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16. Abstract

In 2006 NHTSA published the event data recorder regulation, CFR 49, Part 563, that specifies uniform requirements for the accuracy, collection, storage, survivability, and retrieveability of onboard motor vehicle crash event data in passenger cars and other light vehicles equipped with EDRs. Part 563 (1) requires light-vehicle EDRs to record a minimum set of specified data elements; (2) standardizes the format of recorded data; (3) helps ensure crash survivability of EDRs and their data by requiring EDR to function during and after front and side vehicle crash tests specified in two Federal Motor Vehicle Safety Standards; and requires vehicle manufacturers to ensure commercial availability of the tools crash investigators need to retrieve EDR data.

NHTSA is now seeking information about the potential for upgrading the EDR requirements, and the potential availability of new EDR capabilities and data elements. This report describes a research program evaluating the current potential of EDRs, planned manufacturer upgrades to EDRs, and potential updates to EDR capabilities based on safety data needs. The evaluation includes assessment of EDR survivability needs and capabilities. The research focuses on light vehicles, i.e., cars, light trucks and multi-purpose vehicles, but also includes an assessment of heavy vehicles including truck-tractors, straight trucks, and buses (transit and motorcoaches).

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[1] In 2016, L3 Communications Holdings, Inc. changed its name to L3 Technologies, Inc., headquartered in New York City. On June 29, 2019, it merged with Harris Corporation to become L3Harris Technologies, Inc., headquartered in Melbourne, Florida.

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Acronyms and Abbreviations

ABS	antilock brake system
ACM	air bag control module
AK-LV	Arbeitskreis-Liefervorschrift [Working Group on Delivery Instructions]
ASTM	American Society for Testing and Materials
ATA	American Trucking Association
BoschNo	Bosch Number
CAN	controller area network
CCM	Counter Block Chaining-Message Authentication Code
CDR	crash data retrieval
CFR	Code of Federal Regulations
CIREN	Crash Injury Research and Engineering Network
CPI	Customer Price Index
CRC	cyclic redundancy checks
CV	commercial vehicle
CY	calendar year
DLC	data link connector
DSRC	dedicated short-range communication
ECM	engine control modules
ECU	electronic control units
EDR	event data recorder
EEPROM	electrically erasable programmable read-only memory
EMS	emergency medical service
ESC	electronic stability control
ESV	Enhanced Safety of Vehicles [conference]
EU	European Union
FARS	Fatality Analysis Reporting System
FDR	flight data recorder
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
FMV	for my vehicle
FRE	Final Regulatory Evaluation
FSR	front-side-rear
GA	general aviation
GAD	general area of damage
GIS	Geographic Information System
GM	General Motors
GVWR	gross vehicle weight rating
HV	heavy vehicle
HVEDR	heavy-vehicle event data recorder
ICF	Informed Consent Form
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
IVI	Intelligent Vehicle Initiative

L3ARD	L-3 Communications [brand] Aviation Recorders Division, now L3Harris Technologies, Inc.
LDR	lightweight data recorder
LTV	light trucks and vans
MAC	message authentication code
MAP	manifold absolute pressure
MIL	malfunction indicator lamp
MMMY	make model - model Year
MMUCC	Model Minimum Uniform Crash Criteria
MOU	Memorandum of Understanding
MY	model Year
NASS/CDS	National Automotive Sampling System/Crashworthiness Data System
NASS/GES	National Automotive Sampling System/General Estimates System
NCAP	New Car Assessment Program
NCHRP	National Cooperative Highway Research Program
NFI	Netherlands Forensic Institute
NIST	National Institute of Standards and Technology
NMVCCS	National Motor Vehicle Crash Causation Survey
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
OBD-II	Onboard Diagnostic-II
OEM	original equipment manufacturer
OTC	Owatonna Tool Company
Part 563	Title 49, Code of Federal Regulations, Part 563
PCB	printed circuit board
PCM	powertrain control module
RHS	right-hand side
RITA	Research and Innovative Technology Administration
ROS	rollover sensor
RP	recommended practice
SAE	Society of Automotive Engineers [since 2006 known as SAE International]
SCI	Special Crash Investigations
SHL	specific horizontal location
SIR	supplemental inflatable restraint
SRS	safety restraint system
TPMS	tire pressure monitoring system
UA	unintended acceleration
VCI	Vehicle Communication Interface
VDR	vehicle data recorder
VIN	Vehicle Identification Number

1. Introduction and Background

Widespread deployment of event data recorders promises a new and unique glimpse of the events that occur during a highway traffic collision. The EDR in a colliding vehicle can provide a comprehensive snapshot of the entire crash event – pre-crash, crash, and post-crash. By carefully collecting and analyzing the details provided by the growing number of EDR-equipped vehicles, the crash safety community has an unprecedented opportunity to understand the interaction of the vehicle-driver-roadway system as experienced in thousands of U.S. highway crashes each year.

EDRs are typically devices that are designed as original motor vehicle equipment for installation in light motor vehicles (generally as a component of the air bag control module) or in heavy-truck and bus engines (generally as a component of the engine control module). Light-vehicle EDRs are designed to capture a small amount of data (generally less than a dozen channels) for a short time (typically 5 seconds or less). Truck engine recorders can capture slightly more data. Despite the great safety potential of EDRs and the fact that more than 90 percent of the new light vehicles are now estimated to have EDRs in some form, use of the data from this new technology has been challenging because of a lack of standardization in data element definitions, the method of data retrievability, and the lack of an accepted storage format.

In August 2006, the National Highway Traffic Safety Administration published EDR regulation Title 49, Part 563 (49 CFR 563), which specifies uniform requirements for the accuracy, collection, storage, survivability, and retrievability of onboard motor vehicle crash event data in passenger cars and other light vehicles equipped with EDRs. Part 563 requires that the EDRs installed in light vehicles record a minimum set of specified data elements; standardizes the format in which those data are recorded; helps to ensure the crash survivability of an EDR and its data by requiring that the EDR function during and after the front and side vehicle crash tests specified in two Federal Motor Vehicle Safety Standards; and requires vehicle manufacturers to ensure the commercial availability of the tools necessary to enable crash investigators to retrieve data from EDRs.

On December 13, 2012, NHTSA published a Notice of Proposed Rulemaking on EDRs in the Federal Register (49 CFR Part 571). Under the proposed rule, most light vehicles would be required to have EDRs meeting the requirements in Part 563. NHTSA estimated that the majority (96%) of MY 2013 passenger cars and light-duty vehicles are already equipped with EDRs, and this rule would only affect a small percentage of light vehicles (NHTSA, 2012). A request for comments was open until February 11, 2013.

NHTSA is seeking information about the potential for upgrading the EDR requirements and the potential availability of new EDR capabilities and data elements. In addition, the NHTSA Rulemaking and Research Priority Plan (NHTSA, 2010) specified that NHTSA should investigate performance requirements for heavy-vehicle EDRs. This research study will inform the NHTSA's decisions on how future generations of EDRs might be regulated.

Objective

The objective of this program is to evaluate the current potential of EDRs, planned manufacturer upgrades to EDRs, and potential updates to EDR capabilities based on safety data needs. The evaluation will include an assessment of EDR survivability needs and capabilities. The research program will focus on both light vehicles e.g., (cars, light trucks and multi-purpose passenger vehicles), but also includes an assessment of heavy vehicles, including truck-tractors, straight trucks, and buses (i.e., transit and motorcoaches).

Approach

The specific tasks to be performed under this research program are as follows.

(1) Assessment of current light-vehicle (10,000 lbs. or less gross vehicle weight rating [GVWR]) EDR installations and performance

(2) Assessment of manufacturer-planned updates to light-vehicle (≤10,000 lbs. GVWR) EDR technologies

(3) Assessment of potential updates to light-vehicle (≤10,000 lbs. GVWR) EDR technologies

(4) Assessment, specifications and testing for survival hardening and tamper resistance

(5) Assessment of heavy-vehicle EDR technologies

2. Task 1 — Assessment of Current Light-Vehicle EDR Technology

Objective

The goal of this task was to assess the capabilities of pre-model year 2013 EDRs in light vehicles with GVWRs of 10,000 lbs. or less. Our specific objectives were as follows.

- Estimate the percentage of MY 2012 fleet installation of EDR technologies
- Develop a catalog of data elements in MY 2012 EDRs
- Assess progress of MY 2012 EDR installations toward meeting Part 563
- Determine the functionality of MY 2012 EDR models, including (1) types of events that trigger recording, (2) number and type of data elements, (3) duration and sample rate of pre-crash/event and crash/event recording, and (4) records of time and location of crash/event
- Assess data storage capacity of MY 2012 EDRs
- Identify strategies for capturing EDR data
- Identify data imaging strategies for reporting of MY 2012 EDR data

Approach

The task determined the capabilities of EDRs in two ways: (1) by evaluating the capabilities of MY 2012 EDRs extracted from crash tests conducted for NHTSA, and (2) by interviewing automaker and supplier EDR subject experts. The data from these two sources were used to develop a data element catalog of data elements in MY 2012 EDRs, assess the progress of MY 2012 EDRs toward meeting the requirements of Part 563, identify the data imaging strategies of each original equipment manufacturer, and evaluate commonly recorded data elements that exceed the requirements of Part 563. Each of these components of our approach is described more fully in the discussion below.

Assessment of Data Elements From EDRs in Crash Tests

After each of the MY 2012 NHTSA New Car Assessment Program crash tests, NHTSA directed the crash test laboratory to extract the EDR from the test vehicle and ship the ACM to the Virginia Tech research team for download. A total of 183 modules were received from the crash test laboratories during the project.

The research team downloaded all modules, which were supported by the Bosch Crash Data Retrieval system using Bosch CDR v.10.2. Using the Bosch tool, we were able to download modules from Chrysler, Ford, GM, Honda, Mazda, Toyota, and Volvo. When modules were not supported by the Bosch tool, the research team contacted several OEMs for assistance in downloading the module. With the help of the OEMs, we were able to obtain downloads from Suzuki, Mitsubishi, and Volvo EDRs. Later in the project after Bosch added support for reading

Volvo EDRs, we were able to download these same Volvo modules using the Bosch CDR tool process. Finally, the research team was able to obtain downloads of the Hyundai and Kia modules using a recently released public download tool from these automakers. Although the Hyundai/Kia readout device was marketed for download of MY 2013 and later modules, we were able to download many MY 2012 modules using this device.

Using these EDR downloads, the research team then developed a catalog of data elements in MY 2012 EDRs. The catalog includes a tabulation of data elements for these EDRs by automaker, duration, and rate at which elements (e.g., delta V) were recorded, and number of events (called databanks or triggers by some automakers). The number of events that can be recorded by each module is tabulated separately in this report.

Approach for Interviewing Automaker and Supplier EDR Subject Experts

The research team interviewed EDR subject experts within the light-vehicle OEM and supplier industry to determine the current capabilities of EDRs. The interviews addressed manufacturer approaches for capturing EDR data, e.g., collection from direct connection of sensors to the EDR versus collection of parameters from the controller area network bus. Also determined were automakers' perspectives on EDR survivability needs.

