

# Crash Severity: A Comparison of Event Data Recorder Measurements with Accident Reconstruction Estimates

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## ABSTRACT

The primary description of crash severity in most accident databases is vehicle delta-V. Delta-V has been traditionally estimated through accident reconstruction techniques using computer codes, e.g. Crash3 and WinSmash. Unfortunately, delta-V is notoriously difficult to estimate in many types of collisions including sideswipes, collisions with narrow objects, angled side impacts, and rollovers. Indeed, approximately 40% of all delta-V estimates for inspected vehicles in the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) 2001 are reported as unknown.

The Event Data Recorders (EDRs), now being installed as standard equipment by several automakers, have the potential to provide an independent measurement of crash severity which avoids many of the difficulties of accident reconstruction techniques. This paper evaluates the feasibility of replacing delta-V estimates from accident reconstruction with the delta-V recorded by EDRs. The analysis is based on over 500 NASS/CDS cases from 2000 - 2002 which have corresponding EDR datasets. The potential of extracting manual belt use from EDRs is also discussed and compared with the corresponding results from NASS gathered by accident investigators. Although EDRs can greatly enhance the investigation of a crash, the study finds that current EDRs are not perfect. The paper discusses the limitations of current EDR technology and the opportunities for enhancement of future Event Data Recorders.

## INTRODUCTION

The vehicle resultant change in velocity, commonly referred to as simply resultant delta-V, is the primary description of crash severity in most crash databases. For the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) database,

the National Highway Traffic Safety Administration (NHTSA) estimates both longitudinal and lateral delta-V from detailed measurements of vehicle deformation using a computer code such as WinSmash [Stucki et al, 1998]. WinSmash and similar codes, e.g. Crash3 [NHTSA, 1982], are most accurate for frontal crashes with full frontal engagement. As crashes deviate from this ideal configuration, the estimates become increasingly less accurate [O'Neill et al, 1996; Stucki et al, 1998]. Delta-V for some crash configurations is notoriously difficult to estimate. These configurations include sideswipe, collisions with narrow objects, e.g. poles and trees, angled side impacts, and rollover. Reflecting this difficulty, approximately 40% of all delta-V estimates for inspected vehicles in NASS/CDS 2001 are reported as unknown.

The Event Data Recorders (EDRs), now being installed as standard equipment by several automakers, have the potential to provide an independent measurement of crash severity which avoids many of the difficulties of accident reconstruction techniques. For vehicles equipped with an EDR, sensors on the vehicle itself provide a direct measurement of vehicle velocity versus time – and hence delta-V. The General Motors (GM) EDR for example measures longitudinal change in velocity vs. time. Other automakers record both longitudinal and lateral acceleration vs. time. An earlier study of WinSmash vs. EDR data showed that an EDR-generated delta-V is available for many of the cases in which the WinSmash-generated delta-V was listed as unknown [Gabler et al, 2003].

## OBJECTIVE

The objective of this paper is to evaluate the potential to supplement and possibly replace WinSmash-estimated delta-Vs with the delta-V recorded in EDRs. The paper will examine those NASS/CDS cases from 2000 - 2002 for which there are corresponding EDR datasets.

## DESCRIPTION OF THE ROWAN UNIVERSITY EDR DATABASE

NHTSA has collected EDR records from several hundred crashes investigated as part of NHTSA NASS/CDS investigations. NASS/CDS is a national sample of 4,000 to 5,000 crashes investigated each year by NHTSA at 27 locations throughout the United States. To date, the majority of cases in NASS/CDS involving EDR data are GM vehicles. At the time of this study, GM and Ford Motor Company were the only automakers that had publicly released the format of their EDRs. In addition, both GM and Ford had signed agreements with the Vetronix Corporation to produce a Crash Data Retrieval System capable of downloading, decoding, and displaying the data recorded in GM and selected Ford EDRs.

As the majority of NASS/CDS cases with EDRs are currently from GM, the analysis which follows will focus exclusively on GM vehicles. As shown in Table 1, NASS/CDS teams from 2000-2002 successfully collected EDR data from 527 GM vehicles involved in traffic crashes.

