Automobile Event Data Recorder (EDR) Technology
- **E**volution, **D**ata, and **R**eliability

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Abstract

Stand alone EDR data collectors of various descriptions have been in use around the world for years. The more recent US adaptation of an EDR systems added to the crash sensing and deployment components of air bag systems in surface motor vehicles is an effort aimed at creating a larger knowledge base from which to draw information on “real world” crashes. Such information will be used to augment traditional crash test data and assist and improve collision analysis as well as further the overall understanding of the traffic collision event in a multilevel approach to improve traffic safety. The automobile *Event Data Recorder* (**EDR**) has become the subject of conjecture and misinformation nearly unequaled in the quest for improved automotive safety.

This paper is a general review of the development of the EDR and related systems and a group of crash tests conducted with different vehicle models in an effort to foster a more complete understanding of the intended purpose and general function of the EDR system, the reliability of the data collected, and to provide some insight into air bag deployment criteria relative to vehicle and collision types. The paper offers examples of the data collected which might be compared to “real world” downloads from EDR equipped vehicles for a more complete understanding of the collision event pre-, during and post-crash.

Introduction

In 1968, a group of engineers from the Cleveland (Ohio) based auto parts manufacturer Eaton, Yale and Towne presented then National Highway Traffic Safety Administration (NHTSA, USA) Commissioner William Haddon with the prototype of a device they called the “People Saver.” The “People Saver” was a nylon cushion that was designed to inflate in a collision. It was the earliest identified incarnation of what has evolved into today’s automobile air bag. Haddon was reportedly “ecstatic” at the presentation of the device. Later NHTSA Commissioner Joan Claybrook recalled that it was “one of the most exciting moments of his life” [1] (1).

At the time, Haddon and others (often called “Haddonites”) who believed as he did worked to advance the notion that traffic safety was most effective when based on the concept that since motor vehicle collisions were going to happen anyway, and because they had resigned themselves to the belief one couldn’t effectively change driver behavior on a large scale; therefore, the goal should be to try to reduce the injuries in those collisions through vehicle design changes. The focus for improvements and advances in safety should, they believed, be found in the vehicle’s engineering rather than the driver’s behavior. As Claybrook reportedly put it: “it’s easier to get 20 auto companies to do something than to get 200 million Americans to do something.”[2]

Before Haddon, the approach to traffic safety had been primarily based on changing driver behavior:

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[1] Superscript numbers, apart from instant footnotes found in parenthesis, refer to references found as endnotes to this paper.

Education and Enforcement - two of the long-standing sides of the triangle which makes up the "Three Es" of traffic safety, the remaining component being Engineering. The pre-Haddon theory held that active driver and passenger behavior modification (through Education and Enforcement) *did* have an effective influence on motorist safety whether it was a matter of *how* they drove (for example vehicle speed or alcohol use) or simply whether or not they *used* the installed seat belts.

When Haddon took the reins of the newly created US Federal agency NHTSA, the focus of his early leadership in traffic safety in the United States was to move toward passive rather than active safety; the remaining "E"- Engineering - taking priority in line with his beliefs. The likes of Haddon, Claybrook and perennial safety crusader Ralph Nader envisioned a future of automotive safety based on passive features; effectively an effort to eliminate the driver's direct involvement, if not ultimate responsibility for, their own safety. This policy was a shift from the focus on individual responsibility for safety away from the vehicle operator and to the vehicle itself and its manufacturers through regulatory efforts including requirements for specific equipment, design or testing changes designated as "safety related." Ultimately, this thinking resulted in the US Federal Motor Vehicle Safety Standards (FMVSS) and other regulations including the requirement for air bags in all new cars sold in the US by the end of the 90's.

Interestingly enough, before the change to a focus on passive safety features, the United States had the lowest traffic collision fatality rate in the world. It remained the leader until the Australian state of Victoria enacted the first compulsory seat belt use law in the early 1970s. Following Australia's example, nearby New Zealand and then, in Europe, Germany and France soon enacted similar requirements. In North America, Canada adopted similar legislation and, by the end of the decade, without comparable requirements in place, the US dropped below tenth place internationally with respect to the number of annual traffic fatalities (adjusted for population and miles driven)[3].

Australia, with nationwide compulsory seat belt use legislation in place by the mid 80's, saw the number of fatalities in that country for occupants drop over the next 15 years (1980-1996) by nearly 30%[4]. In the US, during the same period, fatalities in motor vehicle collisions dropped by only 18%[5] although, over that period, many states enacted compulsory belt use laws and air bags were slowly phased in as required equipment (effectively starting in 1987 in he US).

Despite mounting evidence to the contrary, "Haddonites" clung to the belief that passive safety through Engineering was still more effective than Education or Enforcement. As recently as 1997, although 49 of the 50 United States finally had some form of compulsory seat belt use laws in place, the application and enforcement of those laws still varied (sometimes widely) from state-to-state from primary enforcement violations to secondary violations to exclusions by age and seating position (front as opposed to rear) in the car.

Statistics demonstrate that proper seat belt use significantly reduces an occupant's exposure to an Abbreviated Injury Scale (AIS) injury 5 or greater[6, 7, 8] and to the probability of a fatality overall by greater than 40%. Unrestrained drivers have almost twice the probability of significant injury than do restrained drivers. In fatal collisions, when seat belts are used, they are effective in reducing the severity of injuries ranked in the AIS 2-4 range[9] as well as in reducing the overall number of AIS 5 and greater injuries (including fatalities).

The detailed analysis of injury probability is indeed complex. As Huelke put it: "With fatalities, crash speed and occupant age are factors that cannot be controlled and thus weigh heavily against the *safety designer* (emphasis mine). Also, intrusion and injury, especially in the higher delta-V (2) crashes, is a formidable problem..." [10]. The mention of a "safety designer" suggests that the prevailing focus would still seem to be primarily on the "Engineering" side of the traffic safety triangle as the solution.

With an eye toward better addressing *all three* "Es" of traffic safety, one needs to objectively and reliably quantify both the crash delta-V as well as the actual crash pulse (duration or time relative to delta-V) as it might be mitigated in later events by Engineering changes such as "crumple zones" and air bags. However, that approach should not be taken to the exclusion of addressing driver behavior(s) which can be quantified and then altered/improved through Enforcement and Education such as the driver's choice of vehicle speed and occupant seat belt use. In short, to really decide where to put the focus of traffic safety efforts - which of the three "E's" needs the most attention in for a given problem - we need to better understand, objectively, "real world" crashes to identify the problem(s) in the first place.

Data Recorders

In the 1950's, Flight Data Recorders (FDR) were installed in commercial aircraft to record control and other flight parameters in the event of an "unanticipated energetic disassembly" of the airplane. The concept was simple: (1) collect objective real-time data from on board instruments in the aircraft and record it to the FDR for post-crash review, (2) gather physical evidence information from the post-crash scene and aircraft and then (3) compare and correlate the FDR data with the physical evidence gathered at the crash site to reconstruct the crash with all the objective information. The end result is an effort to establish and explain the underlying cause of the collision and then identify appropriate opportunities to prevent similar events in the future by whatever means depending on the cause of the event. Using all of these bits of information, analysts could decide where to put the focus of aviation safety efforts, whether a change in Engineering, Enforcement or Education as each relate appropriately to aviation activities.

To date, for the most part, many of the same basic collision investigation techniques have been employed in automobile crash analysis. Relying almost exclusively on information developed during the post-crash investigation, collision reconstructionists have analyzed the objective scene data, information about the people (ie: injuries) and about the involved vehicle(s) to better understand the automobile crash event: to complete a "reconstruction." Unlike aviation crash investigators; however, surface transportation crash investigators typically don't (haven't) had the benefit of FDR-like data.

Haddon developed a 3-by-3 matrix which has not surprisingly become known as the "Haddon Matrix" and is often used to describe the information about and understanding of an automobile crash from its three sources of information: the human, the vehicle and the environment ("HVE"). One application of this matrix and sources of information for each item is shown in Table 1.

As it is currently applied in the "Haddon Matrix," all of the information gathered is based on an investigative individual's or team's evaluation of that which is identified and collected or, in the case of subjective human recollections, may be adopted as reliable for one purpose or another. Making Education, Enforcement or Engineering decisions based on those methods, while largely effective to date, has its obvious potential drawbacks, not the least of which are the possibility of error, whether unintentional or otherwise, and the lack of certain pieces of information which would not readily be available

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[2] Delta-V (ΔV) is the vector quantity change of speed measured as it acts on the a vehicle's center of mass and is a function of its change of momentum relative to the application of force in a collision event along the "PDOF" or principle direction of force which is measured relative to a vehicle's longitudinal ("X") axis.

	Human	**Vehicle**	**Environment**
Pre-Crash	*subjective* recollections by parties/witnesses as to observations and actions		post-crash roadway evidence *may* indicate driver pre-crash behavior
Crash		post-crash vehicle deformation *may* suggest generalized crash parameters	
Post-Crash	post-crash evaluation of the injuries *may* indicate occupant position, action(s) and restraint use	post-crash vehicle deformation *may* suggest general crash parameters	post-crash roadway evidence is inspected, documented and analyzed after the crash

Table 1 - The typical "Haddon Matrix"

(in a purely objective form) to the investigator in a typical surface vehicle crash during an after-crash "post mortem" of the event.

Enter the surface vehicle **E**vent **D**ata **R**ecorder (EDR).

Having the benefit of observing the positive effect of FDRs on aviation safety, an early effort to capture objective crash data to supplement that relied on by reconstructionists and to support other safety activities, the NHTSA was involved in the experimental installation of about 1,000 disc (data) recorders during the "Disk Recorder Project" in several surface vehicle fleets in the US in and before 1974.

As a product of this effort, 23 (by some reports 26) crashes were analyzed which included delta-V's of up to 20 mph (32.1km/h). In the ensuing years, other similar efforts were made but none would appear to be as demonstrably effective as the 1992 General Motors (US) installation of sophisticated crash-data recorders in seventy Formula-One "Indy" race cars. Analyzing the data recorded from crashes with delta-Vs exceeding more than 60 mph (96.5 km/h) and vehicle decelerations in excess of 100 g's, biomechanical engineers have been able to further refine their understanding of human injury potential. By analyzing other data collected from these crashes, changes in crash energy attenuation systems and driver protection systems were made which demonstrably reduced the number of serious driver injuries during the 1998 racing season[11].

In 1997, seizing on this history and other similar observations of the practical application for data recorders in aviation as well as in other surface vehicles, the US National Transportation Safety Board (NTSB) issued recommendations to pursue vehicle crash information using Event Data Recorders[12]. Based partly on a public hearing held that year, the NTSB recommended to the NHTSA that it "...Develop and implement, in conjunction with the domestic and international manufacturers, a plan to *gather better information on crash pulses and other crash parameters in actual crashes,* utilizing current or augmented sensing and recording devices (NHTSA H-97-18)..."

It almost appeared as though someone from the aeronautics side of the transportation department was transferred to the surface transportation side of the NTSB. Working from that easily made comparison with aviation FDRs or, as they're commonly called "black boxes," the misapplied moniker of "automotive black box" was then attached to the surface vehicle EDR effort(s) under way.