Our approach was to conduct structured interviews with light-vehicle OEMs and ACM suppliers using a common list of questions. The OEM survey questions and cover letter are provided in the appendices. EDR subject specialists at GM, Ford, Chrysler, Toyota, Nissan, Honda, and Hyundai/Kia were invited to participate in the interviews. Five OEMs (GM, Ford, Chrysler, Toyota, and Honda) accepted our invitation and were interviewed. A separate invitation and set of questions was developed for the ACM/EDR suppliers and sent to Autoliv, Bosch, Continental, Delphi, Denso, Takata, and TRW. The supplier survey questions and cover letter are provided in the appendices. Three ACM suppliers (Autoliv, Continental, and Delphi) accepted our invitation and were interviewed. The Virginia Tech Institutional Review Board informed us that no IRB application was necessary in order to conduct these interviews.

In our instructions to each OEM and supplier, we stated that the research team was conducting a study sponsored by NHTSA to assess the current and expected future capabilities of light-vehicle EDRs. The evaluation would include an assessment of EDR survivability needs and capabilities. We also informed each potential interviewee that NHTSA would use our study findings to support possible upgrades to Part 563. The charter for the study was only to gather facts, and we would not be making policy recommendations to NHTSA. We realized that many of the OEMs' or suppliers' planned updates or future upgrades were proprietary and agreed to honor the confidentiality requests of any of the OEMs or suppliers interviewed. The details of the discussions with each automaker would be kept confidential, but when de-identified and aggregated with observations from other manufacturers would allow us to assess general directions of future EDR generations.

Method for Analysis of MY 2012 EDR Elements

Using the Bosch tool, we were able to download modules from Chrysler, Ford, GM, Honda, Mazda, Toyota, and Volvo. Using the CDR tool, version 11.1, each EDR readable by the Bosch

CDR tool was downloaded with the cables specified by Bosch. Each EDR was then categorized into one of 16 EDR families identified by a “Bosch number.” The BoschNo is a designator found on the second line of the CDRx file when viewed in a text editor. An example is shown in Figure 1. Data elements for each vehicle were extracted from each Bosch CDR report and compared among vehicles of the same BoschNo. We were also able to separately obtain downloads of Hyundai, Kia, Mitsubishi, and Suzuki modules. These modules do not have Bosch numbers and were assigned the vehicle make as the family name. As an example, Suzuki modules were assigned a family name of “Suzuki.” Note that our dataset does not contain all EDR families for MY 2012 vehicles that were Bosch-readable.

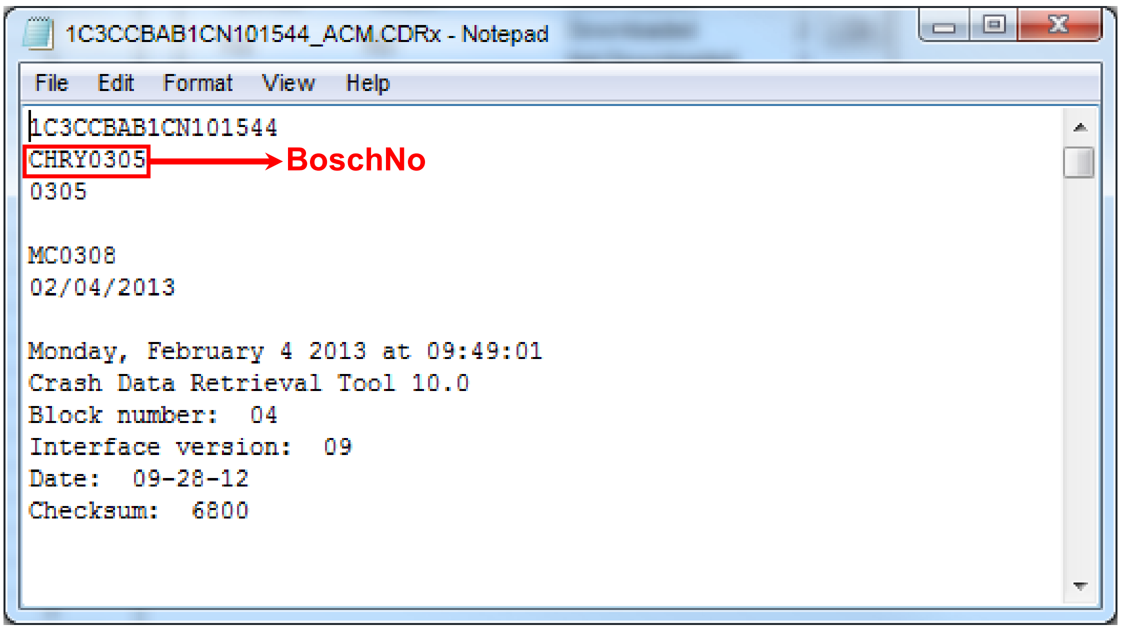

Figure 1. Sample CDRx file showing BoschNo.

Using the data catalogs, each EDR family, as identified by BoschNo, was assessed for its progress toward meeting Part 563 Tables I and II. The data catalogs were searched for an element with content that corresponded to a Part 563 element. Each element identified in this manner, e.g., delta V vs. time, was also checked against the recording interval and sampling frequency, if any, specified in Part 563 for this element. The rating scheme is shown in Table 1. Data elements that met the Part 563 requirement were indicated by a check with solid green background. Data elements that did not meet the minimum Part 563 requirements were annotated with three dashes on a white background. Given in the appendices are notes specifying why Part 563 was not met. As data elements in Table I are required, the dashed line annotation was also given when the module did not report the element. However, the specifications for Part 563 Table II data elements are only required to be met if the corresponding element is recorded by the EDR. Any Part 563 Table II data element that was not recorded is indicated by “NR” on a gray background.

In most cases, all data elements in a particular BoschNo EDR family were recorded consistently for all modules in that family in our dataset. However, a few BoschNo EDR families contained data elements that were not recorded consistently across a family. This typically occurred when modules from a particular BoschNo EDR family were manufactured by multiple suppliers. This may be because of instructions from the OEM to the individual supplier. Regardless, in the analysis that follows, differences within a given EDR family were identified.

Table 1. Part 563 Progress rating scheme

✓	Data element satisfies Part 563
✓1	Data element was not uniformly observed in all tests of the same BoschNo
✓2	Data element was observed in report, but would display "Data Not Available", "Not Configured", or "Not Supported" as the family was unequipped with sensor
---	Data element was recorded, but does not satisfy Part 563
NR	Data element was not recorded (Part 563 Table II only element)

Comparison to Pre-563 EDR data elements

Although the effective date of Part 563 was September 2012, the regulation was published in 2006. Thus, there are concerns that the Part 563 requirements are more representative of mid-2000 EDR technology. To evaluate whether and to what extent EDRs have advanced since the publication of Part 563, EDRs manufactured prior to the 2006 Part 563 final rule were compared to MY 2012 EDRs and evaluated against current Part 563 requirements. Twenty-nine MY 2005 and MY 2006 Chrysler, Ford, GM, and Toyota EDRs were compared to a subset of 94 MY 2012 EDRs of identical OEMs. These EDRs were read with the Bosch CDR tool v. 11.1, and their data element quantities were compared.

Estimating Percentage of MY 2012 Fleet Installation of EDR Technologies

U.S. light-vehicle market sales figures for calendar years 2012 and 2013 were obtained from Automotive News (2011 to 2013 et seq.) and used to estimate MY 2012 and MY 2013 EDR percentages. The sales figures encompassed September 1, 2011 to August 31, 2013 for a total of 20 OEMs. Sales for all subsidiaries of each OEM were combined. For example, GM includes Chevrolet, GMC, Buick, and Cadillac. Several assumptions were made to approximate the number of vehicles that have EDRs, as follows:

- A vehicle was assumed to have an EDR if either Bosch CDR[2] or a proprietary download tool was available for that OEM. Although the Hyundai/Kia download tool was only marketed for MY 2013 and later models, Hyundai/Kia was included in both the MY 2012 and MY 2013 totals as our study showed that MY 2012 Hyundai/Kia EDRs could be downloaded with this tool. Nissan was included as we knew from discussions with this OEM that its vehicles had some degree of EDR functionality. Suzuki and Mitsubishi

[2] Bosch CDR Tool Help (version 10.2), Robert Bosch LLC, Santa Barbara, CA, 2000.

were included in MY 2012 totals as these OEMs had downloaded modules for the research team.

- All MY 2013 BMW and Rolls Royce vehicles were included in our EDR estimates as these makes will be supported by Bosch for MY 2013. Mini is also a subsidiary of BMW and will not be supported for MY 2013 Bosch. Mini sales only make up 19 percent of the total U.S. BMW sales.
- EDRs for BMW, Jaguar, Land Rover, Subaru, and Saab vehicles were only included in the MY 2013 totals. These modules were not readable by the Bosch CDR for MY 2012, but were readable for MY 2013.
- OEMs were only included in our analysis if Automotive News sales figures were available for these vehicles. As a result, some smaller volume OEMs, e.g., Aston Martin, Coda, Lotus, McLaren, were not included, even though some MY 2012 vehicles, e.g., Lancia, were supported by the Bosch CDR.
- Our approach estimates EDR coverage only at the OEM level. Some OEMs may not have EDR functionality in selected vehicles. However, as Automotive News figures were not available for individual models, our analysis could not estimate EDR coverage at the model level.
- Vehicles that were not supported throughout the entire CY 2012 were still considered to have an EDR. For instance, Bosch CDR only provided support if the vehicle was manufactured after September 2012 for some vehicles (e.g., Acura MDX, Acura TL, Honda Pilot, Honda Ridgeline). We assumed coverage across the entire model year.
- The Automotive News data does not indicate the MY of the vehicles sold. To estimate MY 2012 and MY 2013, we assumed that sales in 9/2011 to 8/2012 were MY 2012. Sales from 9/2012 to 8/2013 were assumed to be MY 2013. We emphasize that this is only an estimate of MY 2012 and MY 2013 sales. Sales overlap of both model years will overlap in summer/fall.

Results

Estimating Percentage of MY 2012 Fleet Installation of EDR Technologies

Our first goal was to estimate the percentage of MY 2012 and MY 2013 passenger vehicles that are equipped with EDRs. The Automotive News reported CY 2012 sales of 14,492,277 vehicles. The five highest-volume OEMs (Chrysler, Ford, GM, Honda, and Toyota) made up 69 percent of the total MY 2012 and MY 2013 fleet. The findings of this analysis are summarized in Table 2. Our estimate was that 89.0 percent of MY 2012 passenger vehicles (sold between September 1, 2011, and August 31, 2012) had EDRs. In MY 2013 we estimate that 93.3 percent of passenger vehicles (sold between September 1, 2012, and August 31, 2013) had EDRs. Note that this estimate is an upper limit as some OEMs, i.e., BMW and Mazda, do not equip all models with EDRs. This is consistent with NHTSA's estimate that 96 percent of MY 2013 vehicles are equipped with EDRs (NHTSA, 2012).