**Table 1. Contents of the Rowan University EDR Database by Source**

Source	Total Number of Cases
NASS/CDS 2000	21
NASS/CDS 2001	192
NASS/CDS 2002	314
Total	527

To analyze this dataset, Rowan University developed a database of the NHTSA EDR cases collected from NASS/CDS 2000-2002. The cases extracted from this database and used in this analysis included only crashes in which an EDR had been successfully downloaded and matched with a corresponding NASS/CDS case [Gabler et al, 2002].

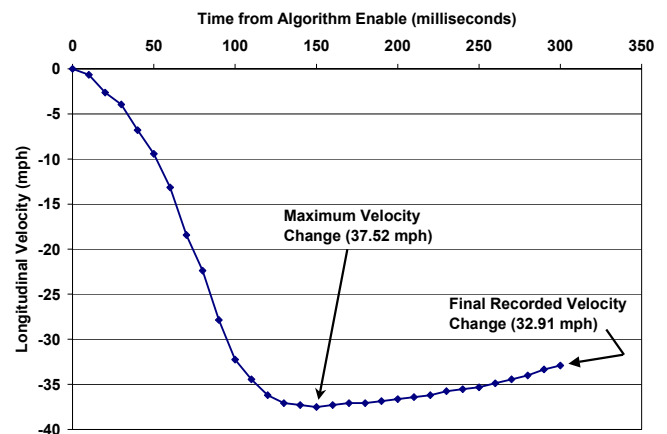
## DESCRIPTION OF THE GM EDR CASES

GM EDRs have the capability to store a description of both the crash and the pre-crash phase of a traffic collision. Crash event parameters include longitudinal change in velocity vs. time during the impact, air bag trigger times, and seat belt status. Later versions of the GM EDR also store 5 seconds of precrash data including a record of vehicle speed, engine throttle position, engine revolutions per minute and brake. Since their introduction in the early 1990's, GM has continuously improved their EDR design. This has been

both a boon and a challenge to researchers who seek to compare the crash performance of vehicles equipped with different generations of the GM EDR. The two most common GM EDRs in the Rowan EDR database are the SDM-R and the SDM-G modules. GM has released several variants of these two modules.

## COMPUTING EDR DELTA-V

Arguably, the most valuable data element stored in an EDR is the delta-V versus time history of the vehicle during the crash. In GM EDRs, the change in longitudinal velocity is recorded every ten milliseconds for up to 300 milliseconds in the older SDM-R design and up to 150 milliseconds in newer EDR designs, e.g. the SDM-G. GM EDRs do not begin to record delta-V until the vehicle experiences sufficient acceleration to wakeup the air bag deployment algorithm, sometimes referred to as 'algorithm enable'. Change in lateral velocity is not recorded.



**Figure 1. EDR record of Longitudinal Change in Velocity vs. Time for a 1999 Pontiac Grand Am involved in a frontal collision with another vehicle**

Figure 1 shows the longitudinal change in velocity vs. time recorded by an EDR in a 1999 GM Pontiac Grand Am involved in a frontal collision with another vehicle. For this paper, the EDR delta-V was obtained for each case by finding the maximum change in velocity as shown in Figure 1. WinSmash and similar computer codes assume fully plastic deformation, i.e. the vehicles do not separate or rebound [Stucki et al, 1998]. In reality, most collisions also involve a rebound phase in which some of the crash energy is restored as kinetic energy. WinSmash and similar computer codes make the assumption that the rebound velocity is small compared with the overall delta-V and can be ignored. In contrast, the maximum EDR delta-V more accurately includes the entire change in longitudinal velocity including the rebound velocity.

## VALIDATION OF GM EDR DELTA-V

To validate the delta-V measurements of GM EDRs, NHTSA examined the performance of GM EDRs in staged frontal-barrier crash tests [Chidester et al, 2001].

In each test, NHTSA compared the delta-V vs. time measured by the EDR with the delta-V computed from accelerometers mounted in the occupant compartment of the vehicle. The study found that the EDR delta-V vs. time was comparable, but slightly lower than that measured by the crash test instrumentation. In an independent validation, Lawrence et al (2002) found that that, in non-deployment events, GM EDRs underestimated the true delta-V by 1-2 mph. In both studies, the underestimation of delta-V was due in part to the fact that GM EDRs do not begin to record delta-V until the vehicle experiences sufficient acceleration to wake up the air bag deployment algorithm.