The US experience in this area is not unique - nor original - as it is applied to surface transportation. Lehmann, for example, reviewed EDR use in Europe and examined trends in data recording back to the 60's in Berlin[13]. In Western Europe, different types of on board data recorders have been examined and evaluated to determine their usefulness in the common goal of both mitigating the effect of crashes as well as in the investigation of those crashes to enable efficient analytical study to enable preventive efforts.

Throughout Europe, EDRs have been used extensively in various ways. The Berlin Police installed EDRs in 62 patrol cars and observed a decrease in "crashes through one's own fault" by some 20%. The Viennese Police equipped 175 of their vehicles with EDRs and, having reviewed the "positive effect" of the installation, directed that all newly purchased cars of the Austrian Police come equipped with EDRs. In the Safety Assessment Monitoring On Vehicle with Automatic Recording (SAMOVAR) research program in Great Britain, the Netherlands and Belgium, data was recorded from EDR equipped vehicles in designated fleets and control groups for a period of 12 months and a decrease in crashes by 28% and a fleet operating cost decrease of 40% was observed[14].

In virtually every study reviewed, Event Data Recorders contribute directly to road safety in two primary and fundamental areas:

1. **The overall collision event is better understood.** The post-crash analysis and reconstruction of the event is provided with another objective tool beyond "traditional" collision reconstruction techniques. Information or data which would frequently not otherwise be discovered using "normal" investigative and analytical efforts is made available to further supplement and improve the traditional analysis.

Fundamental to this is the concept that the ultimate application of a credible reconstruction of the collision event is an essential component of any effective traffic safety effort. Where the analysis of the collision is used simultaneously to (a) form the basis for proposed changes in Engineering, (b) make and evaluate decisions and rationale for an Enforcement policy and (c) to establish the appropriate and effective focus of Educational initiatives that underlying analysis must be as objective, thorough and reliable as possible to ultimately be effective.

A competent and efficient basic collision investigation is, therefore, the basis for a meaningful analysis and reconstruction of the event which offers the opportunity to detect recurring traffic safety problem(s). The development and implementation of any effective plan to correct the problem and thereby improve traffic safety flows from that analysis. In short, *proactive* efforts necessarily rely on the results of *reactive* undertakings.

It goes to the question of how can one reasonably suggest a program for *any* of the three "E's" until the "problem" which they would propose to address is actually identified? That, of course, begs the question: how can one identify a "problem" (a crash trend with a particular car or at a particular intersection, for example) without appropriate investigation and a complete and thorough analysis? The addition of the EDR capability is one more tool - albeit a clearly valuable one - to be used in overall traffic safety effort.

2. **EDRs have a positive preemptive effect on traffic safety.** Fleet studies have shown that the preventive effect of the installation of Event Data Recorders can reduce collisions by 20-30% [15]. Clearly, the driver's knowledge that an objective record of different aspects of his or her driving behavior will exist and be available post-crash would weigh heavily on the reasonable driver's choice of actions and behaviors while operating the vehicle. Unlike the analytical benefit, which is a reactive effort necessary to support a proactive change or program, the EDR system in this light is proactive; designed to alter, in advance, driver behavior through essentially a

common sense understanding of human nature.

The inclusion of the EDR in surface vehicles may turn out to be the ultimate combination of Haddon's original belief that the best safety measures are passive and the beliefs of those who held that the driver should ultimately be actively responsible for his or her own safety. By installing a *passive* device (the EDR) as a part of a *passive* safety system (in this case, the air bag system), it appears that technology has provided an *active* component to the mix: driver awareness of a "permanent record" of their behavior. In some way, it may be that technology caught up with the "Haddonites" ... or perhaps it is the other way around.

The "Permanent Record"

If the "reasonable man" test were applied to the justifications previously offered for the installation of an EDR in surface vehicles, one could not rationally argue against its benefit, nor the reasons which would follow clearly suggesting in favor of such inclusion. Compared in this respect to the FDRs, surely only the "unreasonable man," ignorant of the EDR's function or capability would suggest that the installation and use of surface transportation EDRs is without either merit or demonstrated purpose.

Nonetheless, particularly in the United States, there are those that would contend that the installation of an EDR is somehow an "invasion of privacy." This position is rooted in no small part to ignorance of the EDR's actual capabilities, and the intended scope and use of the data to be collected. In American society, privacy is viewed as a "right" and any perception that "Big Brother is watching" is almost immediately met with resistance.

The General Motors position, as outlined in the NHTSA EDR Working Group's Final Report, articulated a reasoned approach to solving this potential dilemma: "...The risk of private citizens reacting negatively to the "monitoring" function of the EDR can be diffused through honest and open communications to customers through owner's manuals by telling them such information is recorded. The acceptance of recording this data is more likely if the "monitored" data is used to improve the product or improving the general cause of public safety"[16].

Another related area of concern would be to the issues of ownership of the data itself. To compile the data, one has to collect it first and the Working Group[17] addressed this as well in its Final Report as well as at the NTSB Sponsored "Transportation Safety and the Law, Proprietary Information, Employee Privacy And Criminal Inquiries" symposium. One discussion of the benefits and ownership of the data was addressed there by Grush[18] of the Ford Motor Company (US) who highlighted the fact that the larger safety and research benefits easily outweighed the few potential negatives if care was taken in the way the data is collection, maintained and used.

The NHTSA Working Group report addressed the underlying ownership issue(s) more than thoroughly detailing US Federal law with respect to the Privacy Act, US Federal Court Decisions and by seeking opinions and positions from member and non-member entities on the ownership of the data. In this regard, the NHTSA position is simply that the owner of the vehicle owns the data.

The recurring theme found in the many positions and discussions offered by groups from auto manufacturers to insurance companies to private attorneys to manufacturers of EDRs in various forms seems to echo the NHTSA position and add that, providing individual privacy is protected appropriately, the public interest - that being for improved traffic safety - is best served if there is full access to and then centralized collection of the core information; without necessarily identifying individual drivers. Earlier on in their inquiries, the NHTSA Working Group contemplated looking to the history of other data collection processes for guidance by way of their experiential examples. The NTSB data collection from FDRs being the most direct example keeping in mind differences and limitations of the FDR compared to the EDR.

Today, no one argues against the ultimate benefit of the data collected from FDRs in catastrophic aviation crashes. The connection between collection, analysis and utilization of that data and the resulting improvements in aviation safety is obvious by virtue of its past application and, most significantly, *results*. Privacy concerns, for the *passengers* on lost flights are a "non-issue" as far as the data collected from the FDR system is concerned.

The list of flight data parameters from the many potential systems onboard an aircraft could run on for pages depending on the aircraft model and vintage of the FDR system and virtually none have anything to do with the passengers individually. Specific to the aviation example; however, the additional existence of the Cockpit Voice Recorder (CVR) arguably adds to the confusion over differences between the ground transportation EDR and the aviation FDR and CVR systems and brings up the issue of cockpit and crew privacy which might be loosely compared by the uninformed to surface vehicle driver and passenger(s) privacy.

The experiential example set by the NTSB in that regard goes to how CVR data, which is undeniably personal and often very private in the final moments of a catastrophic event, is and is not disseminated. In more instances than not, the last moments of the crew's reaction to the impending catastrophic event are viewed as private, kept confidential and not released publicly. Their conversations whilst "working the problem" such that the investigators and the Safety Board may benefit from that perspective on the crew's often heroic efforts to try to recover the lost aircraft are a valuable part of the process and are used and often disseminated on a limited basis for that purpose.

In the aviation experience, catastrophic events often last several seconds if not minutes when all the related pre-crash activity is considered. In surface vehicle crashes, pre-crash activity is significant for only a very short period, often a very few seconds, before the collision itself. The ability of the aviation crash analyst to objectively "observe" the cockpit crew's perception of and reaction to a problem lends a new dimension to the understanding of the event and may work to eliminate as failed or include as effective certain countermeasures available to the flight crew in similar future events.

But such voice recording is *not* available in the ground transportation application as currently employed in the US experience; there simply is no provision for passenger compartment voice recording in the ground transportation EDR application and, at this point, it doesn't seem to be an area of interest because the limited value in surface crashes does not outweigh the privacy concerns. So, what ***is*** recorded?

What is Recorded?

Recent ground transportation efforts to collect crash data began in model year 1989 when General Motors began gathering very limited data in what was then called the Diagnostic Energy Reserve Module (DERM).

It is important, at this point, to reiterate the distinction between this device - the "DERM" - and the aviation FDR. The aviation "Flight *Data Recorder*" was, as the name suggests, designed to capture and record flight data. The design purpose of the "*Diagnostic* Energy Reserve Module" was to analyze the air bag system for faults at start-up, report those faults to the driver through the instrument cluster warning lights and store fault codes for service personnel when those warning lights prompted the driver to bring the vehicle in for service.

The DERM also stored electrical energy in a capacitor to potentially deploy the air bag(s) in multi-impact collision events should the battery be disabled in an initial impact in the series and there had not yet been a deployment.

Given those two *primary* functions (system diagnostic and deployment function), features were later added to the DERM which were designed to collect and store limited related information about the status of certain vehicle features at the time of a deployment. The sum total of the information collected by this unit amounted to 6 basic system data points:

1. The "on" or "off" condition of the air bag system warning lamp at the time of the event
2. The length of time that warning lamp had been illuminated
3. The crash sensing activation time or that the sensing deployment criteria was met
4. The time from "impact" to air bag deployment command
5. Diagnostic trouble codes present at deployment
6. Ignition cycle count at deployment

Notably, no specific crash pulse data (delta-V or event duration, for example) was captured in these early units.

In 1994, GM began using a next generation "air bag (control) module," called the Sensing Diagnostic Module (SDM). The SDM's primary design function is, like its predecessor the DERM, to conduct power-up diagnostics of the air bag system and then maintain the system in a state of readiness to respond to a crash event while the vehicle's ignition is in an "on" position. The most significant difference between the two systems (DERM as compared to SDM) is found in the way each "recognizes" and responds to the crash event.

The DERM relied on input from simple "on/off" mechanical switches which, as a result of a sufficient crash acceleration ("deceleration"), completed an electrical circuit sending an "on" message to the DERM. If the proper number of these mechanical sensors (typically 2 - a "crash" sensor and a "safing" or "discriminating"sensor) closed in a crash in the appropriate time interval relative to each other given their relative placement in the vehicle, the system would deploy the vehicle's air bag(s).

The SDM, while it may be connected to what are called Auxiliary Discriminating Sensors (ADS) which are still mechanical sensors, has an internal accelerometer which measures the actual negative acceleration "experienced" by the car in the form of a crash pulse: -g's and time as (negative) acceleration. Once the system computer's algorithm is activated (enabled) as a result of sufficient negative acceleration along the car's longitudinal ("X") axis(3) (typically on the order of between -1 and -2g's in two consecutive integrated samples) the SDM begins its second function: to make a deployment or non-deployment decision and then command that deployment when appropriate.