Table 2. Estimated percentage of MY 2012 and MY 2013 vehicles that contain EDRs

OEM	Model Year 2012			Model Year 2013			
	Total Sales	Total %	EDR %	Total Sales	Total %	EDR %	
General Motors	2,551,179	18.4%	18.4%	2,768,511	18.0%	18.0%	
Ford	2,199,527	15.9%	15.9%	2,435,615	15.8%	15.9%	
Chrysler	1,538,271	11.1%	11.1%	1,757,144	11.4%	11.4%	
Toyota	1,973,848	14.3%	14.3%	2,216,712	14.4%	14.4%	
Honda	1,332,437	9.6%	9.6%	1,526,987	9.9%	9.9%	
Nissan	1,109,607	8.0%	8.0%	1,221,327	7.9%	7.9%	
Volkswagen	517,019	3.7%		589,576	3.8%		
Mitsubishi	61,568	0.4%	0.4%	57,454	0.4%	0.4%	
Mazda	266,540	1.9%	1.9%	289,727	1.9%	1.9%	
Hyundai	665,984	4.8%	4.8%	716,334	4.6%	4.6%	
BMW	313,033	2.3%		373,395	2.4%	2.0%	†
Daimler	279,014	2.0%		326,117	2.1%		
Volvo	65,116	0.5%	0.5%	65,473	0.4%	0.4%	
Subaru	315,927	2.3%		400,313	2.6%	2.6%	
Kia	523,608	3.8%	3.8%	549,170	3.6%	3.6%	
Suzuki	26,194	0.2%	0.2%	13,561	0.1%	0.1%	
Jaguar Land Rover	54,607	0.4%		62,197	0.4%	0.4%	†
Porsche	31,346	0.2%		41,221	0.3%		
Maserati	2,514	0.0%		2,912	0.0%		
Saab	1,837	0.0%		0	0.0%	0.0%	†
Others	3,165	0.0%		2,978	0.0%		
Total Light Vehicles	**13,832,341**	**100.0%**	**89.0%**	**15,416,724**	**100.0%**	**93.3%**	

† EDRs supported by Bosch for these OEMs in model year 2013.

Development of Model Year 2012 EDR Data Catalog

The next objective in this analysis was to develop a catalog of the data elements recorded in MY 2012 EDRs. This catalog is used later in this report to examine the progress of MY 2012 EDRs toward meeting Part 563 requirements. Note that MY 2012 EDRs are not required to meet Part 563, but were a good indication of what could be expected in MY 2013.

Table 3. ACMs received from NCAP MY 2012 crash tests

	Download Status	Quantity of ACMs
Bosch Supported ACMs		**116**
Cadillac	Downloaded	6
Chevrolet	Downloaded	15
	† Not Downloaded	2
Chrysler	Downloaded	9
Dodge	Downloaded	12
Fiat	Downloaded	4
Ford	Downloaded	16
Honda	Downloaded	13
Jeep	Downloaded	3
Lexus	Downloaded	3
Mazda	Downloaded	4
Ram	Downloaded	5
Scion	Downloaded	3
Toyota	Downloaded	18
Volvo	Downloaded	3
ACMs Supported by Other Tools		**29**
Hyundai	Downloaded	13
Kia	Downloaded	10
Mitsubishi	Downloaded	3
Suzuki	Downloaded	3
Not Supported ACMs		**38**
Acura	¤ Not Downloaded	6
Ford	Not Downloaded	3
Honda	¤ Not Downloaded	2
Kia	Not Downloaded	2
Mitsubishi	Not Downloaded	4
Nissan	Not Downloaded	9
Subaru	Not Downloaded	5
Volkswagen	‡ Not Downloaded	7
Total EDRs Received		**183**

† Damage sustained during vehicle extraction prevents downloading
‡ Volkswagens are ACMs and provide no EDR function
¤ Specific module not supported primarily because of manufacture date of ACM

During the project, the research team received 183 EDRs from NHTSA crash test labs, as shown in Table 3. All modules received were ACMs. Table 3 shows 145 EDRs from this set of modules that could potentially be downloaded, and of those, 143 were actually downloaded. The Bosch CDR tool was used to download 116 modules. Suzuki assisted with the download of 3 EDRs, and Mitsubishi assisted with the download of 3 EDRs, both included in the total 143 EDRs. The research team used Hyundai and Kia readout tools to download 13 Hyundai modules and 10 Kia modules.

Many of the EDRs from the test labs showed damage to the EDR housing, which occurred presumably during extraction. These EDRs appeared to have been pried loose from the car rather than simply unbolted. In most cases, the EDR was still readable. However, 2 of the Chevrolet EDRs that were damaged during extraction could not be read. Inspection of the EDR interior showed damage to the printed circuit board. This experience shows the need to unbolt EDRs during extraction rather than prying them from the car.

One early outcome of this project was enhancement of the Bosch CDR tool for MY 2012 EDRs. In our initial downloads, we discovered that several MY 2012 GM, Toyota, and Chrysler modules could not be read with the Bosch CDR v4.2 tool. Bosch agreed to examine and diagnose the problem with imaging these modules. During its examination, Bosch identified an issue in its tool, which was fixed for the 2012 Toyota Camry in CDR v4.3. Bosch also corrected the issues we were having with MY 2012 Chevy Sonic and Chevy Camaro modules in v4.3. Finally, earlier versions of the Bosch tool did not allow EDR imaging by direct connection to Chrysler 200 and Dodge Avenger modules, and instead required download through the On-Board Diagnostic-II (OBD-II) connector. On October 22, 2012, Bosch resolved the issues with these Chrysler modules by releasing a new adapter (F00K108790) in conjunction with software version 8.1.

Data elements for each vehicle were compared with all other vehicles of the same BoschNo or vehicle make. The Chrysler EDRs were from five families (BoschNo: CHRY0305, CHRY0403, CHRY4005, CHRY4101, and CHRY0000). The Ford EDRs were from three families (BoschNo: FordAB10, FordRC6_2011, and FordRC62011CGEAD). The GM EDRs were from three families (BoschNo: SDM10, SDM10P, and SDM10_AUTOLIVNEW). The Mazda EDRs were from two families (BoschNo: MAZDA001 and MAZDA002). The remaining OEMs of Honda (HONDA001), Toyota (TOYOTA001), and Volvo (VOLVO001) each had one BoschNo.

Progress Toward Fulfilling Part 563

A complete list of the modules is provided in the appendices for those modules that were downloaded in this research program. The entry for each module contains vehicle make, model, Vehicle Identification Number (VIN), EDR family name, and supplier. Also provided in the appendices is an analysis of how closely each EDR family met the requirements of Part 563. These tables of progress toward Part 563 were the basis for Table 4 (Summary of EDR progress toward Part 563 Table I fulfillment) and Table 5 (Summary of EDR progress toward Part 563 Table II fulfillment). In most cases, all data elements in a particular BoschNo EDR family were consistent across all modules that were examined. However, some BoschNo EDR families contained the data elements that were not recorded consistently across the family. An example was the GM SDM10 EDR family, which was provided by two suppliers: Continental and Delphi. In our dataset, the Chevrolet Suburban, Chevrolet Silverado, and Cadillac CTS were equipped with the SDM/Continental module while the Chevrolet Camaro and Sonic were equipped with the SDM/Delphi module. These cases were labeled with a check and superscript 1 on a striped background accompanied with notes that identify specifics. Additionally, these cases were determined to signify fulfillment. The following are a few elements that were contained in the Delphi group but not the Continental group:

- Battery Cutoff Loop (If Equipped)
- Driver 1st Stage Deployment Loop
- Time from [Front-Side-Rear] FSR/Rollover Event Enable to Driver Pretensioner Loop #1 or Loop #2 Deployment Command Criteria Met (ms)
- Time from FSR/Rollover Event Enable to Passenger Thorax/Curtain Deployment Command Criteria Met (ms)
- SDM Recorded Vehicle Longitudinal Acceleration After FSR Enable

Each CDR file contains a list of OEM data elements and a corresponding value. However, several of these values were denoted as "Data Not Available" when the OEM data element was labeled with "(If Equipped)." This indicates that among the vehicles of the same BoschNo, not all were consistently equipped with identical instrumentation but were prepared to record the data element regardless. These instances were marked with a check and superscript 2 on a striped background and were observed in the GM SDM11_AUTOLIVNEW and Chrysler CHRY0305, among other EDR families. The following are a few elements that were present in the CDR file but were not equipped with the appropriate instrumentation and thus contained the value "Data Not Available."

- Battery Cutoff Loop (If Equipped)
- Driver Seat Position Status (If Equipped)
- Passenger SIR [Supplemental Inflatable Restraint] Suppression Switch Circuit Status (If Equipped)
- Panic Brake Assist Active (If Equipped)
- Seat Track Position Switch, Foremost, Status, Driver (Driver Seat Position Status) (If Equipped)

Table 4. Summary of MY 2012 EDR progress toward Part 563 Table I fulfillment

	CHRY0000	CHRY0305	CHRY0403	CHRY4005	CHRY4101	FordAB10	FordRC6_ 2011	FordRC62011 CGEAD	HONDA001	HYUNDAI	KIA	MAZDA001	MAZDA002	MITSUBISHI	SDM10	SDM10P	SDM11_ AUTOLIVNEW	SUZUKI	TOYOTA001	VOLVO001	Fraction which fulfills Part 563
Delta V, longitudinal	✓	✓[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	20/20
Maximum delta V longitudinal	✓	---	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[2]	✓	✓	✓	✓[1]	✓	19/20
Time, maximum delta V	✓	---	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	---	✓	18/20
Speed, vehicle indicated	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	---	✓	---	✓	✓[1]	✓	18/20
Engine throttle (or accelerator pedal)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	---	✓	---	✓	---	✓	17/20
Service brake, on/off	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	---	✓	---	✓	✓[1]	✓	18/20
Ignition cycle, crash	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	---	✓	19/20
Ignition cycle, download	✓	✓[1]	✓	✓	---	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	19/20
Seat belt status, driver	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	20/20
Frontal air bag warning lamp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	---	✓	19/20
Frontal air bag deployment, time to deploy (or first stage deployment), driver	✓	---	✓	✓	✓	✓[1]	✓[1]	✓[1]	✓	✓	✓	✓	✓	✓	✓	✓[2]	✓[2]	✓	✓[1]	✓	19/20
Frontal air bag deployment, time to deploy (or first stage deployment), right front passenger	✓	---	✓	✓	✓	✓[1]	✓[1]	✓[1]	✓	✓	✓	✓	✓	✓	✓	✓[2]	✓[2]	✓	✓[1]	✓	19/20
Multi-event, number of event	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	20/20
Time from event 1 to 2	✓	✓	✓	✓	---	✓	✓	✓	---	✓	✓	✓	✓	✓	✓[2]	✓[2]	✓[2]	✓	✓[1]	✓	18/20
Complete file recorded	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	20/20
	15/15	11/15	15/15	15/15	13/15	15/15	15/15	15/15	14/15	15/15	15/15	15/15	15/15	15/15	12/15	15/15	12/15	15/15	11/15	15/15	

✓	Satisfies Part 563	✓[2]	Observed in report, but would display "Data Not Available", "Not Configured", or "Not Supported"
✓[1]	Not uniformly observed in all reports of the same BoschNo	---	Does not satisfy Part 563