### STORING MULTIPLE CRASH EVENTS

GM EDRs can store three types of events: a non-deployment event, a deployment event, and a deployment-level event. A non-deployment event is defined as a crash of too low a severity to warrant deploying the air bag. A deployment event is an impact in which the air bag was deployed. A deployment-level event is an impact of sufficient severity that the air bag would have been deployed if a previous event had not already deployed the air bag. GM EDRs can store up to two (2) events associated with a crash.

For NASS/CDS 2000-2002 cases, Table 2 lists the distribution of cases in the EDR database. As shown in Table 2, approximately one-half of the cases in the database were of sufficient severity to deploy the air bag. This paper will focus on EDR data from these deployment events only.

**Table 2. Non-Deployment vs. Deployment EDR Cases for NASS/CDS 2000-2002**

Source	Total
Non Deployment Events Only	254
Case with both Non Deployment + Deployment Events	182
Cases with both Deployment + Deployment-Level Events	12
Deployment Events Only	79
Total	527

### AVAILABILITY OF EDR LONGITUDINAL DELTA-V

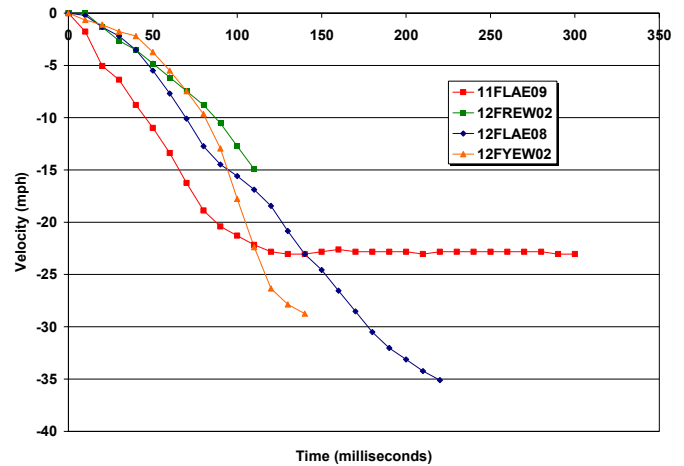
Table 3 shows that delta-V data were successfully recovered from EDRs in 98% of the deployment events. Delta-V was not recovered in only 5 of 273 air bag deployment cases.

**Table 3. Deployment Events: Availability of EDR Delta-V versus Time Data**

Type of Event	Cases with Delta-V vs. Time	Cases with Zero Delta-V vs. Time	Cases with Missing Delta-V vs. Time	Total
Deployment Only	79	-	-	79
Deployment + Non Deployment	177	4	1	182
Deployment + Deployment -Level	12	-	-	12
Total	269	4	1	273

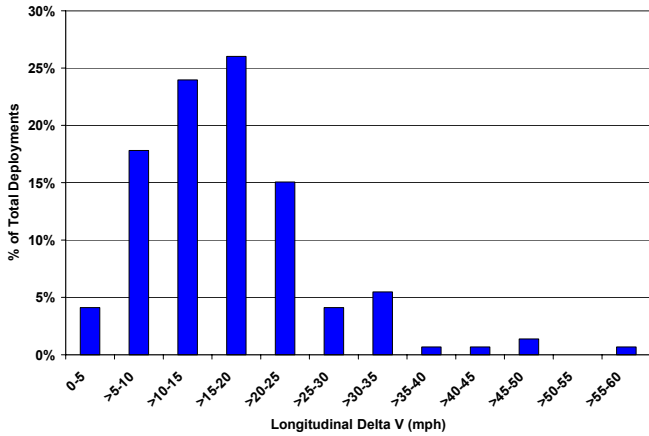
In GM EDRs, the change in longitudinal velocity is recorded every ten milliseconds for up to 300 milliseconds in the older SDM-R design and up to 150 milliseconds in newer EDR designs, e.g. the SDM-G. For deployment events, the SDM-G may not record the full 150 ms of delta-V vs. time: the SDM-G will record for only 100 milliseconds after the air bag is deployed and up to 50 milliseconds before the air bag is deployed.