The DERM was simply a mechanical device reacting to a "fire" signal. With sensors ideally calibrated to the stiffness of a given make/model vehicle based on barrier crash tests conducted up to that point, the DERM didn't "make decisions." While it ultimately recorded some bits of data, it didn't "evaluate" the actual developing crash pulse in a given situation.

The SDM, on the other hand, relies on either a signal from the ADS to "wake up" to the possibility of a crash situation developing or, more typically, a series of readings from its built-in accelerometer to engage or activate the analytical functions of the SDM's internal microcomputer. The microcomputer, having been "jostled awake," as it were, by a sufficient negative acceleration, begins analyzing data passed through a low pass filter from its accelerometer. It examines those data points

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[3] See Society of Automotive Engineers Surface Vehicle Information Reports J1733, and Recommended Practice J211/1 for a further explanation of the standardized vehicle axial system orientation. See also Fig 4.

looking for a trend in the developing acceleration slope (-g's over time), and then makes the appropriate deployment/no-deployment decision based on anticipated crash severity given those samples examined in that particular situation.

In the end, air bag deployment is not based on the actual/total delta-V for a given "real world" crash. In other words, the *actual* delta-V for a given crash is the *total* speed change (as a vector velocity) and is not the *immediate* criteria on which the deployment decision is - or should be - made. "Total" necessarily means that the collision's harmful event is "totally" over. If the SDM were to wait until it "knew" or evaluated/reviewed the *actual* (total) delta-V for a given real-world event, the harmful event would, of course, be over and there would no longer be a need for a deployment to provide for occupant protection.

The purpose of the air-bag system is to eliminate or reduce the impact of the driver against interior vehicle components (steering wheel, instrument panel, doors, B-pillar). For that reason, "of decisive importance in ensuring the protective system's effectiveness is to trigger the process at precisely the right instant. The occupants should contact the airbag at the instant in which it is fully inflated and just starting to deflate...The entire impact and energy absorption process is therefore *completed* within approximately 150 ms" (emphasis mine).[19]

Obviously, from a practical perspective, the microcomputer's algorithm must evaluate and predict/project the developing trend in the vehicle's longitudinal negative acceleration as quickly as possible and anticipate - given specific vehicle make/model properties such as mass and stiffness - the ultimate severity of the collision in order to be effective. All this must be done in a very short time interval and using a correspondingly small number of acceleration samples captured early in the event; in most cases, between 15 and 50ms after the algorithm is enabled[20]. If the projected acceleration slope is relatively "shallow" indicating a comparatively lower crash pulse, the algorithm has to respond to that acceleration/timing observation just as appropriately as if it was responding to a relatively "steeper" or more severe crash pulse.

Once a negative acceleration event of sufficient severity has occurred and the SDM begins analyzing that event and concludes its secondary purpose - the "fire" / "don't fire" decision and command (4) - it begins its tertiary function: that of data collection. One can see again that the SDM is demonstrably different from both the DERM and the FDR in very significant ways.

The DERM simply "reacts" to a mechanical signal and "approves" deployment. Whereas by comparison, the SDM analyzes raw acceleration data to predict severity and then may command deployment.

The FDR neither commands nor directs any aircraft system's operational function, it simply records data. The SDM commands deployment, when appropriate, and *then,* since the algorithm used to evaluate that data is enabled and active, analyzed the raw data and then reached a predictive decision, it begins to record crash and vehicle system status data.

In 1994, the earlier basic data collection capabilities were increased to include an additional 5 system parameters (in addition to the previous 6 listed for the DERM):

1. Recorded longitudinal ("X") axis delta-V and time for a deployment
2. Maximum recorded longitudinal ("X") axis delta-V in a near deployment
3. Time from "algorithm enabled" to maximum recorded delta-V
4. Driver's seat belt circuit switch - "buckled or unbuckled"
5. Time between deployment and near

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[4] Its primary purpose having been the system diagnostic at start-up.

deployment events appropriate to the event and unit capabilities

While the NTSB's 1997 recommendation to NHTSA to implement a crash data collection program wasn't to occur for another 3 years, GM advanced this technology and began what has evolved into a comprehensive effort to collect crash data at the SDM in the EDR components of that unit ***and*** make it widely available for analysis. In 1999, GM further improved on the unit's data collection capabilities by the inclusion of another 5 data points (in addition to the 11 previously listed):

1. Front passenger air bag enabled/disabled (a switch controlled feature)
2. Percent throttle applied during the 5 seconds before the algorithm is enabled
3. Engine RPM (engine speed) during the 5 seconds before the algorithm is enabled
4. Vehicle speed during the 5 seconds before the algorithm is enabled
5. Status of the brake switch (on/off) during the 5 seconds before the algorithm is enabled

These last 5 included in the GM SDM/EDR unit have already been augmented, in 2001 models, to include, for example, the time between a first and second stage air bag deployment or firing command as well as other related vehicle system parameters. While other features have been added, more are being developed.

The Ford Motor Company (US) is rapidly approaching a point where their vehicles and their SDM system (reportedly called the Restraint Control Module (RCM)) will be widely in place and begin to provide similarly useful information. By some accounts, in place on a limited basis since 1997 and more recently installed with reportedly significant data collection capabilities, the RCM may be actively collecting data in crashes involving the 2000 Ford Taurus & Mercury Sable and the 2001 Crown Victoria, Windstar, Grand Marquis, and Towncar (US production models).

Of any group of the system parameters collected on the GM SDM units, the most recently added 5 parameters along with delta-V and deployment timing will go a long way toward bringing the SDM/EDR truly in line with what the NTSB envisioned as being the basis for data which, when gathered and analyzed, will surely advance ground transportation safety.

Of course, before any effective decisions can be based on the information collected from "real world" crashes through the EDR component of the SDM, a responsible analyst would necessarily want to know the level of accuracy, precision and reliability of the data being offered for analysis.

Accuracy, Precision & Reliability

Accuracy, taken literally, means "freedom from error" or "correct, exact..." "Precision" means "minutely accurate or accurately stated." While these words would almost seem synonymous, there is a world of difference between their applied meanings, particularly in an applied science; such is collision analysis/reconstruction. Reliability means "being able to depend on something with great confidence for its applied use." The following example is offered to further demonstrate the absolute, difference in the meanings of the two distinct constructs: accuracy, and precision, and their near cousin reliability[21].

A gas tank gage in an automobile has a finely divided *scal*e which can be used to read the fuel level to the nearest 1/10 gallon. However, unbeknownst to the operator of the vehicle, a miscreant has secretly bent the needle of the gage at a point near the needle's pivot, a point that is hidden by the fascia of the instrument panel. The miscreant who bent the gage needle arranged the bend so that when the needle showed the gas tank as being "full," the tank would actually be half-full. The gage then becomes an instrument that is *precise* (it may be read at 0.1gal increments), but is woefully *inaccurate* (in error by half the *true value* when indicating full). As a result, it is *unreliable* for its intended purpose.

1. How close a reading is to the **true value** of the quantity being examined is the measure of the **accuracy** of the device or instrument.

2. To how many places can the **scale** be read or set is the measure of the **precision** of the device or instrument[22].

Taken in terms of the EDR data being collected today, one has to decide what is more useful and reliable to the end user: an "accurate" number or "precise" value and, in that context, evaluate the answer against a "real" value one is attempting to measure or quantify. One may calculate an answer to 6th decimal place precision based on inaccurate quantities and be *precisely inaccurate*. Another way to look at it is: is a value reported to the *precision* of 0.1 mph, for example, a "sufficiently" finite number for the intended purpose and given the accuracy of that number or is it sufficiently useful to report a value *accurately* to the *precision* of the nearest whole mile per hour?

Applied to the EDR, how does one evaluate the *reliability* (moreover the usefulness) of the EDR data in terms of its *accuracy* and, separately, its *precision?* Using the example previously set forth as a guide, one may evaluate all three aspects of the EDR delta-V data as collected in raw terms and as ultimately reported to the intended end user.

In this approach, one must first understand the basic operation and data collection capabilities of the SDM. Specifically, the GM EDR equipped SDM employs an accelerometer which is set to monitor longitudinal acceleration and is low-pass filtered at approximately 400Hz. Acceleration is sampled every 312 microseconds (μs) and the microcomputer integrates the average of 4 such samples. Because of physical memory limitations in the EDR equipped SDM, integrated delta-V is stored and ultimately reported in 10ms intervals[23].

One may therefore conclude, using the examples cited above, that there is a reasonably high level of acceleration data *precision* available through the SDM; however, the *accuracy* of that data is not addressed. That separate issue of *accuracy,* in terms of the intended end-user application(s), can be demonstrated and defended empirically as later discussed.

The limitations of the accuracy of the delta-V data is a result of 3 sources of potential error: (1) tolerance of the SDM components, in particular the accelerometer, (2) integer based mathematics where delta-V is reduced to single data bits and (3) a +1 to +2g bias in the algorithm[24]. In Chidester's paper; the net effect of this bias appears to be somewhat overstated when compared to the tests conducted and reviewed herein (see also Figure 2).

From a practical perspective, the frequency content of the crash pulse which is of interest to the crash analyst does not generally exceed 60Hz[25] and is well represented by the low frequency delta-V data reported by the EDR. This position can be empirically supported by a series of crash tests conducted by this author in conjunction with other individuals and entities (5).

A series of 48 crash tests of varying severity were conducted using a cross section of SDM/EDR equipped GM vehicles (list, Appendix A) . The tests were all conducted vehicle-to-vehicle, that is, no barrier crash tests make up part of this group. The vehicles were instrumented using triaxial accelerometers and various vehicle operating parameters were captured using other independent, external devices (6). The crash tests were conducted at closing speeds of 1 mph (1.6 km/h) to 49.6mph (79.8 km/h) and include observed delta-Vs from -0.22 mph (-0.35 km/h) to -24.6 mph (-39.6 km/h). A total of 12 deployment events were observed within that group of tests. The remaining tests are "non-deployment" events.

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[5] See Appendix A.

[6] See Appendix B.

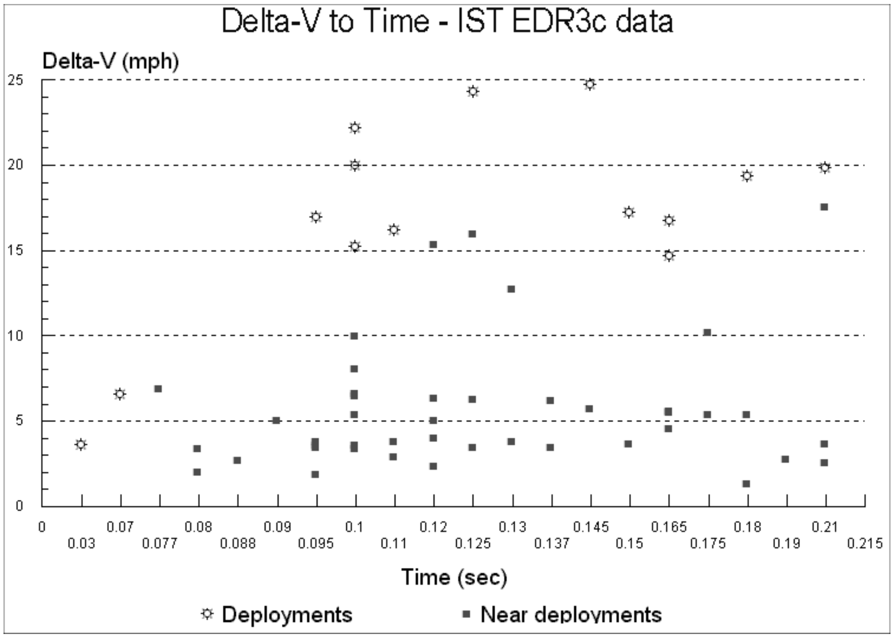

Figure 1

A “non-deployment” collision is one where the magnitude of the negative longitudinal acceleration is greater than -1 to -2g’s for two consecutive samples as “observed” by the SDM but the projected characteristics of the developing crash pulse as “analyzed” and the anticipated severity predicted by the algorithm is insufficient to warrant an actual air bag deployment. This is referred to as a “near deployment” event. Such events may be recorded to the EDR, depending on previously recorded events and timing relative to another event as later discussed.

