occurred	0
Time From Algorithm Wakeup to Pretensioner (msec)	25
Time From Algorithm Wakeup to First Stage - Unbelted (msec)	25
Time From Algorithm Wakeup to First Stage - Belted (msec)	0
Time From Algorithm Wakeup to Second Stage (msec)	0
Driver Seat Belt Buckle	Not Engaged
Passenger Seat Belt Buckle	Engaged
Driver Seat Track In Forward Position	No
Runtime (msec)	129
Number of Invalid times in recording	0

Parameter	Driver	Passenger
Time From Algorithm Wakeup to Pretensioner Deployment Attempt (msec)	Unbelted	25
Time From Algorithm Wakeup to First Stage Deployment Attempt (msec)	25	Not Deployed
Time From Algorithm Wakeup to Second Stage Deployment Attempt (msec)	Disposal	Not Deployed

The retrieval of this data has been authorized by the vehicle's owner, or other legal authority such as a subpoena or search warrant, as indicated by the CDR tool user on June 5, 2002, at 3:34 PM.

File loaded | Event: DEPLOYMENT | NO Interface

Start

Example of Crash Pulse Data extracted from the Ford RCM:

Vetronix Crash Data Retrieval Tool - [Crash Pulse Data]

File Edit View Run Window Help Special

Time (msec)	Long. Acc. (Gs)	Long. Cumulative Delta V (MPH)	Lat. Acc. (Gs)	Lat. Cumulative Delta V (MPH)
0	-1.82	0.13	18.85	0.90
2	-7.38	-0.46	18.04	1.51
4	-6.69	-0.75	18.12	2.50
6	-3.96	-0.66	18.13	3.25
8	-4.55	-1.14	20.66	4.00
10	-6.68	-1.32	24.69	5.27
12	-9.00	-1.56	23.74	6.28
14	-10.70	-2.50	19.63	7.20
16	-11.68	-2.26	21.35	7.82
18	-9.16	-3.45	26.60	9.35
20	-0.90	-3.16	26.49	10.47
22	1.31	-2.88	25.37	11.37
24	-7.72	-3.40	30.70	12.82
26	-13.11	-4.22	35.78	14.45
28	-11.65	-4.41	32.34	15.87
30	-14.51	-5.01	23.82	16.91
32	-18.97	-6.15	19.44	17.72
34	-16.64	-6.67	22.62	18.62
36	-10.65	-7.11	25.36	19.89
38	-5.37	-7.55	20.45	20.92
40	-3.16	-7.46	14.79	21.12
42	-5.15	-7.64	13.22	22.06
44	-4.69	-8.28	8.52	22.46
46	0.81	-7.71	1.39	22.28
48	4.63	-7.90	-0.72	22.37