As illustrated for four selected EDR cases in Figure 2, this may be an insufficient amount of time to completely record the event. In one of the cases (CDC=11FLAE9), the vehicle reaches a constant velocity at about 125 ms after impact signaling that the crash event is over. Note however that in the other three cases velocity is still decreasing at the point when the EDR stopped recording. In these cases, the EDR does not provide a correct final delta-V.



**Figure 2. The Effect of Recording Time for four selected GM EDR cases**

Figure 3 shows the distribution of longitudinal delta-V for deployment events with complete delta-V vs. time data.



**Figure 3. Deployment Events: Distribution of EDR Longitudinal Delta-V (NASS/CDS 2000-2002)**

**RESULTS**

The following section explores the use of EDR data as an improved method of collecting data in crash reconstruction. Specifically, this section discusses (1) the feasibility of obtaining delta-V estimates in crashes where a WinSmash estimate was not available, (2) a comparison of recorded EDR delta-V versus WinSmash delta-V estimates, and (3) a comparison of belt usage rate as obtained from crash investigators versus direct EDR measurement.

**CAN EDRS RECOVER UNKNOWN DELTA-VS?**

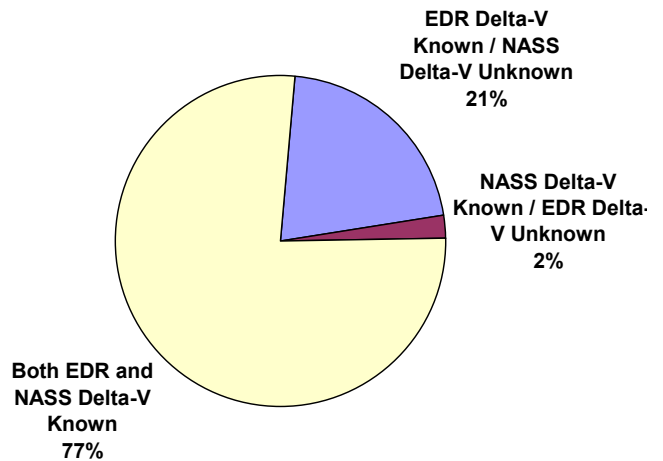
The following analysis evaluates the potential of EDRs to provide a measurement of delta-V in collisions for which a WinSmash estimate of delta-V was not possible. In NASS/CDS, these cases have delta-V coded as unknown. As shown in Figure 4 and tabulated in Table 4, EDR delta-V data were frequently available in crashes where a WinSmash delta-V estimate was not possible.

The analysis which follows excludes any EDR-equipped vehicles which NASS designated as having experienced multiple events. When a vehicle experiences multiple crash events, it can be difficult to identify which event was recorded by the EDR. In addition, only crashes severe enough to deploy the air bag are included. EDR cases meeting these criteria are hereafter referred to as single event deployment collisions. In single event deployment collisions, the single NASS/CDS event corresponding to the single EDR event can be identified without ambiguity. The EDR-recorded delta-V was compared with the NASS/CDS most harmful event delta-V. For single event deployment collisions, the most harmful event is also the event which deployed the air bag.

The NASS/CDS 2000-2002 dataset contains 146 single-event deployment collisions with EDR data. In 77% of the single-event deployment collisions, both the EDR and the WinSmash delta-V were available. In an additional 21% of the cases, a WinSmash estimate of delta-V could not be obtained, but the delta-V was recorded by the EDR. In 2% of the cases, a WinSmash estimate of delta-V was available for collisions in which the EDR failed to record non-zero delta-V versus time data.