Figure 1(7) is a graph of the overall *total* delta-Vs observed during the tests broken down into deployment and near deployment events as captured using the IST EDR3c accelerometers described in Appendix B. The data in Figure 1 is representative of all data collected for each individual car not by individual test. Also depicted in Figure 1 are near deployment events, For the same reason, there are more samples reported in this Figure than there were individual tests *(events)* conducted.

Figure 1 illustrates, as stated, the *total* delta-V observed for these cars in these tests. In this graph, it is the *total* integrated value of acceleration (g’s over time) as observed at the IST EDR3c triaxial accelerometers. It does not, independently, reflect the delta-V anticipated, observed at or that finally reported by the EDR component of the SDM. In fact, an overly simplified, total delta-V -to- total delta-V comparison would be without probative value, particularly without an understanding of the limitations of the EDR component of the SDM.

As previously mentioned, the EDR component of the SDM has physical memory limitations. Typically, the GM verison of this device has 32kb (kilobytes) of ROM (Read Only Memory) for program code, 512 to 640 bytes of RAM (Random Access Memory) and 512 bytes of EEPROM (Electronically Erasable Programmable Read Only Memory) [26].

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[7] Figures are also included in a larger format at the end of the document. Figures 1 and 2 have been laid out using truncated values. Actual values for Figure 2 are found in in the table Appendix C.

The SDM's microprocessor directly operates with and relies on the 32kb of ROM which is programmed during the actual manufacturing process and contains the system's deployment logic (algorithm). This cannot be overwritten without destroying that logic/programming and rendering the SDM inoperable.

The RAM is the active storage memory for the SDM/EDR unit. While the system is powered up, data is actively collected and buffered for potential capture from the various vehicle systems and from the SDM's internal accelerometer, to this volatile RAM. When power is cut to the module, when the car is turned "off," the RAM is cleared.

By comparison, once data is written to the EEPROM, it is stored there even when the power to the SDM is cut. The GM EDR equipped SDM captures both deployment and near deployment events to the EEPROM but may treat them differently in individual events or event sequences.

In the case of deployment events, the data collected (see "What is Recorded?" above) is written permanently to the EEPROM. That is, in the case of a deployment, that data is written to the EEPROM and that event's data cannot be overwritten by another deployment event.

Data from a near deployment event which occurs within 5 seconds of a deployment event may be permanently locked into the EEPROM along with the deployment data. Both events would then be recorded and stored and, in that case, cannot be overwritten. The general rule is that events within 5 seconds before a deployment will typically be recorded and locked with the deployment while those which occur within 5 seconds after will sometimes be recorded and locked.

If there is a near deployment outside that 5 second window, it may be recorded to the EEPROM but may also be overwritten by a subsequent near deployment event depending on its severity and the functional generation of the system itself.

The severity of a subsequent event may also approach or become a "deployment level" event which should overwrite a previously stored but outside the 5 second window lesser severity near deployment event. A "deployment level" event is one in which the anticipated delta-V is significant enough to otherwise warrant a deployment but for the fact that one had already occurred and is recorded in the EDR. In some instances, the "deployment level" event may be recorded in the EEPROM's near deployment space - if available - overwriting a previously recorded volatile near deployment data file.

The discussion of the EEPROM capability is important from the perspective that it leads us back to how event(s) may be captured and how one might make a reasoned comparison to external data collected in crash tests to evaluate the EDR data's reliability. Crucial to this understanding is that there is "only" 512 bytes of storage space on the EEPROM. By way of comparison, a typical PC floppy disk holds 1.44 megabytes of data or effectively 1,400,000 bytes of data but the EDR has just the capability to store 512 bytes in EEPROM space (8).

In short, there's just not a lot of physical storage space available for this tertiary function of the SDM: data collection. To capture all the various pre-crash data points, system parameters (i.e.: seat belt circuit status), and delta-V trade-offs necessarily occur. Some data, outside an anticipated time interval or level, for example, may be lost in favor of capturing other data points seen as more valuable to the larger probative view of the event.

For this reason, the SDM may only report acceleration integrated to delta-V beginning 10ms after "algorithm enabled" and ending about 100ms later (or more depending on the model vintage of the particular SDM unit). For most

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[8] Data is stored in hexadecimal format.

purposes, this is more than ample time to capture the total delta-V in a given barrier crash test and sufficient time to capture the post-impact area of interest to a collision analyst in a "real-world" collision. In few of the crash tests described herein, the SDM's EDR recorded delta-V (with 512 bytes of memory available) was related to a time period significantly shorter than that observed and recorded by the IST EDR3c accelerometer (with 4mb of memory available).

The average time difference (that reported as observed by the SDM/EDR and the total time for the event as captured by the IST EDR3C) was 0.05sec. The single greatest difference between the two was 0.176 sec and only 6 of the tests had a difference greater than 0.1 sec. Of the tests, 14 had a difference of greater than 0.05 sec (including those 6 previously mentioned). There were 17 which had a difference of 0.03 sec or less in this group.

Another consideration is the initial bias found in the SDM accelerometer/microcomputer and -1 to -2g pulse which must be observed by the EDR before analysis even begins. By comparison, while the IST EDR3c was set to trigger at a specified acceleration threshold, it captured data for a set period before that trigger to reveal the total acceleration pulse for the crash and then the integral delta-V was calculated for that total acceleration including data back through the trigger level to the actual onset of the collision event.

It would, therefore, be intellectually dishonest to simply compare the "total" delta-V reported for the limited period observed by the EDR and with the actual total event acceleration pulse integrated from the IST EDR3c data in an effort to use the latter as the control for an evaluation of the *accuracy* of the SDM EDR data. The more reasoned comparison would be to evaluate the IST EDR3c acceleration equal to that period of time observed/captured by SDM EDR, calculate the integral for that period and then make the comparison. In Figure 2, there is a graphical representation of such comparison.

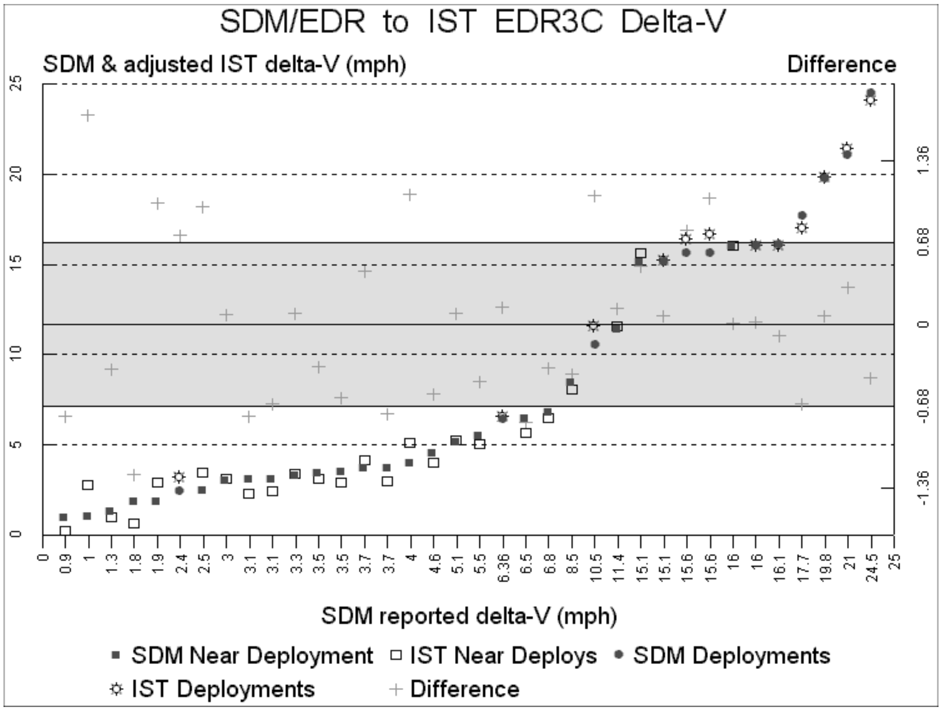

Figure 2

In Figure 2, the SDM/EDR reported delta-V is truncated on the X axis of the graph and then the actual value reported and the actual time adjusted value for the delta-V to the same time interval captured by the IST EDR3c accelerometers is shown for comparison. The difference between the two is depicted as well, in an adjusted right side vertical axis on the graph, scaled larger for easier reading. Thirty six tests are examined in Figure 2. These were those tests, of the larger group conducted, where the SDM/EDR reported both a delta-V and a time interval from which to make the comparison with the IST EDR3c.

Once the IST data is adjusted to examine the same period of time, but exclusive of an adjustment for the initial bias, the SDM EDR under reports delta-V by an average of 0.022mph (0.035km/h) for all crashes observed, deployments and near-deployments. For deployments in the group observed, it under reported delta-V by 0.247 mph (0.397 km/h).

For the difference between the SDM reported delta-V and time adjusted EDR3c delta-V, the standard deviation is 0.68 (seen as the highlighted area in Figure 2) and 0.53 for the twelve time adjusted deployment events in the group.

When one considers the same group but looks instead at the entire delta-V observed by the IST EDR3c compared to that reported by the SDM EDR, the SDM under reports delta-V by an average of 1.13mph (1.81km/h) (a standard deviation of 1.11). For the time unadjusted deployment events in the group, the under reporting difference is 1.22mph (1.96 km/h) (a standard deviation of 1.4). See also Appendix C for details.

If, as previously proposed, *accuracy* is to be defined as how close something is to the true value, and we adopt that the IST EDR3c may be used to establish that true value, we may conclude that the SDM EDR data *is amply accurate and therefore reliable* for its intended purpose(s): an evaluation of *"crash pulses... in actual crashes..."* (see NHTSA directive).

With few exceptions; however, these crash tests were conducted with the target vehicle at an initial velocity of zero and the bullet vehicle being examined moving such that the acceleration was observed directly along that bullet vehicle's longitudinal (X) axis. This consideration in the testing protocol largely eliminated the need to consider a non-X axis Principal Direction of Force (PDOF), thereby removing another variable during the tests conducted for this analysis.