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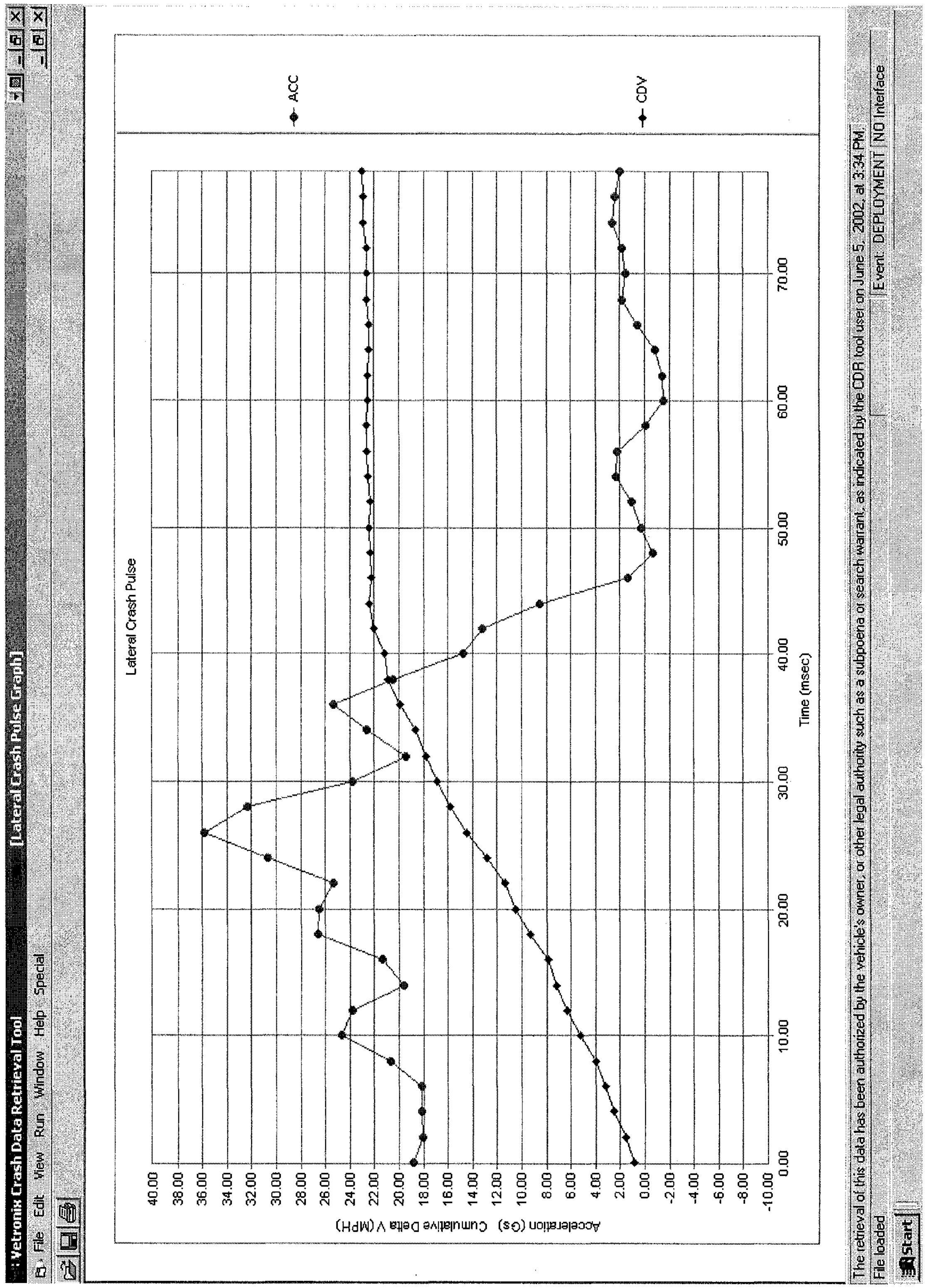
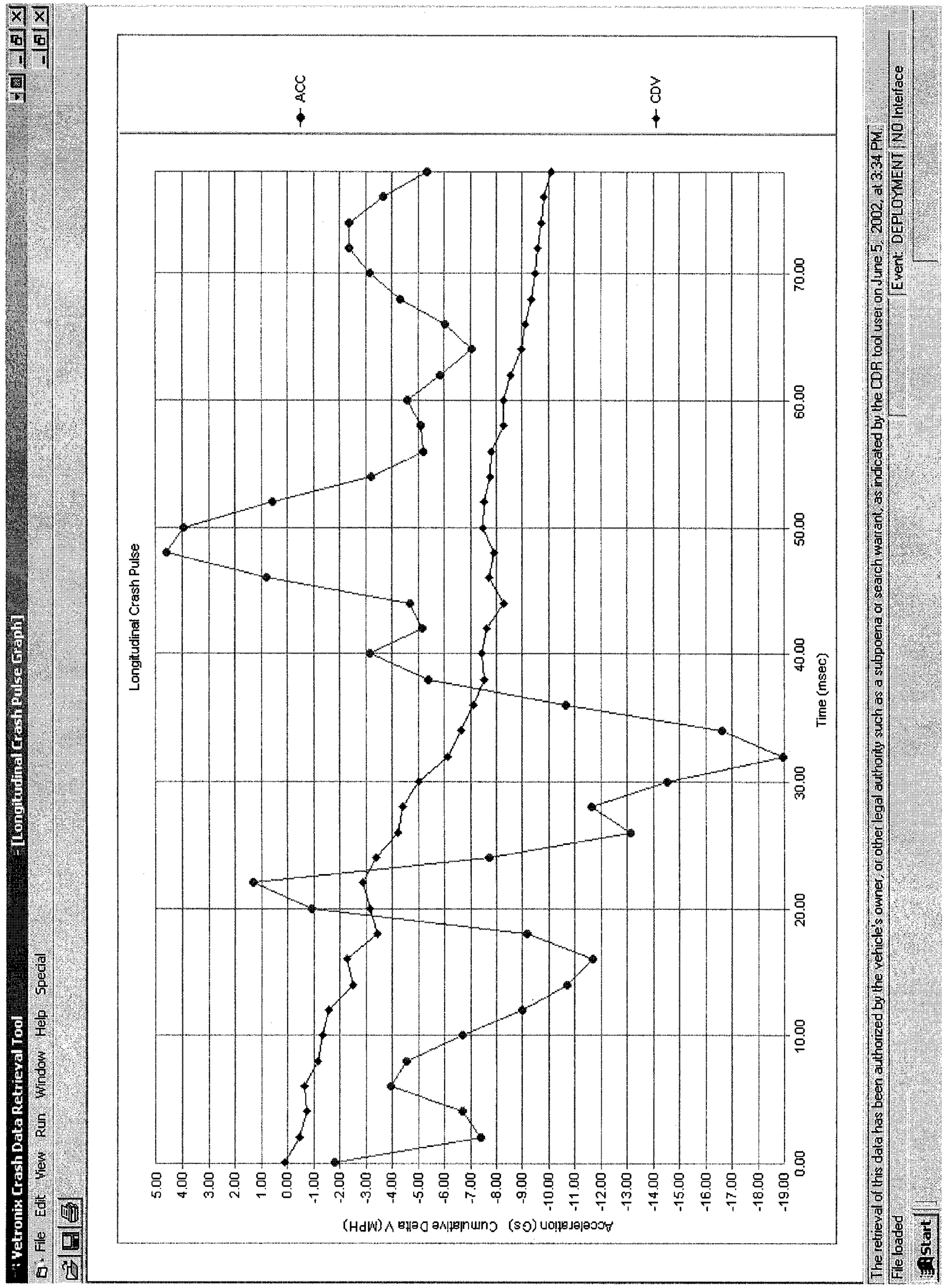
Example of the Lateral Crash Pulse Graph extracted from the Ford RCM:



Example of the Longitudinal Crash Pulse Graph extracted from the Ford RCM:



Example of Hexadecimal Data extracted from the Ford RCM:

Vetronix Crash Data Retrieval Tool - [Hexadecimal Data]

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1FA
 0800:  0F 4A 40 76 14 FB FF FF FF FF 0E 24 0F 2D 3A 4C
 0810:  C8 FF 00 FF 52 60 52 60 60 52 E3 20 3C 78 D6 A0
 0820:  08 03 28 37 5F 0F 0F 0A F5 0A B7 84 A1 5E D5 AA
 0830:  03 0C 1B 1E 00 FF 3C 3C 80 06 28 64 64 00 0C 01
 0840:  5A 96 50 FF FF FF EF DF D5 E7 FF 72 4E 13 25 B1
 0850:  EC 14 09 0F 01 FF FF 88 7F FF CD 44 08 FF FF 95
 0860:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
 0870:  05 3B 4D 4E 69 00 8F FF 59 46 31 41 00 02 FF 19
 0880:  04 FF 80 09 FF 80 0A FF 80 0F FF 80 13 FF 80 FF
 0890:  17 FF 80 1C FF 80 25 FF 80 02 FF 80 03 FF 80 FF
 08A0:  5F 87 88 10 30 2B 3C 01 01 02 FF FF FF FF FF FF
 08B0:  02 FF 81 38 00 8D 01 FF FF FF FF FF 33 01 DB 67
 08C0:  FF 14 01 DB 68 51 01 DB 68 51 02 84 60 06 FF FE
 08D0:  01 0E 0C 80 02 58 16 87 1F BE 01 0A 00 8C 01 04
 08E0:  00 F0 01 36 00 A0 01 54 00 3F 02 30 02 C7 02 8A
 08F0:  05 14 07 08 01 2C 03 CA 04 CE 06 40 73 33 00 A0
 0900:  3F FF 00 03 00 4B 01 CC 00 03 0F FF 00 14 00 78
 0910:  00 A0 00 6E 0A 16 FF 01 00 00 00 7F 0F 0C 0F 02
 0920:  03 5A 32 46 05 50 02 02 FA 1E 08 0C 0A 1C 02 23
 0930:  09 06 28 32 16 20 16 1F 5F FF FF 02 FF FF FF 11
 0940:  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
 0950:  19 00 00 00 19 00 00 09 08 00 01 06 0F 0F 0B 22
 0960:  08 0D 11 13 19 14 0F 00 00 00 00 18 5C 0A 13 00
 0970:  00 00 81 50 A1 83 B3 C2 D4 C5 9D D5 AE 66 97 97
 0980:  90 99 8F B8 CD B5 B6 A3 B0 8F 8E A3 9B C0 B5 CC
 0990:  CF A8 AA B1 B2 B7 AC A0 A0 B6 B5 AB AA B1 AE A7
 09A0:  86 94 A5 8B 99 96 76 AC 6B AE AE 89 7C 98 86 6D
```

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