**Table 4. EDR vs. WinSmash: Delta-V Availability in Single Event, Deployment Events**

		WinSmash		Total
		Delta-V estimate available	Delta-V estimate unavailable	
EDR	Known delta-V vs. time	112	31	143
	Zero delta-V vs. time	3	-	3
	Missing delta-V vs. time	-	-	-
Total		115	31	146

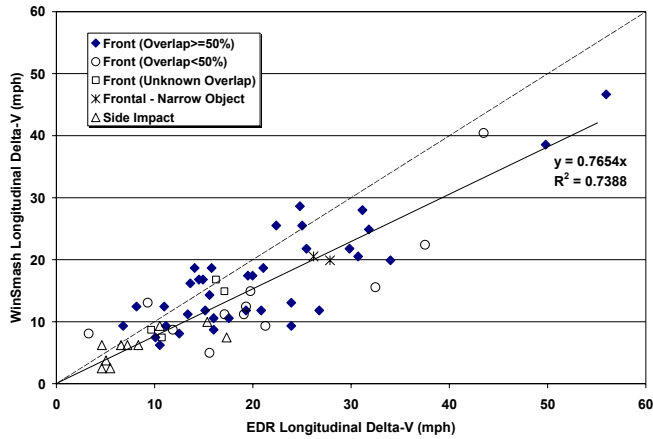


**Figure 4. EDR vs. NASS: Delta-V Availability in Single Event Deployment Collisions**

EDRs are clearly a promising means to determine delta-V for crashes in which crash severity is difficult to estimate using conventional methods. In all single-event collisions for which a WinSmash estimate of delta-V could not be obtained, and which were severe enough to deploy the air bag (31 of 146), an EDR delta-V estimate was available as an alternative measure.

**WINSMASH DELTA-V VERSUS EDR DELTA-V**

EDRs directly measure the acceleration of a vehicle from onboard sensors and have the potential to be a more accurate gauge of vehicle response to a crash than would an after-the-fact crash reconstruction. This section compares delta-V as directly measured by EDRs with delta-V as reconstructed using the WinSmash computer code. As before, the comparison is restricted to EDR-equipped vehicles subjected to single event deployment collisions. In addition, EDR cases in which the entire crash pulse was not completely recorded or was invalid were excluded from the analysis.



**Figure 5. Longitudinal Delta-V comparison for single event cases in which the air bag deployed (NASS 2000-2002)**

Of the NASS/CDS 2000-2002 cases, 65 single-event deployment cases had both a WinSmash-generated longitudinal delta-V and a corresponding EDR file with complete longitudinal delta-V versus time data. Figure 5 compares the delta-V estimated by WinSmash with the corresponding delta-V computed from EDR data for these 65 cases.

Symbols falling on the dashed line drawn diagonally across the plot are cases where the EDR and WinSmash delta-V perfectly matched. Different symbol types indicate the crash mode for each case. Symbols falling below the dashed line represent cases in which WinSmash underestimated delta-V. WinSmash underestimated delta-V for approximately 77% of the cases (50 of 65). A least squares curve fit to the data is shown as a solid line in the figure. Based on the least squares fit ( $R^2 = 0.7388$ ), WinSmash underestimated longitudinal delta-V by approximately 20%, on average, for these deployment cases. In two cases, WinSmash underestimated delta-V by over 60%. Based on this limited sample, no conclusions can be drawn for how this correlation varies by crash mode.

The findings from the preceding analysis have several important restrictions: (1) the analysis was based upon cases drawn from the Rowan EDR database. The Rowan EDR database is not a nationally representative sample of crashes, (2) the analysis is based entirely on

EDRs from a single automaker, (3) the correlation is based upon a limited number of cases.