"Real-world" collisions; however, are rarely simple in-line events and surely the effect of PDOF in a collision would need to be considered both in terms of the representative or observable effect but also for the evaluation of data accuracy in that type situation as well.

Other Than In-line Collisions

Collision alignments are often described by the terms "Head-on," "Broadside," "Rearender," and "Angled, Other Than 90." The first three are depicted in Figure 3. If, in those instances, the only moving vehicle is the "bullet" vehicle (labeled "B" in Figure 3), then the only momentum brought to bear in the collision comes from that vehicle and the direction of force can be simplified to that which can be measured directly along the bullet vehicle's "X" axis (as shown in Figure 4). In the collision orientations depicted in Figure 3, the positive direction for that axis is forward (relative to the driver's orientation in the car), and what is measured by the SDM's accelerometer is front-to-rear acceleration or acceleration in the negative direction, X axis.

When the orientation is "Other Than 90 (degrees)" and both vehicles are moving, then the direction of force (PDOF) is no longer "simply" on one of the car's "X" axis. In that instance, the force applied can be measured as a vector relative to the X axis, individually for each car.

A crash test example of such a collision orientation is identified as "MSP2." In that test, a moving “bullet” vehicle struck a moving air bag and SDM equipped “target” vehicle (a Chevrolet Cavalier) at 50 degrees as depicted in Figure 5.The measured angle of the PDOF for the target vehicle was 50 degrees (+/- less than 5 degrees on each side of that angle). In this particular test, the impact alignment was such that the bullet vehicle struck the target vehicle at the right rear of the four door Cavalier. Sustained contact damage on the target vehicle shows that the bumper on the bullet vehicle first dug into the right rear door then slid along the side before it caught on the right rear wheel and wheel well, bending the wheel and suspension rearward then spinning the target vehicle clockwise.

Notably, the impact was not directly to the front of the target car. There was a time when the belief was that the “only way” an air bag would deploy was if there was a collision which generated some unspecified but “sufficient” (total) delta-V, when that impact as within 30 degrees of the X axis and was directly to the front of the car. In “MSP2,” this was demonstrated not to be the case as the air bag in the target vehicle deployed, the impact was to the right rear side and the 50 degree angle obviously fell outside the 30 degree “window.” The implication was clear: the air bags deploy when there is a *net negative acceleration observed relative to the X axis.*

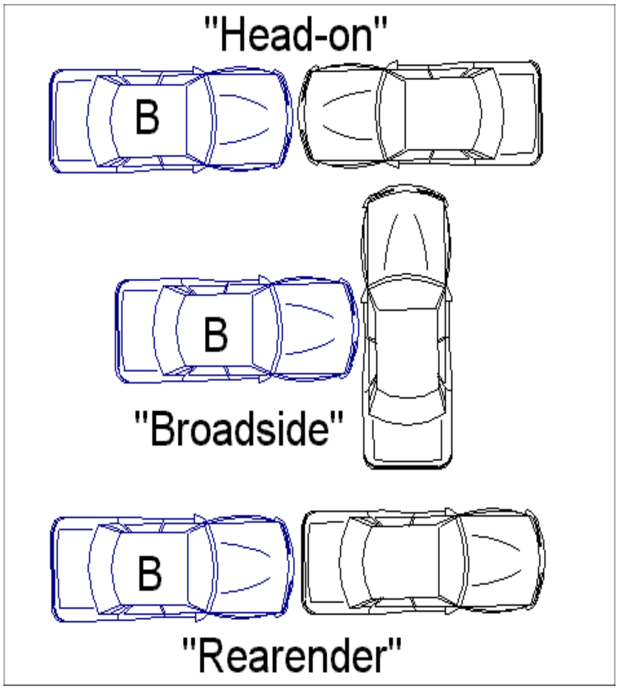

Figure 3

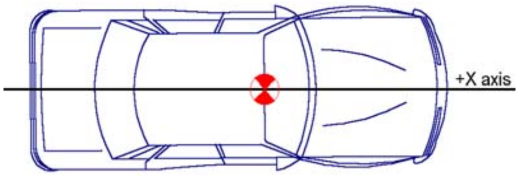

Figure 4

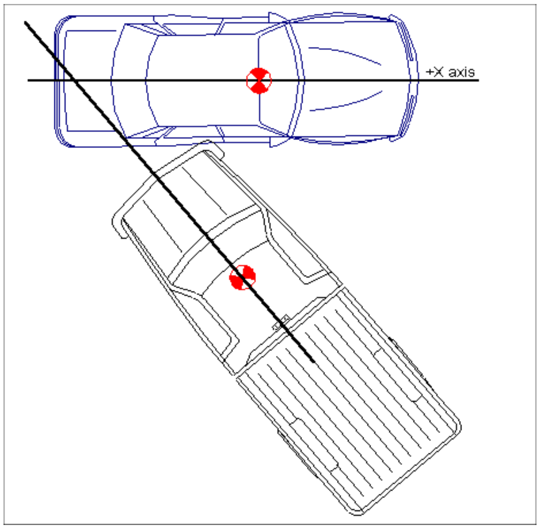

Figure 5

This test (MSP2), was set up to illustrate the net effect of a force application other than directly on the X axis and examine how sensitive the SDM EDR is to such off axis accelerations. In this test, an IST EDR3c was set up in the target car and turned such that the accelerometer's X axis was at 50 degrees to the car's longitudinal (X) axis. After the test, the IST EDR3c recorded an integrated delta-V of -10.11mph (-16.27 km/h). The car's EDR held a deployment file and a maximum delta-V of -6.36mph (-10.23 km/h). Adjusting for the angle between the IST EDR3c and the X axis of the car (50 degrees) the net effect of a -10.11mph delta-V at 50 degrees should be -6.49mph (-10.44 km/h). Assuming the angle to be measured at precisely 50 degrees, the SDM appears to have under reported the effective X axis delta-V by 0.13mph (0.21km/h).

Given the uncertainty of the actual angle at impact, one may reasonably approach this analysis with a larger calculated range for the net effect on the X axis given the actual dynamic PDOF of this particular crash.

Adopting the -10.11mph delta-V from the IST EDR3c accelerometer as a control, one finds the net effect given the potential uncertainty of 45-55 degrees to be -5.79 to -7.14 mph (-9.31 to -11.49 km/h) or +0.65 to -0.7 mph (+1.04 to -1.12 km/h) off that central value of 50 degrees keeping in mind that the IST EDR3c X axis was set at a measured 50 degrees to the vehicle X axis along which the SDM EDR accelerometer was measuring acceleration. Only the accuracy of the angle measurement, given the precision of the angle measurement equipment used, gives rise to that larger potential range of uncertainty.

Even on the outside of the range, the level of accuracy, as calculated, is well within reason for the crash pulse analysis to be undertaken. It also reenforces the point that the SDM is analyzing only X axis data and that collisions with a PDOF off that axis should be more closely examined and the PDOF accurately established to better understand or explain that which is reported by the SDM EDR.

A similar test was conducted with another Cavalier in this series again at a measured 50 degrees such that there was one IST EDR3c set at 50 degrees to the X axis of the target car and another IST EDR3c set such that its X axis was parallel to the car's "X" axis. In this test (CRSH13), where the target Cavalier was *not* moving, the offset EDR3c measured a delta-V on the 50 degree angle at -5.38mph (-8.65 km/h). The EDR3c set on the vehicle's X axis measured a delta-V of -3.66 mph (-5.89 km/h).

Mathematically, if the angle between the EDR3c and X axis was measured with great accuracy and is precisely reported, the -5.38mph delta-V should result in a calculated delta-V "observed on" the X axis of -3.45 mph (-5.55km/h). An apparent difference, assuming the angle to be absolutely accurate as reported, of 0.21mph (0.33km/h). This is within the anticipated tolerance given the precision of the devices used to measure the angle between of the pair of individual EDR3c units as well as the potential for imprecision in the integral calculation of delta-V.

The SDM did not register a deployment nor did it record a near deployment event in test "CRSH13." Was it because the area of contact, like "MSP2," was on the side of the target vehicle and outside the "30 degree window" suggesting the results from MSP2 were unreliable? The answer lies in understanding air bag deployment criteria and what is meant by "anticipated severity."

Anticipated Severity

There are a number of "crash sensing concepts" which have been suggested by different authors (see Chan[27]). One that closely approximates what has been observed in the testing done to date with SDM equipped vehicles in car-to-car crashes is found in Gioutsos[28]. Gioutsos suggests deployment should be based on an early examination of the slope of the developing waveform of the crash pulse as jerk. Jerk is the rate of change of acceleration or, put another way, "how fast something gets faster (or slower)."

An example of jerk would be the observation of a car skidding with all wheels locked and slowing at a rate of -22.54f/s^2 (-6.87m/s^2). The car skids off one surface onto another, more rough surface. Because the second surface is rougher, the rate of slowing changes, in this example, to -28.98 f/s^2 (-8.8m/s^2). In both cases, the vehicle is still slowing but the *rate* of that slowing changes. One might plot those rates on a graph relative to time and see that the slope of a line drawn would get "steeper" and the negative acceleration viewed as "greater" or "more severe."

The underlying theory holds that when delta-V **increases** *and* duration (time) **decreases**, the crash is relatively **more severe**. Gioutsos described this in terms of an evaluation of the developing acceleration slope where, as the slope increases, the crash severity is correspondingly greater and predicting that slope early enough to effectively protect the occupants should be the goal of the air bag system. Specifically it should be the design objective of the predictive algorithm in the SDM's microcomputer.

While the actual operation of the General Motors SDM algorithm is proprietary and a discussion of the appropriateness of a specific situational deployment command "decision" would be ineffective and limiting, an examination of the ultimate delta-Vs observed for the tests addressed herein relative to a deployment or no-deployment decision, as a comparative group, may be instructive.

The SDM does not, as previously discussed, respond to the total delta-V of a given crash and *then* deploy the air bag(s) (see "What Gets Recorded"). Nonetheless, an examination of the total delta-V relative to the decision to deploy or not to deploy might be one standard to evaluate the effectiveness of a given approach when the underlying acceleration waveform or pulse can **also** be examined (ie: Gioutsos). To do this, we might more closely examine four crash tests for which we have both SDM EDR data and IST EDR3c data. From the group previously described, these are:

(1) a high delta-V, long duration no-deployment (IAARS-5),
(2) a low delta-V, long duration no-deployment (SCARS-3),
(3) a high delta-V, short duration deployment (CRSH-14), and a
(4) a low delta-V, short duration deployment (IAARS-4).

In Figure 1, we see a plot of the tests described in this paper where the total delta-V observed is compared to the total time for the event. As seen in the larger version of Figure 1 found at the end of the document is a representation of that range where the SDM may or may not make a deployment decision, a range identified as the "sensing tolerance zone." A similar representation is found in Figure 6 as "Figure 2" to SAE document J2431[29]. "IAARS-5 would fall into this "sensing tolerance zone.'