Table 5. Summary of MY 2012 EDR progress toward Part 563 Table II fulfillment

	CHRY0000	CHRY0305	CHRY0403	CHRY4005	CHRY4101	FordAB10	FordRC6_2011	FordRC62011 CGEAD	HONDA001	HYUNDAI	KIA	MAZDA001	MAZDA002	MITSUBISHI	SDM10	SDM10P	SDM11_AUTOLIVNEW	SUZUKI	TOYOTA001	VOLVO001	Fraction which fulfills Part 563
Lateral acceleration	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	NR	✓	✓	NR	✓	NR	✓	8/8
Longitudinal acceleration	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	NR	✓	✓	NR	✓	NR	✓	8/8
Normal acceleration	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓[2]	✓[2]	NR	NR	NR	NR	NR	NR	NR	NR	✓	3/3
Delta V, lateral	✓	✓[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	NR	19/19
Maximum delta V, lateral	✓	NR	✓	✓	✓	NR	✓	✓	✓	✓	✓	✓	✓	✓	✓[2]	✓	✓	✓	✓[1]	NR	17/17
Time maximum delta V, lateral	✓	NR	✓	✓	✓	NR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NR	✓	NR	NR	15/15
Time for maximum delta V, resultant	NR	NR	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	✓	✓	NR	NR	NR	✓	NR	NR	7/7
Engine rpm	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NR	NR	✓	---	✓	---	✓	✓[1]	NR	15/17
Vehicle roll angle	NR	NR	NR	NR	NR	NR	✓[1]	✓	NR	✓[2]	✓[2]	NR	NR	✓	NR	NR	NR	NR	NR	✓	6/6
ABS activity	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	✓	NR	NR	NR	NR	NR	NR	✓	NR	NR	12/12
Stability control	✓	✓	✓	✓	✓	NR	✓	NR	✓[1]	✓	✓	NR	NR	NR	NR	NR	NR	✓	NR	NR	10/10
Steering input	✓	✓	✓	✓	✓	NR	✓[1]	✓	✓[1]	✓	✓	NR	NR	NR	NR	NR	NR	✓	NR	NR	11/11
Seat belt status, right front passenger	✓	✓	NR	✓	✓	✓	✓	✓[1]	✓	✓	✓	✓	✓	✓	✓[2]	✓	✓[2]	✓	✓[1]	✓	19/19
Frontal air bag suppression switch status, right front passenger	NR	NR	NR	NR	NR	NR	NR	✓[1]	✓	NR	NR	✓	NR	✓[2]	✓[2]	✓[2]	✓[2]	✓	NR	✓	20/2
Frontal air bag deployment, time to nth stage, driver	✓	---	✓	✓	✓	✓[1]	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓[2]	✓[2]	✓	NR	✓	17/18
Frontal air bag deployment, time to nth stage, passenger	✓	---	✓	✓	✓	✓[1]	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓[2]	✓[2]	✓	NR	✓	17/18
Frontal air bag deployment, nth stage disposal, driver, Y/N	NR	NR	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	✓	✓	NR	NR	NR	✓	NR	NR	20/2

✓	Satisfies Part 563	NR	Not recorded	✓[2]	Observed in report, but would display "Data Not Available", "Not Configured", or "Not Supported"
✓[1]	Not uniformly observed in all reports of the same BoschNo	---	Does not satisfy Part 563		

Table 5 (cont'd). Summary of MY 2012 EDR progress toward Part 563 Table II fulfillment

	CHRY0000	CHRY0305	CHRY0403	CHRY4005	CHRY4101	FordAB10	FordRC6_ 2011	FordRC62011 CGEAD	HONDA001	HYUNDAI	KIA	MAZDA001	MAZDA002	MITSUBISHI	SDM10	SDM10P	SDM11_ AUTOLIVNEW	SUZUKI	TOYOTA001	VOLVO001	Fraction which fulfills Part 563
Frontal air bag deployment, nth stage disposal, right front passenger, Y/N	NR	NR	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	✓	✓	NR	NR	NR	✓	NR	NR	7/7
Side air bag deployment, time to deploy, driver	---	NR	---	---	---	✓[1]	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	NR	NR	NR	✓	NR	✓	10/14
Side air bag deployment, time to deploy, right front passenger	---	NR	---	---	---	NR	NR	NR	✓	✓	✓	NR	✓	✓	NR	NR	NR	✓	NR	✓	7/11
Side curtain/tube air bag deployment, time to deploy, driver side	---	NR	---	---	---	✓[1]	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓	✓[2]	✓	NR	✓	13/17
Side curtain/tube air bag deployment, time to deploy, right side	---	NR	---	---	---	NR	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓	✓[2]	✓	NR	✓	12/16
Pretensioner deployment, time-to-fire, driver	---	---	---	---	---	✓	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓	✓	✓	---	✓	13/19
Pretensioner deployment, time-to-fire, right front passenger	---	---	---	---	---	✓[1]	✓[1]	✓[1]	✓	✓	✓	NR	✓	✓	✓[2]	✓	✓	✓	---	✓	13/19
Seat track position switch, foremost, status, driver	✓	✓[2]	✓[2]	✓	✓	✓	✓	✓[1]	✓	✓[2]	✓[2]	✓	✓	✓	✓[2]	✓[2]	✓[2]	✓	✓[1]	✓	20/20
Seat track position switch, foremost, status, right front passenger	✓	✓[2]	✓[2]	✓	✓	✓	✓[1]	✓[1]	✓	✓[2]	✓[2]	NR	NR	✓	✓[2]	✓[2]	✓[2]	NR	NR	✓	16/16
Occupant size classification, driver	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓[2]	✓[2]	NR	NR	✓	NR	NR	NR	NR	NR	NR	3/3
Occupant size classification, right front passenger	NR	NR	NR	NR	NR	✓	✓[1]	✓[1]	✓	✓[2]	✓[2]	✓	✓	✓	✓	✓	✓	✓	✓[1]	✓	15/15
Occupant position classification, driver	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓	NR	NR	NR	NR	NR	NR	1/1
Occupant position classification, right front passenger	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	✓	NR	NR	NR	NR	NR	NR	1/1
	12/18	8/12	11/17	12/18	12/18	13/13	19/19	19/19	25/25	27/27	27/27	12/12	19/19	24/24	15/16	17/17	13/14	24/24	6/8	17/17	

✓	Satisfies Part 563	NR	Not recorded	✓[2]	Observed in report, but would display "Data Not Available", "Not Configured", or "Not Supported"
✓[1]	Not uniformly observed in all reports of the same BoschNo	---	Does not satisfy Part 563		

Part 563 Table I progress

Ford (FordAB10, FordRC6_2011, and FordRC62011CGEAD), Hyundai, Kia, Mazda (MAZDA001 and MAZDA002), Mitsubishi, Suzuki, and Volvo (VOLVO001) MY 2012 EDRs in our dataset met the existence, interval, and sampling requirements for all 15 (100%) elements contained in Part 563 Table I.

Chrysler MY 2012 EDRs varied in how closely they met Part 563 Table I data element requirements. The CHRY000, CHRY0403, and CHRY4005 module met all existence, interval, and sampling requirements for all 15 elements. In contrast, the CHRY0305 EDR module met only 11 of the 15 Part 563 Table I data element requirements (73%). Two of the four elements that did not meet Part 563 Table I specifications were not recorded ("maximum delta V longitudinal" and "time, maximum delta V"). The remaining two elements described frontal air bag deployment; however, the CHRY0305 modules did not provide the time to deployment. Additionally, the CHRY4101 EDR module met 13 of the 15 Part 563 Table I data element requirements (87%). This module lacked "ignition cycle, download" and "time from event 1 to 2."

The MY 2012 GM SDM10P EDR family in our dataset also met all the requirements of Part 563 Table I. The remaining MY 2012 GM EDRs (BoschNo groups SDM10 and SDM11_AUTOLIVNEW) in our dataset met the requirements for 12 of the 15 data elements (80%) in Part 563 Table I. The exceptions were the duration of the pre-crash variables vehicle speed, engine throttle, and service brake. Part 563 Table I specifies that these variables should be recorded from 5 seconds to 0.5 seconds prior to the crash at a frequency of two samples per second. These GM EDRs in our dataset only recorded from 2.5 seconds to 0.5 seconds prior to the crash at a frequency of two samples per second.

MY 2012 Honda modules (HONDA001) recorded 14 of the 15 data elements (93%) specified in Part 563 Table I. These modules lacked the data element "time from event 1 to 2;" however, none of these modules contained more than one event.

The data elements recorded by Toyota modules (TOYOTA001) were not consistent across all modules. None of the Part 563 Table I data elements were consistently present throughout all Toyota modules in our dataset. These modules recorded 11 of the 15 data elements (73%) specified in Part 563 Table I. In particular, they did not record "time, maximum delta V," "engine throttle, % full (or accelerator pedal, % full)," "ignition cycle, crash," and "frontal air bag warning lamp, on/off." Many of these early 2012 Toyotas did not meet Part 563: pre-crash data was reported at 1 Hz (Part 563 requires 2 Hz), delta V data was measured for 200 ms (Part 563 requires 250 ms), and accelerator pedal position was expressed as a sensor voltage (Part 563 requires percentage).

Part 563 Table II progress

On average, each EDR family recorded 18 of the 30 data elements in Part 563 Table II. The number of Part 563 Table II elements recorded varied widely by OEM. Hyundai and Kia each recorded 27 of 30 elements (90%); while Toyota only recorded 8 of the 30 elements (26%).

Table 6. Status of recording Part 563 Table II data elements in MY 2012 EDRs ranked by number recorded out of 30 data elements possible

OEM	Number of Part 563 Table II elements recorded	Number of Part 563 Table II elements recorded to Part 563 specifications
Hyundai	27/30	27
Kia	27/30	27
Honda	25/30	25
Mitsubishi	24/30	24
Suzuki	24/30	24
Ford	13-19/30	13-19
Mazda	12-19/30	12-19
Chrysler	12-18/30	8-12
GM	14-17/30	13-17
Volvo	17/30	17
Toyota	8/30	6

Not all Part 563 Table II data elements were recorded to Part 563 specifications. Chrysler modules, for example, included several data elements indicating whether restraints (i.e., side air bag, curtain, and pretensioner) deployed but did not provide the time-to-fire in most cases.

The most frequently recorded data elements from Part 563 Table II include:

- "Delta V, lateral,"
- "Maximum delta V, lateral,"
- "Engine RPM,"
- "Seat belt status, right front passenger,"
- "Frontal air bag deployment, time to nth stage, driver," and
- "Frontal air bag deployment, time to nth stage, passenger."

All EDR families recorded "seat track position switch foremost, status, driver."

The least frequently recorded data elements were:

- "Occupant position classification,"
- "Occupant size classification, driver,"
- "Normal acceleration," and
- "Vehicle roll angle."

Only Mitsubishi recorded "Occupant position classification" for the driver and right front passenger.

The Growth in EDR Data Elements Since Part 563 Rulemaking Began

The number of data elements stored in EDRs has grown dramatically since the MY 2005-2006-time period during which Part 563 was being formulated. As shown in Table 7, the median number of data elements has more than doubled from MY 2005-era EDRs (median=24 elements) to MY 2012 EDRs (median=58 elements). Not included in these figures were the many system status fields or diagnostic codes. On average, there were 57 ± 18 non-diagnostic data elements in the subset of MY 2012 EDRs compared to the average of 35 ± 15 data elements in MY 2005 and MY 2006 EDRs.