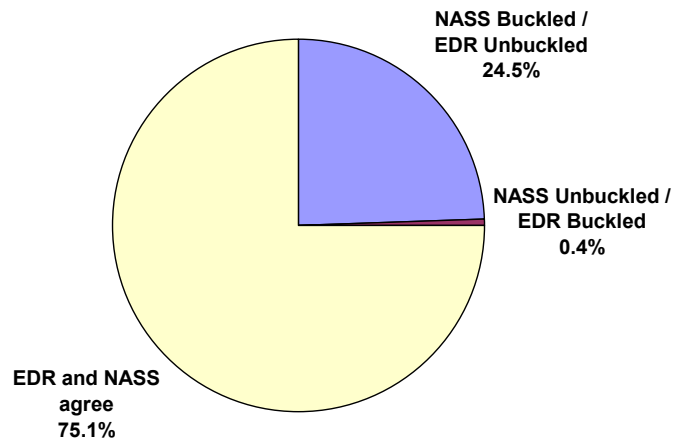
### DRIVER SEAT BELT BUCKLE STATUS

Seat belt use is one of the more important and controversial data elements collected by crash investigators. Driver seat belt use is typically collected by a combination of vehicle inspections and medical reports. In lower speed crashes, this physical evidence may be supplemented by interviewing the occupant. As GM EDRs record driver seat belt buckle status, EDRs have the potential to more accurately collect this crucial data element. It should be noted that seat belt use and seat belt buckle status may not be the same: in some cases, the belt may be buckled, but not actually worn by the occupant.

Table 5 compares NASS-reported driver belt usage with EDR-measured driver belt usage in deployment events.

**Table 5. NASS/CDS Seat Belt Usage vs. EDR Driver Seat Belt Buckle Status in Deployment Events**

		NASS		Total
		Buckled	Unbuckled	
EDR	Buckled	146	1	147
	Unbuckled	67	59	126
Total		213	60	273



**Figure 6. EDR vs. NASS - Driver Seat Belt Buckle Status when NASS/CDS Belt Usage is known in Deployment Events**

For deployment events, Figure 6 shows that the EDR and crash investigators agreed in 75% of all cases (146 buckled cases and 59 unbuckled cases). However, in approximately 25% of the cases (67 of 273 cases), NASS/CDS reported a buckled driver while the EDR reported an unbuckled driver. In one case, NASS/CDS reported the driver was unbuckled while the EDR recorded a buckled driver.

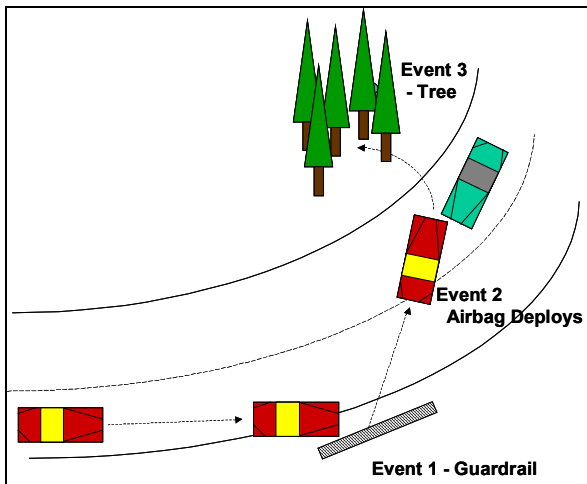
Figure 6 should not be interpreted as evidence that NASS/CDS belt usage rates are over-reported. Chidester et al (2001) have observed that some models of the GM SDM-G EDR may not always correctly record seat belt buckle status. Their study presented definitive physical evidence showing the seat belt was buckled in real-world crashes in which the SDM-G reported that the belt was unbuckled. In some models of the SDM-G, the recorded seat belt buckle status may be incorrect due to crash damage to either the seat belt buckle sensor or the connection between the seat belt buckle sensor and the EDR.

## LIMITATIONS OF EDRS

EDRs directly measure the acceleration of a vehicle from onboard sensors and have the potential to provide a better measure of delta-V than an after-the-fact crash reconstruction. Although EDRs are expected to greatly enhance the reconstruction of a crash, current EDRs are not perfect. In our study, we noted a number of limitations of the current EDR devices in the fleet.

### 1. THE PROBLEM OF MULTIPLE EVENTS

A crash is frequently characterized by multiple events. For example as shown in Figure 7, a car may first inadvertently leave the road and glance off a guard-rail – the first event, careen into the path of an oncoming car – the second event, and finally strike a tree on the opposite side of the highway – the third event.