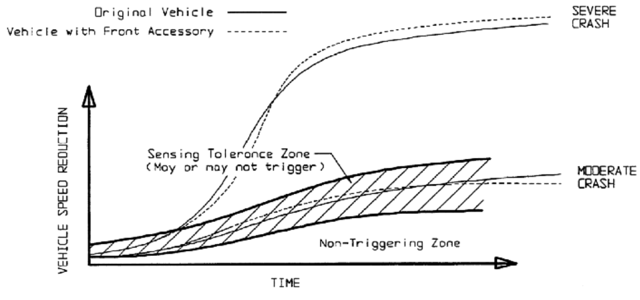

FIGURE 2—CRASH-SENSING SCENARIOS

Figure 6

Data points from the four tests to be compared are found in Table 2. These tests were conducted as part of the larger group described by this paper. They are all car-to-car tests where the PDOF is directly on the X axis of the vehicle being examined. For consistency, the data reflected is that taken from the IST EDR3c accelerometer

Test ID	IST / SDM delta-V mph (km/h)	IST delta-t (s)	time (s) to -1g	time (s) to -2g	time to max/ max g's	delta-V at 15ms mph (km/h)	delta-V at 50ms mph (km/h)
SCARS - 3 near-deploy	-4.53 / -3.71 (-7.29 / -5.97)	0.168	0.0112	0.0195	0.0439s -3.28g's	-0.23 (-0.37)	-2.00 (-3.22)
IAARS - 5 near-deploy	-17.71 / -15.99 (-28.5 / -25.73)	0.211	0.002	0.0034	>0.0166s -10.99g's	-2.04 (-3.28)	-7.31 (-11.76)
IAARS - 4 deploy	-3.54 / -2.42 (-5.69 / -3.89)	0.026	<<0.001	<<0.002	<0.0146s -12.96g's	-1.84 (-2.96)	-3.54 (-5.69)
CRSH - 14 deploy	-24.27 / -24.49 (-39.05 /-39.41)	0.123	<<0.002	<<0.003	0.078s -18.1g's	-2.05 (-3.3)	-9.368 (-15.07)

Table 2 - Selected Tests Comparison

since the involved vehicles were different models and had correspondingly different SDM units with different recording capabilities. For a more complete comparison; however, the second column reflects first the IST EDR3c delta-V followed by the SDM reported delta-V for the given crash. Time to -1 and -2g's is offered to provide some idea of *approximately* when the algorithm would have enabled on the SDM (given acceleration levels found using the IST EDR3c) and the delta-V at 15 and 50ms is offered given the figures cited in Chidester[30].

In test "IAARS-5," peak g's were observed very near the 15ms mark. In test "IAARS-4," the event was actually over by 50ms. In the test "CRSH-14," the -1g level was not observed in the filtered acceleration data and the -1.5g's level is represented instead in the table. The same applies to the test "IAARS-4," such that filtered samples did not allow for an observation of -1g, rather the first reported samples exceeded that mark. In both "IAARS" tests, there was pre-impact braking. Braking in "IAARS-5" took place for 0.227 sec resulting in a speed loss of 1.28mph (2.05km/h). Braking in "IAARS-4" took place for 0.3525 seconds pre-impact resulting in a speed loss of 3mph (4.8km/h).

Even a cursory examination of the selected tests suggests a striking, if not obvious, commonality for the two deployment events: the onset of -1 to -2g's occurs very early during the event. Although the ultimate duration may be different (one longer and one far shorter), the initial observed acceleration to the -1 to -2g level occurs in well under 0.003s for either event(9). Assuming the SDM's accelerometer is sampling at the previous rate (approximately 300μs), that would equate to approximately 100 acceleration samples, filtered and analyzed as the level of negative acceleration approached -1 to -2g's.

By comparison, in the near deployment events, the occurrence of the -1 to -2g level is markedly later. Arguably, one may observe that in test "IAARS-5," the -1 to -2g level was reached *relatively* early on in the event; however, further examination of the time to reach max g's *and* the level of that acceleration suggests a slope far less steep than that which would be represented in the 2 deployment events offered in Table 2.

Examining the time to max g's and then the delta-V for each test as far out as 15 and then 50ms it

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[9] In an attempt to identify the point in those tests where -1 to -2g's were observed, the unfiltered raw data was examined. In "IAARS-4," no early -1g sample was observed at all and samples exceeded that from the outset of the event.

becomes more apparent that the acceleration slope for each of the deployments are similar to one another as are those for the near deployment events. However, there is little to compare between the deployments and the near deployments in that regard..

Is the algorithm predicting the developing severity "appropriately?" Using the Gioutsos[31] work as a guide, the conclusion one may reach is: "yes." But what other conclusions may be drawn?

Conclusions

The conclusions offered in this paper are qualified with the understanding that this treatment has been a review of the current state of an *evolving technology*. It is not difficult to draw a parallel between the evolution of the EDR and that of the personal computer; moving first slowly from the "CPM" machine era into the 8088 processor then more quickly through the 80286 to 80486 generations.

In that light, one might consider the application of the EDR capabilities to the SDM - and to a certain extent the SDM itself - as moving now into the "early Pentium" stages of evolution: it's good and it has the potential for getting far better. Efforts to date suggest that it has the potential to evolve to the point where all or most of the NHTSA Working Group's[32] "Data Elements" would be included in future models found in ground transportation fleets.

In total, there are 74 data elements listed in the Working Group's report; an ambitious list with one recurring theme: improving traffic safety efforts on a larger scale. While the system does not yet include all of the elements found in the NHTSA Working Group's "Top Ten" list of desired data elements, the GM EDR and the GM "On Star" system effectively address half of those elements in one way or another.

The list was clearly prepared with the idea in mind that there are several end users of this data whether private or public entities. Each of these entities would be able to use some or all of the collected data from crashes to improve their traffic safety efforts. For example, highway engineers could use the data to evaluate roadside furniture including poles and guard rails to evaluate their effect in real world crashes. Collision reconstructionists can use the data to (re)evaluate techniques or a given analysis and compare the data with traditional methods of collision analysis.

The EDR will not; however, be a replacement for the collision investigator nor the reconstructionist but will, over time, become an integral part of the analytical process, particularly as EDRs find more widespread use. This may be best explained using the Haddon Matrix..

Earlier in this paper, Table 1 was a representation of the typical Haddon Matrix using traditional collision reconstruction techniques and methodologies. With a better understanding of the capabilities of the EDR, Table 3, is that same matrix offered with the added benefit of the information from EDR data points which are *currently available* (**in bold**), to the exclusion of that would potentially become available in later versions or generations of EDRs. One can easily see that the EDR and related systems (for example, the GM "On Star" feature) potentially effect every cell in the Haddon Matrix. It is just as easy to see that this technology will have the similar potential to touch every aspect of traffic safety efforts which would flow from understanding collisions more throughly in an effort to identify and then find solutions to traffic safety problems.

If we look to the history of the FDR and CDR, concerns over ownership of the data and privacy will be solved just as they were in the aviation experience. The issue of physically accessing and interpreting EDR data from the various systems which may evolve over time is potentially a larger concern given both the litigious propensities of American society and the demonstrated delays to this point getting manufacturers beyond General Motors to even admit to the existence of this data not to mention provide keys to the interpretation of the stored digital data itself.

If we are to agree that to better address *all three* "Es" of traffic safety, one needs to better understand the entire collision event as it relates to all three components: the Human, the Vehicle and the Environment, then from that perspective, one easily sees not only the rationale but the overwhelming justification for the installation of EDR capabilities as they relate to both passive and active approaches to traffic safety - assuming the EDR data may be relied on.

The "data reliability" concern has been addressed herein using the example of the crash tests conducted with EDR equipped cars and the comparison of that data to independent accelerometers. The observation, across this broad range of crash tests, is that the variance between total accelerometer integrated delta-V data and total reported EDR delta-V data is insignificant. That conclusion is clearly supported by the empirical results themselves.

When the accelerometer data used to calculate the control delta-V and for that comparison is narrowed to examine the same time period as addressed by the EDR, the EDR tends to under report by a very small margin. Using a term familiar to those who study accelerometers: such little difference is effectively "lost in the noise."

Even when collisions are observed off the longitudinal axis of the EDR equipped vehicle, the "observed delta-V" at the EDR may be relied upon providing the collision analyst adequately addresses the effect of this off-axis PDOF. That observation also reinforces the point that the EDR will no more replace the collision investigator or reconstructionist than the FDR and CVR have replaced aviation crash investigators or the Safety Board which analyzes and reviews those crashes.

The only reasonable conclusion supported by the empirical evidence is that the data from the EDR is *accurate* to a level of *precision* necessary for the suggested analysis and uses and that it *may be relied* on for the intended end users and purposes.

The EDR is **E**volving, and the **D**ata is **R**eliable.

As traffic safety professionals work to define where to most effectively put the focus of their efforts - to determine which of the three "E's" needs the most attention in for a given problem - we need to better understand, objectively, "real world" crashes to identify the problem(s) in the first place. Because it helps to accurately and reliably define problems so solutions may be sought, the emerging EDR technology has and will continue to play a major role in traffic safety in the future.

	Human	**Vehicle**	**Environment**
Pre-Crash	**5 seconds of objective pre-crash data - especially braking, speed and accelerator application - supplement** the *subjective* recollections by parties/witnesses as to observations and actions	**The status of certain parameters related to the air bag system including errors and warning messages are recorded**	**5 seconds of objective pre-crash data - especially braking and accelerator application - supplement and enhance** the post-crash roadway evidence evaluation
Crash	**Notification of authorities by way of the GM "On Star" system that a crash has occurred enables the activation of the EMS system more quickly**	**Actual crash pulse in the form of delta-V and time will be available for comparison to traditional** post-crash vehicle deformation analysis to suggest generalized crash parameters	**Actual crash location may be established through the GM "On Star" system**
Post-Crash	**Driver's belt circuit status, air bag deployment and seat belt pre-tensioner command times would supplement** post-crash evaluation of the injuries to better indicate occupant position, motion & restraint use	**Collected delta-V data can be compared to traditional methods such as** post-crash vehicle deformation to better understand suggest general crash parameters	Post-crash roadway evidence is inspected, documented and analyzed after the crash **which may be used with EDR data by the reconstructionist to more fully understand the event**