The growth in EDR data content is even more impressive when examined on an individual OEM basis. In MY 2005-2006, Chrysler EDRs were recording 23 data elements. By MY 2012, Chrysler tripled the number of data elements and recorded between 61 and 96 data elements depending on the module. Toyota doubled the number of its EDR data elements growing from a max of 21 data elements recorded in MY 2005-2006 to 47 data elements recorded in MY 2012 EDRs. On average, GM and Ford increased the number of its data elements by more than 50 percent during this time span. Another interesting trend is Ford and GM hadlower standard deviations in MY 2012 than in MY 2005-2006, which may reflect a trend toward standardizing their non-diagnostic data elements.

Table 7. Data element comparison before (MY 2005-2006) and after (MY 2012) Part 563 rulemaking began

	Before Part 563 Rulemaking Began						After Part 563 Rulemaking Began					
OEM	n	min.	max.	avg.	std. deviation	median	n	min.	max.	avg.	std. deviation	median
Chrysler	1	23	23	23	-	23	33	61	96	75	10	73
Ford	2	34	53	44	13	44	16	50	69	56	5	56
GM	22	22	60	37	15	39	21	49	62	57	5	58
Toyota	4	20	21	21	1	21	24	10	47	35	12	41
ALL	29	20	60	35	15	24	94	10	96	57	18	58

EDR Data Elements That Exceed Part 563 Specifications

A number of EDRs contained data elements or data element specifications that exceeded the requirements of Part 563. These additional EDR features include data elements that could be potentially useful for enhanced studies of crashworthiness, e.g., rollover curtain air bags or active safety system activation, or performance specifications that exceeded Part 563 specifications, e.g., recording pre-crash information at 10 Hz rather than the Part 563 specification of 2Hz. This section reports the results of our analysis of the data catalog to determine commonly recorded data elements that exceeded Part 563. We restricted the list below to data elements that could be potentially useful for enhanced studies of crashworthiness or pre-crash vehicle behavior. Not included here were the many system status fields or diagnostic codes.

An expanded data element survey of our dataset is shown in Table 8, sorted by the number of OEMs, which recorded these elements.

- Part 563 Table II included “pretensioner deployment, time-to-fire” for both front seat occupants. Our study found that four OEMs (Chrysler, Ford, Suzuki, and Volvo) elaborated further upon this data element by identifying the type of seat belt pretensioners. Chrysler identified the status of the pretensioner and the remaining OEMs recorded the time-to-fire. Volvo additionally included pretensioner information for each rear passenger seat, e.g., “2nd Row Right Belt Pretensioner, Time to Deploy (msec).”
- Beyond required front, side, and curtain deployment information, our study also found that Chrysler and Suzuki are additionally recording knee air bag deployment information. Specifically, Chrysler recorded the deployment status of the knee air bag (whether triggered or not), and Suzuki recorded the time-to-fire. GM included diagnostic status on knee deployment algorithms but not specific deployment information.
- Some OEMs recorded occupant restraint information. Ford included a data element describing adaptive load limiter deployment time-to-fire. Ford also included “CAN adaptive vent deployment” time-to-fire for both front seat occupants. This vent system senses the position of the occupant and regulates the gas within the air bag to reduce the deployment forces on the occupant. Additionally, Chrysler recorded active head restraint status (Yes/No).
- Part 563 Table II specifies vehicle roll angle; however, our study found that few OEMs recorded this information. As an alternative, some OEMs (e.g., Chrysler, Ford, GM) included data elements that recorded vehicle rotational rates, such as roll (or “angular”) rate and yaw rate.
- Several OEMS recorded data on the engine-drivetrain, which exceeded Part 563 specifications. Three OEMs (i.e., Chrysler, Ford, and GM) recorded the engine torque. Chrysler recorded the engine torque status (Yes/No) from -5.0s to -0.1s at a rate of 10 Hz. Ford recorded engine torque in units of N-m from -5s to 0s at a rate of 2 Hz and GM recorded in units of lb-ft for two data points at -1s and -0.5s. One OEM, Chrysler, additionally recorded raw manifold pressure in units of kPa from -5.0s to -0.1s at a rate of 10 Hz. Two OEMs recorded malfunction indicator light information about the powertrain control modules (PCM).
- The only active safety data elements in Part 563 are antilock braking system and stability control. Chrysler and Ford recorded several additional active safety data elements, including electronic throttle control status, panic brake assist status, cruise control status, and traction control status.
- Additional MY 2012 data elements beyond Part 563 included: odometer information, outside temperature, tire pressure, wheel speed, wheel torque, shift position, and operation system time at the event (indicates the amount of time, over the ACM’s lifetime that the ACM has been powered up).

The dataset of MY 2012 EDRs also included two OEMs, Chrysler and GM, that exceeded data element specifications given by Part 563. Part 563 specifies that lateral and longitudinal delta V should be measured over a recording interval of “0 to 250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter” and a sample rate of 100 data samples per second. As shown in Table 9, Chrysler greatly exceeded the duration and frequency for both of these data elements. GM exceeded the delta V recording duration specification, but followed the Part 563 recording frequency. Chrysler exceeded the Part 563 specifications for the pre-crash variables of vehicle speed, engine throttle, accelerator pedal, service brake, engine RPM, antilock brake system activity, stability control, and steering input. The regulation specifies a recording interval of "–5.0 to 0 sec" and duration of two data samples per second for these data elements. However, the MY 2012 Chrysler EDRs in our dataset recorded at 10 Hz.

Table 8. Commonly recorded MY 2012 data elements that exceed Part 563 requirements

	Total OEMs	Chrysler	Ford	GM	Honda	Hyundai	Kia	Mazda	Mitsubishi	Suzuki	Toyota	Volvo
Retractor/Belt/Shoulder Pretensioner - Status or Time-to-Fire	4	☑	☑	☐	☐	☐	☐	☐	☐	☑	☐	☑
Buckle/Anchor/Lap Pretensioner - Status or Time-to-Fire	4	☑	☑	☐	☐	☐	☐	☐	☐	☑	☐	☑
Shift Position (P/R/N/D)	3	☑	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐
Cruise Control - Status ("Yes/No" or "On/Off")	3	☑	☐	☑	☐	☐	☐	☐	☐	☑	☐	☐
Engine Torque - Status (lb-ft or N-m)	3	☑	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐
Roll/Angular Rate (deg/sec)	3	☑	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐
Knee Air bag Deployment - Status or Time-to-Fire	2	☑	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Operation System Time (sec)	2	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐
Tire Pressure – Status	2	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Powertrain Control Module (PCM) Malfunction Indicator Lamp (MIL)	2	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Yaw Rate (deg/sec)	2	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Traction Control – Status	2	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rear Passenger Pretensioner, Time to Deploy	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
CAN adaptive vent deployment – Time-to-Fire	1	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Adaptive load limiter deployment – Time-to-Fire	1	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wheel Torque	1	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Temperature Outside (°C)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Odometer (mi or km)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wheel Speed (RPM)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Raw Manifold Pressure (kPa)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Panic Brake Assist – Status (Yes/No)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Active Head Restraint – Status (Yes/No)	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Electronic Throttle Control (ETC) - Status	1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Table 9. Elements that exceed Part 563 specifications – either in higher sampling rate, longer recording duration, or both

Table	Data Element		Chrysler	GM
I	† Delta V, longitudinal	Duration (ms):	0 to 298	290 ms interval (-70 to 220) OR (10 to 300)
		Frequency (Hz):	500	100
I	‡ Speed, vehicle indicated	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
I	‡ Engine throttle, % full (or accelerator pedal, % full)	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
I	‡ Service brake	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
II	† Delta V, lateral	Duration (ms):	0 to 298	290 ms interval (-70 to 220) OR (10 to 300)
		Frequency (Hz):	500	100
II	‡ Engine rpm	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
II	‡ ABS activity	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
II	‡ Stability control	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	
II	‡ Steering input	Duration (sec):	-5 to -0.1	
		Frequency (Hz):	10	

† *Part 563 specifies a recording interval of "0 to 250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter" and a duration of 100 data samples per second.*

‡ *Part 563 specifies a recording interval of "−5.0 to 0 sec" and a duration of two data samples per second.*

Functionality of MY 2012 EDRs

The next objective of the analysis was to determine the functionality of MY 2012 EDR models. Again, we note that these modules were not required to meet the requirements of Part 563, but we believe MY 2012 modules are a good indication of what can be expected to be recorded in MY 2013 modules. In the discussion above, we described the characteristics of the data elements stored in MY 2012 EDRs, and duration and sample rate of pre-crash/event and crash/event recording in MY 2012. In the discussion that follows, we use both the EDR data catalogs described above and interviews with the OEMs and suppliers to present additional aspects of MY 2012 EDR functionality. In addition to the foregoing topics, OEMs and suppliers have also indicated that some EDR modules have or will have the ability for the OEM to turn them off.

Types of events that trigger recording

All the OEMs that we interviewed recorded front and side impact events. Similarly, all NCAP frontal and side crash tests for which the EDR was Bosch CDR-readable contained data. Ford, GM, Honda, and Toyota told us that their vehicles can record roll data if the vehicles are equipped with rollover sensors. GM, Honda, and Toyota told us that their modules can record rear impacts.

For 2012 models, most OEMs told us that their minimum thresholds for recording non-deployment events (as defined in Part 563) in frontal, side, and rear crashes followed the Part 563 minimum delta V of 8 kph (5 mph). Other OEMs told us that their non-deployment thresholds in MY 2012 vehicles were 2G.

Two of the three suppliers we interviewed provided input on event triggers and told us that their modules use 5 mph (8 kph) thresholds for frontal and side events in accordance with Part 563 regulation. One supplier told us that there was concern about deviating from the regulation; i.e., the suppliers were unsure if a threshold less than 5 mph would be acceptable to meet Part 563. They worried that if the recording threshold was lower the EDR might fill an event recording slot and prevent other more important events from being recorded. A second supplier stated that it had experimented with lower thresholds but had problems with false alarms. All the suppliers' customers used air bag deployment as fail-safe triggers for recording. One supplier told us that Part 563 has driven changes in its recording trigger thresholds. Its threshold used to be 4 mph, but now it has been raised to 5 mph.

One constraint on lowering thresholds was the concern that this increased the computational load on the ACM microcontroller. One supplier told us that lowering delta V for recording might increase the number of events, but that overwriting a lower severity event with higher delta V events might take more time, as the microcontroller would need to make the decision if a new event actually was more severe, and then decide what event to overwrite.

Like the OEMs, the suppliers told us that almost all their modules record frontal and side events. Side impacts are recorded if the vehicles were equipped with side air bags (even if not equipped in some cases). If rollover-curtain equipped, their modules recorded rollover events. Several OEMs and suppliers stated that almost all light trucks and vans (LTVs) have rollover curtains, and this feature is being increasingly installed in cars. Two of the suppliers told us that all but their legacy modules were capable of recording rear impacts, but this capability had not been activated in all MY 2012 modules. Rollovers are recorded only upon deployment. One supplier told us that OEMs believe that rollover recording is necessary even though the data element is not a direct requirement of Part 563. They also noted that unlike for planar FSR crashes, Part 563 does not provide a comparable minimum recording trigger for rollover events, and some OEMs are instead using their own angular trigger.