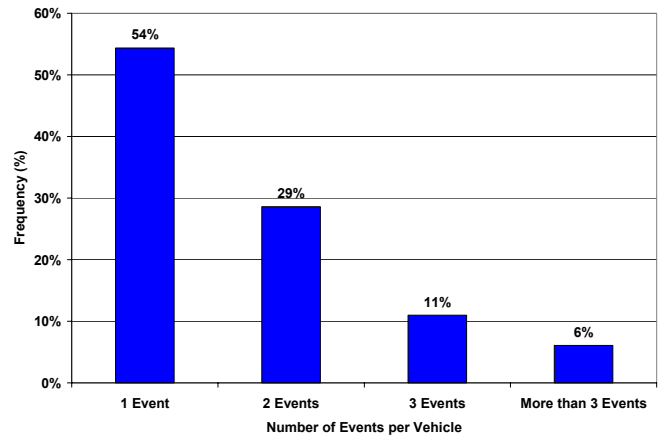


**Figure 7. Current EDRs may not capture all events in a crash.**

Most current EDRs are not equipped to record all the events that may occur in a crash. The GM EDRs analyzed in this study were capable of capturing two events: a non-deployment event and a deployment event. For some later GM EDR designs, a deployment level event, which occurs after bag deployment, can record over a non-deployment event. However, even these newer GM devices can only capture two events. Some automakers' EDRs are only capable of capturing a single event. As the typical event captured is the

event that deployed the air bag, any subsequent events may not be recorded even if these events are more harmful.

Figure 8 presents the distribution of events per vehicle for the 2000-2002 NASS/CDS cases with a successful EDR download. 46% of the EDR cases involved two or more events. In 17% of the cases, the vehicle was involved in three or more events. As GM EDRs can only store a maximum of two events, it is likely that potential EDR data were "lost" from one or more events in these crashes.



**Figure 8. Events per Vehicle for NASS/CDS 2000-2002 EDR Cases**

### 2. THE DIFFICULTY OF CORRELATING THE EDR EVENT WITH POST-CRASH INVESTIGATIONS

An additional challenge is determining which events, of the many events a vehicle was subjected to, were captured by the EDR. For example, Table 6 presents the case of a 2001 Chevrolet Monte Carlo along with the delta-V estimated for each of the 2 events to which the car was exposed. The first event is a narrow frontal impact to the rightmost 1/3 of the vehicle. The second event is an overlapping wide frontal impact to the center and right 2/3 of the vehicle. The front bumper was displaced rearward to just forward of the firewall. The delta-V measured by the EDR was 26 mph. For this case, it is unclear which event triggered the EDR or was recorded.

**Table 6. Example NASS/CDS case with Multiple Events**

Event	CDC	Estimated Delta-V
1	12FREN3	Unknown
2	12FZEW3	19 mph

As discussed earlier, 46% of the NASS/CDS cases examined were characterized by multiple events. The NASS/CDS database records the delta-V from the event judged by the crash investigator to be the most harmful and the event judged to be the second most harmful. In both cases, it can be very difficult to match the EDR delta-V with the correct NASS/CDS estimate of delta-V. To avoid this difficulty, the approach taken in this paper has been to only consider only vehicles that were exposed to a single event.

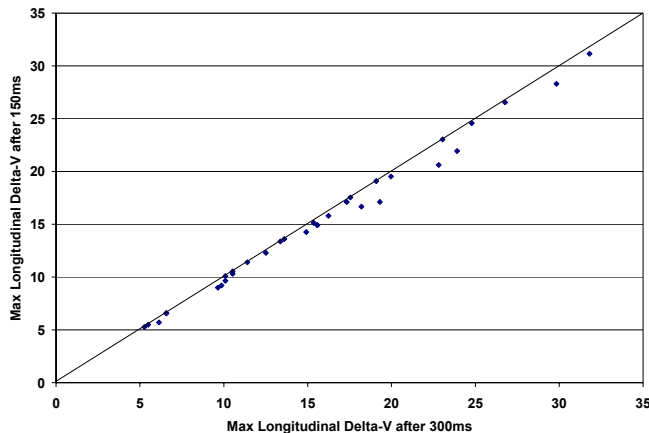
### 3. LIMITED RECORDING TIMES

NHTSA crash tests show that typical offset crashes may last longer than 150 milliseconds (ms). Table 7 shows the time duration for which current generation EDRs record crash pulse or velocity versus time.