Table 3 - The "Haddon Matrix" with the benefit of EDR data

References

1. **Gladwell, Malcolm**, "Wrong Turn," *The New Yorker*, 11 June, 2001, 55.
2. **Graham, John**, "Auto Safety," Harvard School of Public Health, from Ibid., 60.
3. National Safety **Council (US), "Accident Facts" multiple annual editions, Itasca, Il., USA; see also** http://www.nsc.org
4. **Federal Office of Road Safety** (AU), "Road Fatalities Australia: 1996 Statistical Summary," Canberra, AU; see also www.dot.gov.au/programs/fors/stats/fatstats.htm
5. **National Safety Council** (US), "Accident Facts" 1997 edition, Itasca, Il., USA, 106
6. **Petrucelli, Elaine**, "The Abbreviated Injury Scale (AIS) - Ten Years of Progress," the Society of Automotive Engineers (SAE) 810212
7. **Association for the Advancement of Automotive Medicine**, "Abbreviated Injury Scale," 1990 Revision, Des Plaines, IL, 1990, 74
8. **Chan, Ching-Yao**, "Fundamentals of Crash Sensing in Automotive Air Bag Systems," The Society of Automotive Engineers, USA, 2000 p4-7
9. **Huelke, Donald**, "The Effects of Belt Use and Driver Characteristics on Injury Risk in Frontal Airbag Crashes," SAE 2001-01-0155
10. **Huelke**, SAE 2001-01-0155
11. **Chidester, A**. "Chip",et al, "Recording Automotive Crash Event Data," International Symposium on Transportation Recorders, Arlington, VA, 1999; see also www.ntsb.gov/events/symp_rec/proceedings/authors/chidester.htm
12. **National Highway Transportation Safety Administration**, "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," Final Report, 2001; see also: www-nrd.nhtsa.dot.gov/pdf/nrd-10/EDR/WkGrp0801.pdf
13. **Lenmann, G.**, "The Features of the Accident Data Recorder and its Contribution to Road Safety," VDO Kienzle GmbH, International Technical Conference on Enhanced Safety Vehicles, 15th Proceedings, Volume 2, Washington, DC, 1996,

NHTSA Report No. 96-S9-W34, UMTRI-91246 A54

14. **National Highway Transportation Safety Administration**, "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," 18

15. **National Highway Transportation Safety Administration,** "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," 18, 67-68

16. **National Highway Transportation Safety Administration,** "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," 55

17. **National Highway Transportation Safety Administration,** "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," 52-56

18. **Grush, Ernie**, "Research Opportunities with Automotive Crash Recorders," presentation at the conference "Transportation Safety and the Law, Proprietary Information, Employee Privacy And Criminal Inquiries" sponsored by NTSB, April, 2000; see also: www.ntsb.gov/events/2000/symp_legal/

19. **Bauer, Horst**, ed. "Automotive Handbook;" 4th Ed; (Stuttgart: Robert Bosch GmbH, 1996), 754

20. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

21. **Alan Morris**, Dr. Eng., P.E.; "Slide Rule Accuracy vs Precision," offered by the author, marked as version 1/30/00

22. **Morris**, "Slide Rule Accuracy vs Precision"

23. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

24. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

25. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

26. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

27. **Chan, Ching-Yao**, "Fundamentals of Crash Sensing in Automotive Air Bag Systems," Ch 6

28. **Gioutsos, T.**, "A Predictive based Algorithm for Actuation of An Airbag," the Society of Automotive Engineers (SAE) 920479

29. **The Society of Automotive Engineers,** "The Effects of Front-mounted Accessories on Air Bag Sensors and Crashworthiness," Surface Vehicle information report J2431, 1997

30. **Chidester, A. "Chip"**, "Recording Automotive Crash Event Data"

31. **Gioutsos, T.**, "A Predictive based Algorithm for Actuation of An Airbag," the Society of Automotive Engineers (SAE) 920479

32. **National Highway Transportation Safety Administration,** "Event Data Recorders - Summary of Findings by the NHTSA EDR Working Group," p40

Appendix A

Vehicles used for crash testing

Vehicles used in the tests conducted and addressed herein were obtained through several sources in the US and Canada and were selected largely at random to reflect a cross section of those late model EDR equipped vehicles found on the road in private use. Actual vehicle sources include Const. Brad Muir and the Ontario Provincial Police (OPP), Ontario, Canada, Lt Bill Brandt and the Michigan State Police, Sgt Ricky Dixon and the South Carolina Highway Patrol and The South Carolina Association of Reconstruction Specialists, Mr Gerry Murphy of the International Association of Accident Reconstruction Specialists, Dr Art Croft of the Spine Research Institute of San Diego, Deputy Greg Russell and the Ann Arundle (MD) County Police, Mr Bill Davies of GM, Canada and through the enormous good will, time, energy and support of Mr Don Floyd of General Motors, USA.

1996 Chevrolet Cavalier
1997 Pontiac Transport
1998 Oldsmobile Eighty-eight
1999 Chevrolet Cavalier

1999 Buick Regal
1999 Buick Century
2000 Buick Century
2000 Chevrolet Impala
2000 GMC Sierra
2000 Pontiac Venture
2001 Cadillac Seville
2001 Oldsmobile Aurora

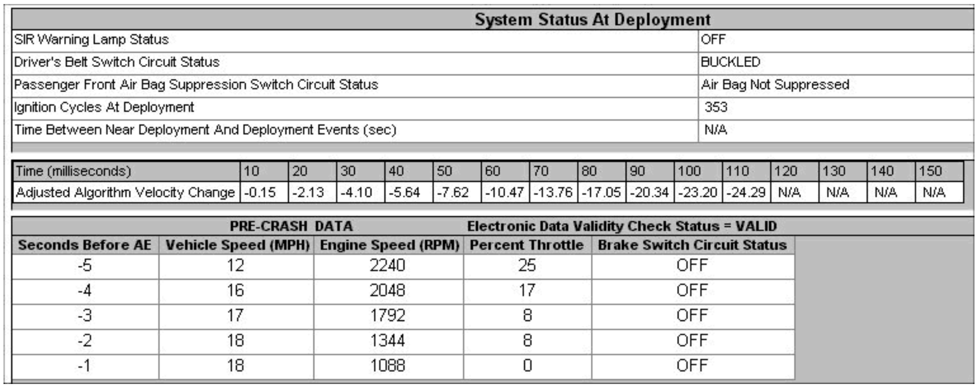
Appendix B

Equipment used for data collection

To simply "slam a couple cars together" would achieve nothing. To demonstrate the actual effect of a car-to-car crash test and to analyze the developing acceleration wave form of the crash tests conducted and then download and interpret the data stored in the EDR requires the use of external equipment. While other equipment from video cameras to measuring equipment, infrared timers to high frequency radar were used in various aspects of the tests conducted, the two primary tools employed were the Vetronix Crash Data Retrieval (CDR) Tool Kit and the Instrumented Sensor Technology (IST) EDR3c accelerometer.

For General Motors SDM EDR equipped vehicles, interface through the car's standard Diagnostic Link Connector (DLC) or directly to the SDM itself may only be accomplished using the Vetronix Crash Data Retrieval (CDR) tool and accompanying software. GM has licensed the software access to the EDR's stored data to Vetronix, a manufacturer of other vehicle interface devices (typically used in service functions). Vetronix has developed and built the actual CDR interface module which connects a standard PC with the SDM through the car's DLC or directly to the SDM itself. For more product information, Vetronix may be contacted at 2030 Alameda Padre Serra, Santa Barbara, CA USA, 93103 +01.805.965.3497 or on the web at www.vetronix.com. Selected sample graphics from the CDR output report for the data retrieved from test CRSH14 are shown as Figures B1and B2.

The control standard selected for comparison with the in-vehicle SDM EDR was the Instrumented Sensor Technology (IST) EDR3c. The EDR3c instrument is a stand-alone data recorder with a built in power supply for a piezoresistive triaxial accelerometer and 4mb memory for storing data. For the series of tests described, the EDR3c was set to record at a sample rate of 1024Hz and the captured data filtered using a standard Butterworth filter protocol with a low pass cut off frequency of 100 Hz through the IST DynaMax software. A typical crash pulse is shown as Figure B3 which is from test CRSH14 in the series.Instrumented Sensor Technology is an international supplier of stand alone event data recorders and accelerometers and may be contacted at 4704 Moore St, Okemos, MI USA 48864 +01.517.349.8487 or on the web at www.isthq.com



System Status At Deployment	
SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Passenger Front Air Bag Suppression Switch Circuit Status	Air Bag Not Suppressed
Ignition Cycles At Deployment	353
Time Between Near Deployment And Deployment Events (sec)	N/A

Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Adjusted Algorithm Velocity Change	-0.15	-2.13	-4.10	-5.64	-7.62	-10.47	-13.76	-17.05	-20.34	-23.20	-24.29	N/A	N/A	N/A	N/A

PRE-CRASH DATA Electronic Data Validity Check Status = VALID

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	12	2240	25	OFF
-4	16	2048	17	OFF
-3	17	1792	8	OFF
-2	18	1344	8	OFF
-1	18	1088	0	OFF

Figure B1

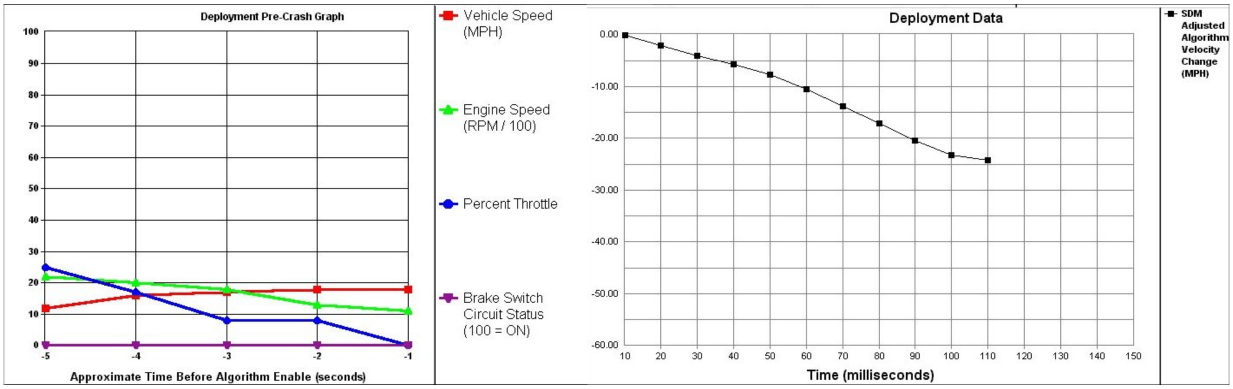


Figure B2

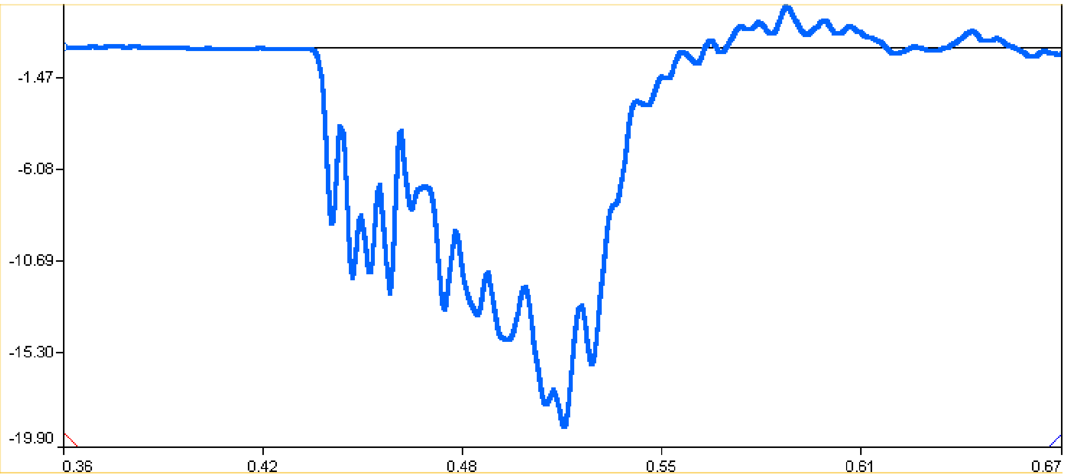


Figure B3 The graph x axis is time (s) and the vertical (y) axis is acceleration (g).