No models record for other triggers such as fuel cutoff or stability control activation. One supplier told us that they were very careful to avoid non-regulatory trigger use (e.g., fuel cutoff). Likewise, this supplier told us its modules are not using resultant delta V as a trigger as its interpretation of Part 563 was that the 5 mph delta V threshold applied to either a longitudinal or lateral delta V, but not resultant.

The suppliers replied that there are currently no triggers or recorded data elements to identify unintended acceleration. Including UA might be possible with auxiliary recorders, but these would require much longer duration and would drive up the cost to the customer.

Time and location of crash/event

None of the OEMs or suppliers that we interviewed was recording the times and/or locations of the crashes or events. Most EDRs only recorded key cycles, sometimes referred to as ignition cycles. One supplier told us that there was interest among the OEMs in recording the hours of operation. From our NCAP crash downloads, we know that two OEMs, Chrysler and Mazda, were recording operation system time in MY 2012 modules.

EDR Data Storage Capacity

This section discusses MY 2012 EDR storage capacity, including memory size, number of data banks available for events, and locations of data storage (e.g., air bag control unit versus engine control unit).

Memory size

Current EDRs store data in either electrically erasable programmable read-only memory or flash memory. The suppliers have told us that older EDRs used discrete EEPROM chips. However, the industry is moving away from discrete EEPROM chips to flash memory embedded in the microcontroller. The typical microcontroller used in these applications has 32k or 64k of flash data. This non-volatile memory is not used exclusively for the EDR function and must accommodate other purposes, e.g., fault recording and ACM operation. Both suppliers and OEMs told us that only a fraction of the memory in an ACM is dedicated to the EDR function. A typical recorded EDR requires approximately 2k per event depending on the OEM.

The memory required by ACMs has increased with the growth in their capabilities. In MY 1998, these units used 512 bytes of memory in the microprocessor. In 2002 and 2003, the industry began to move toward separate EEPROMs in 2k- to 4k-size chips. Most recent modules are going to 32k flash data memory in the microprocessor. Although memory requirements have increased, memory costs have gone down.

Adding additional events or data elements may require expansion of EDR memory. We asked the suppliers, “Beyond the sensor cost, what would be the incremental cost to add a single data element or time series data elements?” The suppliers mentioned three consequences: (1) additional throughput may be required in the microcontroller, (2) additional RAM would be required for temporary storage before transferring data to non-volatile memory, and (3) additional non-volatile memory, e.g., EEPROM or flash, would be required. One supplier told us, however, that modest expansions of memory may have a zero memory cost up to a threshold. Not all memory is currently being used in many modules. However, one OEM indicated its EDR models were at memory limits and would have to delete a parameter before it could add others. Larger chips would only be needed if the EDRs went beyond this threshold. When asked what the cost would be to double the memory, another supplier told us that this would increase costs by 50 percent - approximately $1 to $2. It pointed out that ACMs have become “commodity” devices and hence the cost pressures are enormous. One supplier noted how rapidly onboard memory is dropping in price and believed that adding parameters would not be that expensive.

Locations of data storage

Earlier-generation EDRs have recorded data in both the ACM and PCM. In some earlier-generation EDRs, GM stored rollover data in its rollover sensor module. However, the OEMs that we interviewed told us that the EDR needed for Part 563 compliance is now stored in the ACM. One OEM told us that this was believed to be a more protected location in the vehicle. One supplier told us that its occupant classification systems have their own module and recording capability.

Number of events

An additional requirement of Part 563 is the number of events that should be recorded by EDRs. Part 563.9b specifies that EDRs must "capture and record… up to two events." To confirm fulfillment of this requirement, the research team inspected the data limitations portion of the CDR report for Bosch supported modules. In the event that this data was not present in the data limitations section of the CDR report, we simply tabulated the maximum number of events observed in each crash test. Note that the observed number provides only a lower limit on the number of events the module could record and does not necessarily reflect the maximum number of stored events.

Part 563 requires that all EDRs store a minimum of two events. As shown in Table 10, our inspection of the data limitations section of the Bosch CDR report showed that several OEMs have gone beyond this requirement. Chrysler EDRs can record up to five events. Likewise, GM modules SDM10 and SDM11 can each record up to three events. The ACM suppliers have told us that up to 75 percent of their customers were requesting three events. The German Arbeitskreis-Liefervorschrift-37 working group, composed of Audi, BMW, Daimler, Porsche, and Volkswagen, has recommended recording six events (Platte, 2011, and personal communication with Cunningham, A., Volkswagen Group of America, Inc., July 1, 2013).

Table 10. Maximum or observed number of stored events by MY 2012 EDR family

Family	Max from Bosch Data Limitations Report	Observed in crash test
CHRY0000	5*	
CHRY0305	5*	
CHRY0403	5*	
CHRY4005	5*	
CHRY4101	5*	
FordAB10	2	
FordRC6_2011	2	
FordRC62011CGEAD	2	
HONDA001	2	
HYUNDAI		2
KIA		2
MAZDA001		2
MAZDA002		2
MITSUBISHI		1
SDM10	3	
SDM10P	3	
SDM11_AUTOLIVNEW	3	
SUZUKI		1
TOYOTA001		2
VOLVO001	2	

** If manufactured by supplier, Continental, the maximum is three events.*

Manufacturer Strategies for Capturing EDR Data

The research team asked the OEMs to identify the sources of data stored in the EDRs. All OEMs interviewed told us that most pre-crash data are obtained from the vehicle CAN bus. All acceleration and rollover data that are stored in EDRs are from sensors in the ACM. Sensors like belt buckle, seat track, position or occupant position sensors may or may not go directly to the ACM. For example, occupant sensing data go first to occupant classification module, which is then read from the CAN bus. GM told us that some of its older models used separate modules to record rollover data.

EDR Imaging Strategies

This section describes current data imaging strategies for reporting of EDR data. All suppliers and OEMs stated that their EDRs can be read both by connecting through the OBD-II ports or directly to the modules.

Download tool availability for MY 2012 modules

The MY 2012 modules for many OEMs could be downloaded using the Bosch CDR system. Using the Bosch CDR v.10.2 tool, the research team was able to download modules from Chrysler, Ford, GM, Honda, Mazda, Toyota, and Volvo. Download of all other MY 2012 modules from Suzuki and Mitsubishi, required access to proprietary download devices from the OEM. As described below, the research team was able to obtain downloads of the Hyundai and Kia MY 2012 modules using recently released public download tools from these automakers. Although the Hyundai/Kia readout device was marketed for download of MY 2013 and later modules, we were able to download many MY 2012 modules using this device.

Difficulties Meeting Part 563 and Opportunities to Enhance Part 563

There are still questions relating to the interpretation of Part 563. Some of these concerns were filed with NHTSA as petitions. NHTSA addressed all outstanding petitions in August 2012.[3] The following is a summary of the issues that were raised by the OEMs and the suppliers.

- **Clipping.** Clipping was the subject of several petitions to NHTSA on Part 563. In response, NHTSA has addressed the issue of data clipping by requiring that EDRs record when sensors first exceeded their full-scale range. The Part 563 accuracy requirement only applies within the range of the accelerometer. However, even with this added to Part 563, many OEMs are moving to higher full-scale range accelerometers. The suppliers told us that the industry is switching from analog to digital sensing (started circa 2010). The result has been to go to ±100 G or higher full-scale range sensors with higher resolution. Most typically, OEMs use a pair of ±100 G accelerometers, rotated at 45° with respect to the longitudinal axis of the vehicle. This provides 70 G along the longitudinal and lateral axes and provides redundant sensing along both axes. One supplier told us that all NCAP crash tests exceed EDR accelerometer full-scale range and clip. This supplier uses ±70 G dual axis accelerometers that when rotated 45° give approximately ±50 G full-scale range along the longitudinal and lateral axes. A concern is that the sensing range for EDRs is different than the sensing range for ACMs. This drives up the cost for the customer. The agency gave the industry extra lead time to meet this clipping requirement in the August 2012 response to petitions.
- **Duration.** The suppliers told us that there are two interpretations of the number of points among OEMs for the 5 seconds of pre-crash data, i.e., should it be 10 or 11 points.
- **Accuracy of Roll Data.** The first generation of rollover sensors were used to determine rollover curtain deployment thresholds. Some EDRs started recording the rollover data up to and past the threshold decision. Since the sensor was optimized to make a deployment decision, rollover sensors may saturate after the deployment time. Analysis of crash test data will be required to better understand this issue.

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[3] 77 FR 47552.

- **Sacrificed Resolution.** One supplier told us that Part 563 resolution requirements were too low. Many parameters have greater resolution on the bus than is recorded in the EDR. For example, vehicle speed is 2 bytes on the CAN bus, but only 1 byte is recorded and/or output by the EDR. A tremendous amount of resolution is sacrificed. This supplier recommended increasing the range and resolution requirements in Part 563. This supplier stated that 1 kph resolution is not fine enough for vehicle speed. The resolution requirement should be changed to 0.1 kph. Identical criticisms about range and resolution were made by this supplier for delta V.
- **Satellite Sensors.** NHTSA has stated that additional sensors located on various parts of the vehicle (satellite sensors) are excluded from Part 563.[4] One supplier suggested that if they are on the vehicle, they should be recorded in a defined format.

Discussion

Our conclusions are limited to those EDRs in our dataset. This study was based upon MY 2012 EDRs extracted from vehicles subjected to NHTSA NCAP crash tests. Although NHTSA conducted a large number of NCAP tests for MY 2012, our sample does not include all EDR families. Likewise, downloads could not be obtained for all MY 2012 EDRs in our sample.

Our approach was to use MY 2012 EDRs to evaluate the progress of the industry toward meeting Part 563 requirements. Note that MY 2012 EDRs are not required to meet Part 563 but were a good indication of what could be expected in MY 2013.

Findings

Percentage of MY 2012 Fleet Installation With EDR technologies

An estimated 89.0 percent of MY 2012 passenger vehicles had EDRs. For MY 2013, we estimated an increase to 93.3 percent.

Development of Model Year 2012 EDR Data Catalog

During the project, the research team received 183 EDRs from the NHTSA crash test labs. All modules received were ACMs. One hundred and forty-three EDRs from this set of modules could be downloaded. Each EDR was downloaded and categorized into one of 16 EDR families that shared common make and data elements. The data catalog included EDRs from a broad swath of the light-vehicle OEMs including Chrysler, Ford, GM, Honda, Hyundai, Kia, Mazda, Mitsubishi, Suzuki, Toyota, and Volvo. The catalog includes a tabulation of data elements for these EDRs by automaker, duration and rate at which elements (e.g., delta V) were recorded, and number of events (called databanks or triggers by some automakers).

[4] 73 FR 2175 and 76 FR 47481.