**Table 7. EDR Recording Durations**

Recorder	Time Duration (milliseconds)
Typical Offset Crash Test	150+
GMC SDM-R (pre-2000)	300
GMC SDM-G (post-2000)	150

Note that the most recent GM EDR does not record for a sufficient time interval to fully capture an event as common as a frontal offset crash. EDRs from some automakers record for an even briefer period. These devices would consequently underestimate the delta-V for longer length crash events.



**Figure 9. Longitudinal Delta-V error for 150 ms vs. 300 ms recording interval: 300 ms cases from NASS/CDS 2000-2002**

To determine the extent to which EDRs did not correctly capture delta-V in the NASS/CDS 2000-2002 data set, those EDR cases, which had complete delta-V vs. time data of 300 ms in duration, were artificially clipped at 150 ms. Delta-V was first computed using the full 300

ms of data and then delta-V was recomputed using only the first 150 ms of data – the recording capacity of the newer GM EDR systems. As shown in Figure 9, a cross-plot of the two delta-V estimates indicates that while there is some error, it is not extensive. Twenty-seven percent (27%) of all cases had an error of 5% or more. However, only one case had an error which exceeded 10%. It should be noted however that 150 ms is the maximum recording duration for the SDM-G module: the SDM-G module only records for 100 ms after air bag deployment. Many of the SDM-G cases in the EDR database have recording durations shorter than 150 ms.

### 4. LIMITED CRASH SENSOR AXES

Crash pulse can only be measured along those axes for which there are active crash sensors. Hence in the GM cases investigated in this study, only the longitudinal delta-V versus time history corresponding to the frontal air bag sensor was available. Lateral delta-V is only anticipated to be available for those vehicles with side impact air bags. Rear impacts are not recorded, as these events are not relevant to frontal air bag deployment. Similarly, rollovers are not recorded as only a limited number of high-end cars have a rollover sensor.

### 5. LIMITED EVENT TRIGGERS

Current GM EDRs record only in the event of an air bag deployment or non-deployment. Presumably, the longitudinal accelerometer in these devices, which detects frontal crashes and deploys the air bag, also detects rear impacts. It would be useful if future EDRs could be designed to capture events such as rear impacts, which are detected by current sensors, but which do not necessarily deploy the air bag.

## CONCLUSIONS

The goal of this study was to examine the feasibility of using EDR data to support crash reconstruction. The analysis was based upon an EDR database, developed by Rowan University, which contains over 500 cases from 2000-2002 NASS/CDS in which EDR data were recovered during crash investigation. The cases are composed entirely of GM vehicles of model years 1996-2003. The conclusions below are based upon current GM EDRs, and may not be applicable to future GM EDR designs or to the EDR designs of other automakers.

Our conclusions are as follows:

- **WinSmash vs. EDR Delta-V.** Analysis of single event deployment collisions in which both a NASS/CDS delta-V and EDR change in velocity data were available suggests that WinSmash underestimates longitudinal delta-V by approximately 20% on average. This analysis was based upon GM vehicles equipped with EDRs which experienced a single impact severe enough to

deploy the air bag, and for which complete EDR change in longitudinal velocity data were available.

- **EDRs can Recover Unknown Delta-Vs.** GM EDRs have the potential to provide a delta-V for many of the NASS/CDS cases now listed as having an unknown delta-V. In every case for which a WinSmash estimate of delta-V could not be obtained and which was of sufficient severity to deploy the air bag, an EDR delta-V estimate was available as an alternative measure.
- **Seat Belt Buckle Status.** As GM EDRs record driver seat belt buckle status, EDRs have the potential to more accurately collect this crucial data element. In deployment events, the NASS-reported driver belt usage differed from the EDR-recorded driver belt buckle status in approximately one-fourth of crashes.
- **Limitations of EDR Data.** Although EDRs are expected to greatly enhance the investigation of a crash, current EDRs are by no means perfect. The limitations of current EDR technology include a) insufficient recording times to capture the entire event b) inability to capture multiple events, c) difficulty of correlating EDR events with the events recorded by crash investigators, and d) the lack of additional crash sensors to supplement the currently available longitudinal sensor.

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