Appendix C
SDM and ISTEDR3c Data (imperial units)

Test ID	Vehicle	SDM reported ΔV - mph	IST ΔV total - mph	Delta-V difference	SDM Δt - sec	IST ΔV adjusted to SDM time	Delta-V difference
OPPA T7	Venture	-8.47	-9.99	-1.52	0.06	-8.05	0.42
OPPA T9	Venture	-10.49	-14.62	-4.13	0.10	-11.55	-1.06
OPPA T11	Sierra	-4.55	-4.98	-0.43	0.06	-3.96	0.59
OPPA T14	Sierra	-6.47	-6.89	-0.42	0.05	-5.65	0.82
OPPA T16	Sierra	-11.39	-12.74	-1.35	0.09	-11.52	-0.13
OPPA T16a	Sierra	-15.12	-15.92	-0.80	0.10	-15.60	-0.48
OPPA T17 - b	Seville	-19.75	-19.91	-0.16	0.10	-19.81	-0.06
OPPA T17 - t	Transport	-21.06	-22.14	-1.08	0.09	-21.36	-0.30
MSP T2x	Cavalier	-6.36	-6.50	-0.14	0.10	-6.50	-0.14
MSP T3 - b	Cavalier	-3.07	-3.60	-0.53	0.06	-2.30	0.77
MSP T3 - t	Cavalier	-3.50	-3.60	-0.10	0.07	-2.88	0.62
MSP T4 - b	Cavalier	-6.80	-6.44	0.36	0.10	-6.44	0.37
MSP T5 - b	Cavalier	-15.14	-15.21	-0.07	0.10	-15.20	-0.06
MSP T5 - t	Cavalier	-16.02	-16.17	-0.15	0.11	-16.03	-0.01
SCARS T1	88	-3.29	-3.38	-0.09	0.08	-3.38	-0.09
SCARS T2	88	-15.58	-16.59	-1.01	0.10	-16.36	-0.78
SCARS T3	Impala	-3.71	-4.53	-0.82	0.07	-2.96	0.75
SCARS T4	Impala	-3.46	-3.80	-0.34	0.07	-3.10	0.36
SCARS T5	Impala	-17.67	-19.35	-1.68	0.11	-17.00	0.67
IAARS PA - t	Century	-0.95	-1.26	-0.31	0.03	-0.18	0.77
IAARS PB - b	Century	-1.84	-2.55	-0.71	0.04	-0.59	1.25
IAARS T1 - b	Regal	-5.13	-6.35	-1.22	0.07	-5.22	-0.09
IAARS T2 - b	Regal	-1.03	-2.77	-1.74	0.19	-2.76	-1.73
IAARS T3x	Century	-1.33	-5.56	-4.23	0.03	-0.95	0.38
IAARS T4	Century	-2.42	-3.54	-1.12	0.03	-3.15	-0.73
IAARS T5	Regal	-15.99	-17.53	-1.54	0.12	-15.99	0.00
IAARS T5a	Regal	-16.09	-17.19	-1.10	0.12	-15.99	0.10
OPPT T1 - b	Aurora-2	-1.88	-3.43	-1.55	0.09	-2.88	-1.00
OPPT T1 - t	Aurora-1	-2.50	-3.77	-1.27	0.09	-3.47	-0.97
OPPT T2 - b	Aurora-2	-3.04	-5.49	-2.45	0.09	-3.11	-0.07
OPPT T2 - t	Aurora-1	-3.70	-5.37	-1.67	0.11	-4.14	-0.44
OPPT T4	Aurora-2	-4.00	-5.33	-1.33	0.08	-5.07	-1.07
OPPT T7	Aurora-2	-15.62	-19.79	-4.18	0.11	-16.66	-1.04
CRSH T10	Cavalier	-3.07	-3.75	-0.68	0.07	-2.40	0.67
CRSH T12	Cavalier	-5.49	-6.85	-1.36	0.08	-5.00	0.48
CRSH T14-b	Impala	-24.49	-24.27	0.22	0.11	-24.04	0.45
			Average difference:	***-1.130***		average:	***-0.022***
			Standard deviation of unadjusted difference, all:	***1.114***		time adjusted std deviation:	***0.680***
			Average difference, deployments only:	***-1.217***		Ave, time adjusted deployments:	***-0.247***
			Standard deviation of unadjusted difference, deployments:	***1.423***		Std deviation, time adjusted deployments:	***0.534***

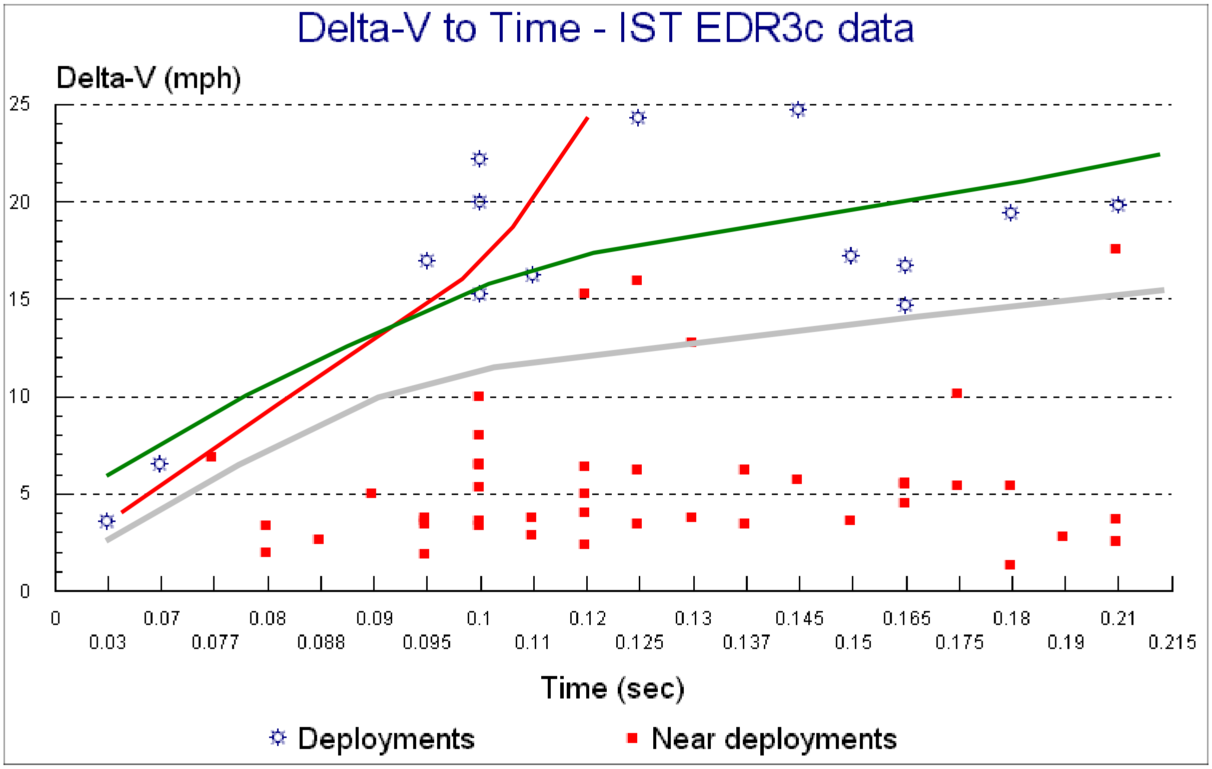


Figure 1 - larger view

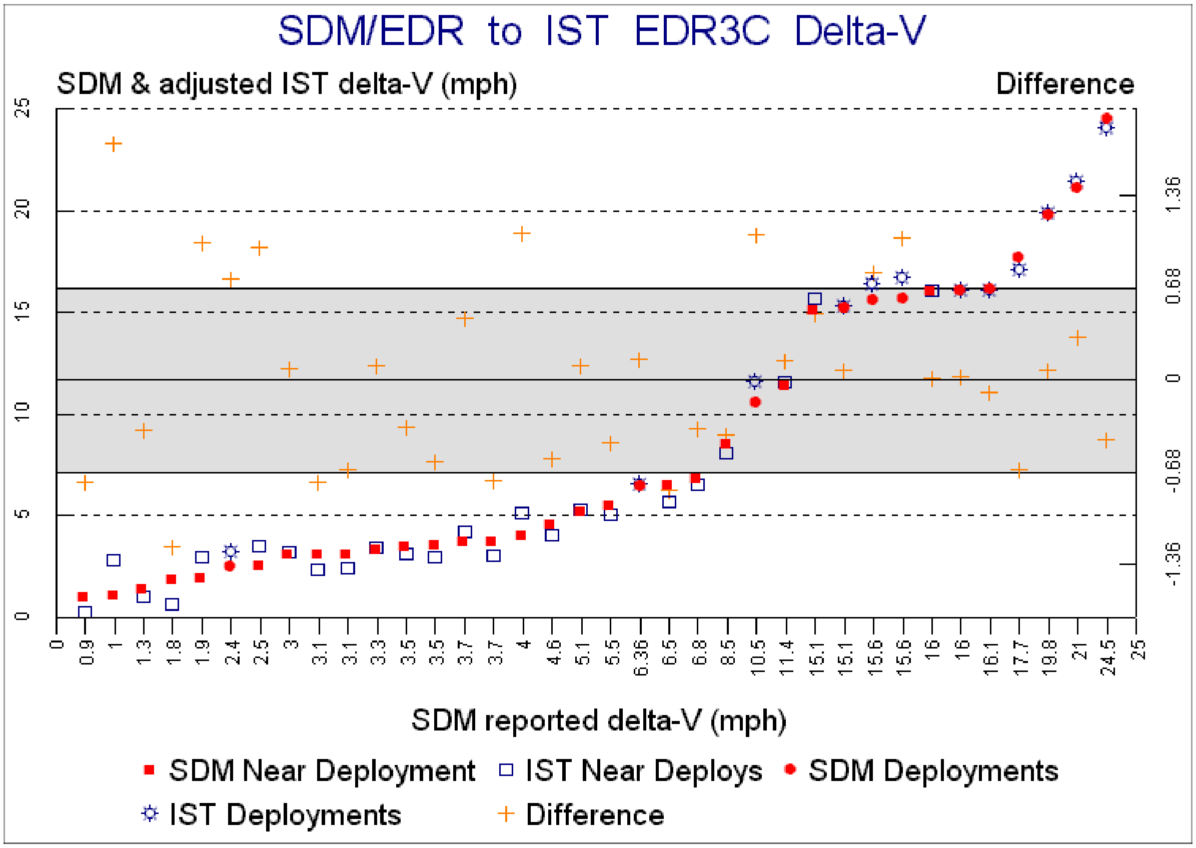


Figure 2 - larger view