Progress Towards Fulfilling Part 563

Part 563 Table I progress

Part 563 Table I contains 15 data elements that must be recorded if a vehicle is equipped with an EDR. Table 4 of this report identifies OEM progress in meeting Part 563 requirements. For the time series data elements in this group, Part 563 specifies requirements for recording interval duration and sampling rate. Our analysis checked how closely each MY 2012 EDR family in our dataset met the existence, interval, and sampling requirements of Part 563 Table I data elements. Seven of 11 OEMs (Ford, Hyundai, Kia, Mazda, Mitsubishi, Suzuki and Volvo) fulfilled 100 percent of the requirements for all 15 elements contained in Part 563 Table I. The GM SDM10P module also met all Part 563 Table I requirements, but other GM EDR families met only met the Part 563 requirements with respect to 12 of 15 data elements. Similarly, three of the Chrysler MY 2012 EDRs families met all Part 563 Table I requirements, but other Chrysler EDR families only met the Part 563 requirements with respect to 11 of 15 to 13 of 15 of the Table I data elements. MY 2012 Honda modules (HONDA001) recorded 14 of the 15 data elements specified in Part 563 Table I. Toyota modules recorded only 11 of the 15 data elements specified in Part 563 Table I specifications.

Part 563 Table II progress

Part 563 Table II provides specifications for 30 data elements; however, these requirements are applicable only if the element is recorded. Table 5 of this report identifies OEM progress in meeting Part 563 requirements. On average, each EDR family recorded 18 of the 30 data elements in Part 563 Table II. The number of Part 563 Table II data elements recorded varied widely by OEM. Hyundai and Kia each recorded 27 of 30 elements; while Toyota only recorded 8 of the 30 elements.

The most frequently recorded data elements from Part 563 Table II include (1) "Seat track position switch foremost, status, driver," (2) "Delta V, lateral," (3) "Maximum delta V, lateral," (4) "Engine rpm," (5) "Seat belt status, right front passenger (buckled, not buckled)," (6) "Frontal air bag deployment, time to nth stage, driver," and (7) "Frontal air bag deployment, time to nth stage, passenger." The least frequently recorded data elements were (1) "Occupant position classification," (2) "Occupant size classification, driver," (3) "Normal acceleration," and (4) "Vehicle roll angle."

EDR Data Elements That Exceed Part 563 Specifications

Our goal was to assess MY 2012 EDRs to establish data elements that the industry captured beyond those indicated in Part 563 Table I and Table II. Across 143 EDRs from 10 OEMs, we found a number of ways in which the EDR data analyzed exceeded the specifications of Part 563. These included:

- Greater detail for current data elements (e.g., anchor and retractor pretensioners),
- Alternative information to Part 563 Table II data elements (e.g., roll rate, as opposed to roll angle), and

- Data elements that describe developing passive (e.g., knee air bags) and active (e.g., traction control) safety systems.

EDR Functionality

Our analysis sought to determine the functionality of MY 2012 EDR models. Again, we note that these modules were not required to meet the Part 563 requirements but we believe MY 2012 modules are a good indication of what can be expected to be recorded in MY 2013 modules.

- **Types of Events That Trigger Recording**: The ability to record both frontal and side impacts appears to be common practice among light-vehicle EDRs. All modules downloaded from NCAP crash tests had the capability to record both front and side impacts. OEMs that we interviewed told us that their modules all have the capability to record both frontal and side impacts. The OEMS told us that vehicles equipped with rollover curtains could record roll event data. Several modules could also record rear impact events.
- **Recording Trigger Thresholds**: For MY 2012 models, all models used restraint deployment as a trigger for recording, and most used the minimum 5 mph delta V threshold for non-deployment recording as specified by Part 563. The industry noted the absence of a required threshold for non-deployment roll events. No MY 2012 models triggered recording for other events, e.g., fuel cutoff or stability control activation.
- **Time and Location of Crash/Event**: None of the OEMs or suppliers that we interviewed were recording the time and/or location of the crash or event.
- **Number of Events**: Part 563 requires that all EDRs store a minimum of two events. Several OEMs have gone beyond this requirement. Chrysler EDRs can record up to five events. Likewise, the GM modules SDM10 and SDM11 can record up to three events. The German AK-LV37 working group (Audi, BMW, Daimler, Porsche, and Volkswagen) recommend recording six events.
- **Source of Data Stored in the EDR**: All OEMs interviewed told us that most pre-crash data are obtained from the vehicle CAN bus. All acceleration and rollover data that are stored in EDRs are from sensors in the ACM. In some vehicles, occupant sensing data goes first to the occupant classification module, which is then read from the CAN bus. There were direct connections to the seat belt buckle switch and seat track switch.
- **Locations of Data Storage**: Earlier generation EDRs recorded data in both the ACM and PCM. In some earlier generation EDRs, GM stored rollover data in its ROS module. However, the OEMs that we interviewed told us that the EDR needed for Part 563 compliance is now stored in the ACM.
- **EDR Access Ports**: All suppliers and OEMs stated that their EDRs can be read by connecting through the OBD-II connector or directly to the module.

EDR Download Tools Other Than the Bosch CDR Tool

Part 563 requires that manufacturers make a tool available but does not specify which tool. For MY 2013 and/or MY 2014 modules, most OEMs including BMW, Chrysler, Daimler, Ford, GM, Honda, Mazda, Nissan, Toyota, and Volvo, are using the Bosch CDR tool. Six manufacturers, however, are known to have chosen to use tool providers other than the Bosch Crash Data Retrieval System. These manufacturers are Hyundai, Kia, Subaru, Mitsubishi, Jaguar/Land Rover (Tata Motors), and Saab.

Difficulties in Meeting Part 563

The industry representatives that we interviewed noted several difficulties in meeting Part 563. The main issue was accelerometer clipping causing errors in the delta V reading. In August 2011 and August 2012, NHTSA responded to that issue (49 CFR Part 571).

Opportunities to Enhance Part 563

In addition, some industry representatives that we interviewed stated that there were opportunities to enhance Part 563. Included in these opportunities were (1) increasing the resolution requirements for EDR vehicle speed to match the vehicle speed read from the CAN bus, and (2) recording the measurements from the satellite sensors in a standardized format.

3. Task 2 — Assessment of Manufacturer Planned Updates to Light-Vehicle EDR Technologies

Objective

The goal of this task was to evaluate and report OEM plans for next-generation EDRs for light vehicles with GVWRs of 10,000 lbs. or less. The specific objectives were to assess OEM planned updates to EDRs, determine OEM plans for data retrieval tool standardization, plans for installations in vehicles with a GVWR of 8,500 to 10,000 lbs., plans for incorporation of automatic crash notification systems, plans for updates to the functionality of future EDR models, including types of events that trigger recording, number and type of data elements, and duration and sample rate of pre-crash/event and crash/event recording. Industry perspectives on plans for improvements to EDR survival performance are presented in the Task 4 chapter on EDR survivability.

Approach

The research team explored these objectives through several avenues including:

1. OEM and supplier interviews,
2. Review of the recommended practices described in SAE J1698, "Vehicle Event Data Interface-Vehicular Output Data Definition,"
3. Comparison of the current capabilities of MY 2012 EDRs extracted from crash tests with the recently released catalog of data elements in SAE J1698,
4. Review of newly released and planned OEM and supplier EDR readers, and
5. Contact with the European AK-LV37 industry group and the CrashCube independent EDR retrieval group.

The research team conducted five OEM interviews and three supplier interviews. During these interviews, we asked questions regarding plans for updating EDR capabilities as outlined in the objectives above. All OEMs and suppliers asked that their specific data be considered confidential; hence, we are presenting summaries of the answers and do not attribute any answer to any particular company. These interviews were instrumental in determining their strategies associated with additional EDR data elements and expanded functionality.

One of the most important information sources for this task was the perspective of the automakers and ACM suppliers on the SAE J1698 standards development committees. The SAE J1698 RP was first issued in March 2005. Because of major technical enhancements to EDRs since that first release, the SAE J1698 committee was reconvened in 2010 to update this recommended practice. In 2013 the SAE J1698 committee completed a major revision to this recommended practice. Updated were:

- SAE J1698 "Event Data Recorder" (under development),
- SAE J1698-1 "Event Data Recorder — Output Data Definition,"

- SAE J1698-2 "Event Data Recorder — Retrieval Tool Protocol," and
- SAE J1698-3 "Event Data Recorder – Compliance Assessment."

Of particular importance to this report is SAE J1698-1, which provides definitions for 84 data elements. Because of the strong representation of the auto industry on the SAE J1698 committee, the SAE J1698 recommended practice essentially provides an industry roadmap to the data elements that are either currently being recorded, planned for near-term enhancements to EDRs, or technically feasible in the long term. This was noted in J1698-1 by classifying the variables. The authors note that technical feasibility should not be construed to imply economic feasibility or consumer acceptability. Two members of the research team, John Hinch and Robert Ruth, are members of the SAE J1698 committee. Both were also members of the J1698-1 task force that rewrote J1698 for consistency with the NHTSA Part 563 on EDRs. The research team got important non-confidential guidance on likely industry directions from this committee. Our findings are presented in this chapter.

We also contacted by e-mail members of the AK-LV37 industry working group, primarily German OEMs, which are developing a guide for how to implement Part 563. We also investigated the progress of the CrashCube group in the Netherlands, which is developing a tool to image freeze-frame data. Many vehicles that do not have EDRs do collect freeze-frame data that does not contain time series data; hence, it does not meet the definition of an EDR given by Part 563.

Results

Near-Term Enhancements to EDR Data Elements

Current status

Based on our analysis of more than 140 MY 2012 EDRs conducted as part of Task 1, many car makers have already incorporated additional data elements beyond those specified in Part 563 Table I. A distribution of these is shown in Table 11, which presents the number of Part 563 Table I, Part 563 Table II, and the number of elements beyond Part 563 Tables I and II by EDR BoschNo family. There are only 15 data elements in Part 563 Table I, but the fifth data element allows for either "engine throttle" or "accelerator pedal." If an EDR family stored both "engine throttle" and "accelerator pedal," we counted this twice in the tabulation. Therefore, some of the BoschNo families stored 16 Part 563 Table I data elements. Some reports also provided two data elements to represent different units, e.g., "Delta V, Longitudinal (mph)" and "Delta V, Longitudinal (kph)." This duplication of data elements for different units was also found for Part 563 Table II, which has 30 data elements. These duplicated elements were only counted once. Counts greater than 30 also occurred when reports gave multiple data elements for pretensioners (i.e., shoulder and lap). On average, OEMs are collecting more than 20 data elements beyond Part 563 Tables I and II. These exclude items such as diagnostic data elements and the standardized "Bosch CDR elements," such as "user entered VIN."

Another interesting way to analyze the advanced data elements is to look at the quantity by actual data element. Table 12 provides a listing of Part 563 Table I and Table II data elements and the number of EDRs that record each.

Table 11. Distribution of data elements found in Part 563 Table I and Table II, as well as other elements

BoschNo	No. Table I	No. Table II	No. Other Elements
CHRY0000	15	12	36
CHRY0305	11	8	40
CHRY0403	16	11	10
CHRY4005	16	12	13
CHRY4101	14	12	39
FordAB10	15	13	34
FordRC6_2011	15	20	30
FordRC62011CGEAD	15	21	14
HONDA001	14	24	3
HYUNDAI	15	27	0
KIA	15	27	0
MAZDA001	15	12	63
MAZDA002	15	19	7
MITSUBISHI	16	24	6
SDM10	9	17	23
SDM10P	16	17	13
SDM11_AUTOLIVNEW	12	13	39
SUZUKI	16	26	38
TOYOTA001	11	6	8
VOLVO001	15	19	24

Table 12. Listing of Table I and Table II Part 563 data elements and the number of MY 2012 EDRs families (BoschNo) that record each

Data Element	Number of BoschNo types that record the data element (out of 20)
Delta V, longitudinal	20
Seat belt status, driver	20
Seat track position switch, foremost, status, driver	20
Maximum delta V longitudinal	19
Ignition cycle, crash	19
Ignition cycle, download	19
Frontal air bag warning lamp	19
Frontal air bag deployment, time to deploy	19
Frontal air bag deployment, time to deploy	19
Multi-event, number of event	19
Complete file recorded	19
Delta V, lateral	19
Seat belt status, right front passenger	19
Speed, vehicle indicated	18
Service brake	18
Time, maximum delta V	17
Engine throttle, % full (or accelerator pedal, % full)	17
Time from event 1 to 2	17
Maximum delta V, lateral	17
Frontal air bag deployment, time to nth stage, driver	17
Frontal air bag deployment, time to nth stage, passenger	17
Engine RPM	15
Seat track position switch, foremost, status, right front passenger	15
Time maximum delta V, lateral	14
Occupant size classification, right front passenger	14
Side curtain/tube air bag deployment, time to deploy, driver side	13
Pretensioner deployment, Time-to-Fire, driver	13
Pretensioner deployment, Time-to-Fire, right front passenger	13
ABS activity	12
Side curtain/tube air bag deployment, time to deploy, right side	12
Steering input	11
Stability control	10
Side air bag deployment, time to deploy, driver	10
Lateral acceleration	9
Longitudinal acceleration	9
Frontal air bag suppression switch status, right front passenger	9
Time for maximum delta V, resultant	7
Frontal air bag deployment, nth stage disposal, driver	7
Frontal air bag deployment, nth stage disposal, right front passenger	7
Side air bag deployment, time to deploy, right front passenger	7
Vehicle roll angle	6
Normal acceleration	4
Occupant size classification, driver	3
Occupant position classification, driver	1
Occupant position classification, right front passenger	1

SAE J1698 data

Over the past few years, the SAE J1698 committee has updated J1698, Event Data Recorders, as J1698-2013 that consists of a suite of recommended practices.

J1698 – Event Data Recorder base document;

J1698-1 – Event Data Recorder – Output Data Definition;

J1698-2 – Event Data Recorder – Retrieval Tool Protocol; and

J1698-3 – Event Data Recorder – Compliance Assessment.

J1698-1 contains output data definitions for 84 data elements. They are listed in the appendices. These data elements are divided into three classifications:

- **Classification I:** Data elements currently found either in the electronic control units or on the communications bus in most vehicles across the industry except some low volume vehicles,
- **Classification II:** Data elements currently found either in the ECUs or on the communications bus in some vehicles but not industry wide, and
- **Classification III:** Data elements either (1) not found in the ECUs or on the communications bus in any current vehicles or (2) only found in a small percentage of vehicles. Further, this data element may be proprietary or not retrievable.

Generally, Classification I items include all the items in Part 563 Table I. Beyond Part 563 Table I, J1698-1 provides guidance for several data topics, including:

1) vehicle dynamics,
2) vehicle location,
3) time and date,
4) vehicle operational statuses (brakes, gear position, etc.), and
5) vehicle fault codes.

Some of these items are found in Part 563 Table II, but others go well beyond, as shown in the appendices. In Table 13, we compared, across manufacturers, the J1698 data elements stored in MY 2012 EDRs extracted from NHTSA crash tests.

Table 13. SAE J1698-1 (rev. 2013) data elements recorded in MY 2012 EDRs

SAE J1698 Data Element Number and Name		Chrysler	Ford	GM	Honda	Hyundai	Mazda	Mitsubishi	Suzuki	Toyota	Volvo	Total OEMs	J1698 Class	563 Table	Notes
6.1.1	Lateral Acceleration	☐	☑	☑	☑	☑	☑	☐	☑	☐	☑	7	II	II	
6.1.2	Longitudinal Acceleration	☐	☑	☑	☑	☑	☑	☐	☑	☐	☑	7	II	II	
6.1.3	Normal Acceleration	☐	☐	☐	☑	☑	☐	☐	☐	☐	☑	3	II	II	
6.2.1	Accident Date - year	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.2.2	Accident Date - Month	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.2.3	Accident Date - Day	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.3.1	Accident Time - Hour	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.3.2	Accident Time - Minute	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.3.3	Accident Time - Second	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.4	Adaptive Cruise Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.5	Ambient Temperature	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	1	III		
6.6	Anti-Lock Brake System Status	☑	☑	☐	☑	☑	☐	☐	☑	☐	☐	5	II	II	
6.7	Blind Spot System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.8	Brake Override Flag	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	II		
6.9.1	Brake Pedal Position	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.9.2	Brake System Internal Pressure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.10	Clipping Flag, XX	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.11	Collision Warning System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.12	Cruise Control System Status	☑	☐	☑	☐	☐	☐	☐	☑	☐	☐	3	III		
6.13.1	Lateral Delta V	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	9	II	II	
6.13.2	Longitudinal Delta V	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	I	I	
6.13.3	Maximum Recorded Lateral Delta V	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	9	II	II	
6.13.4	Maximum Recorded Longitudinal Delta V	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	I	I	
6.13.5	Maximum Recorded Resultant Delta V	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	II	II	
6.13.6	Time to Maximum Recorded Delta V, Lateral	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	8	II	II	
6.13.7	Time to Maximum Recorded Delta V, Longitudinal	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	9	I	I	
6.13.8	Time to Maximum Recorded Delta V, Resultant	☐	☐	☐	☑	☑	☑	☑	☑	☐	☐	5	II	II	
6.14	Door Lock(s) Status	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		

Table 13 (cont'd). SAE J1698-1 (rev. 2013) data elements recorded in MY 2012 EDRs

SAE J1698 Data Element Number and Name		Chrysler	Ford	GM	Honda	Hyundai	Mazda	Mitsubishi	Suzuki	Toyota	Volvo	Total OEMs	J1698 Class	563 Table	Notes
6.15.1	ECU(s) Hardware Part Number(s)	☐	☐	☐	☐	☐	☐	☑	☐	☑	☐	2	II		
6.15.2	ECU(s) Serial Number(s)	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐	2	II		
6.15.3	ECU(s) Software Part Number(s)	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	1	III		
6.15.4	ECU(s) Power Applied	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	1	III		
6.15.5.1	ECU(s) Life Timer at event	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	3	II		
6.15.5.2	ECU(s) Life Timer, at imaging	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	II		
6.15.6	Event Data Recording Complete	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	I	I	
6.16	Electronic Stability Control System Status	☑	☑	☐	☑	☑	☐	☐	☑	☐	☐	5	II	II	
6.17	Electronic Stop Start	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.18	Front Wiper Status	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.19	Gear Position	☑	☑	☐	☐	☐	☐	☐	☑	☑	☐	4	II		
6.20	Gear Selection Status	☑	☑	☐	☐	☐	☐	☐	☑	☐	☐	3	III		
6.21	Headlight Status	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.22.1	Ignition Cycle at Event	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	I	I	
6.22.2	Ignition Cycle at Imaging	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	9	I	I	
6.22.3	Ignition Button Counter per key cycle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.23.1	Brake Warning Indicator Status	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.23.2	Door(s) Ajar Indicator Status	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.23.3	Occupant Protection System Warning Lamp Status	☑	☑	☑	☑	☑	☑	☑	☐	☐	☑	8	I	I	
6.23.4	Occupant Protection System Warning Lamp On Time	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	2	III		GM uses (sec), J1698 unit is (min)
6.23.5	Number of Cycles Occupant Protection System Warning Lamp Has Been On	☐	☐	☑	☐	☐	☐	☐	☐	☑	☐	2	III		
6.23.6	Passenger Frontal Air bag Disabled Indicator Status	☐	☐	☑	☐	☐	☐	☐	☑	☐	☐	2	II	II	
6.23.7	Powertrain Control Module Malfunction Indicator Status (PCM MIL Status)	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	2	II		
6.23.8	Tire Pressure Monitoring System Warning Lamp Status	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	2	II		
6.24	Lane Departure System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.25	Latitude	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.26	Longitude	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.27	Manifold Absolute Pressure (MAP) (if applicable)	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	1	II		*Raw Manifold Pressure (kPa)
6.28	Mass Airflow (if applicable)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	II		

Table 13 (cont'd). SAE J1698-1 (rev. 2013) data elements recorded in MY 2012 EDRs

SAE J1698 Data Element Number and Name			Chrysler	Ford	GM	Honda	Hyundai	Mazda	Mitsubishi	Suzuki	Toyota	Volvo	Total OEMs	J1698 Class	563 Table	Notes
6.29	Minutes in Operation at Event		☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	1	III		
6.30.1	Occupant Protection Device Deployment Status		☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	II		
6.30.2	Occupant Protection Device Deployment Time	Driver/Passenger Frontal Air Bags	☑	☑	☑	☑	☐	☑	☑	☑	☑	☑	9	I	I	
		All Other Occupant Protection Devices or Air Bag Stages	☑	☑	☑	☑	☐	☑	☑	☑	☑	☑	9	II	II	
6.31	Parking Brake Switch Status		☑	☑	☑	☐	☐	☐	☐	☑	☑	☐	5	III		*Brake Switch #2 Status
6.32	Propulsion Source Torque		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.33.1	Pitch Angle		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.33.2	Roll Angle		☐	☑	☐	☐	☑	☐	☑	☐	☐	☑	4	II	II	
6.33.3	Yaw Angle		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.34.1	Pitch Rate		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.34.2	Roll Rate		☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	2	II		*Stability Control Roll Rate
6.34.3	Yaw Rate		☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	2	II		*Stability Control Yaw Rate
6.35	Revolution Per Minute (RPM) - (Internal Combustion engines only)		☑	☑	☑	☑	☑	☐	☑	☑	☑	☐	8	I	II	
6.36	Seat belt Status	Driver/Passenger Frontal Air bags	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	9	I	I	
		All Other Seating Positions	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	9	II	II	
6.37	Seat Track Position Switch; Forward: Status		☑	☑	☑	☑	☑	☑	☑	☐	☐	☑	8	II	II	
6.38	Service Brake, On and Off		☑	☑	☐	☑	☑	☑	☑	☐	☐	☑	7	I	I	
6.39	Speed Vehicle Indicated		☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	10	I	I	
6.40	Steering Input		☑	☐	☐	☑	☑	☐	☐	☐	☐	☐	3	II	II	
6.41.1	Event Synchronization Timer		☐	☑	☐	☐	☐	☐	☑	☐	☑	☐	3	III		
6.41.2	Pre-Event Synchronization Timer		☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	1	III		
6.42	TEND		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	II		
6.43.1	Engine Throttle Position, Percent Full (Internal Combustion engines only)		☑	☐	☑	☐	☐	☑	☑	☐	☐	☐	4	I	I	
6.43.2	Accelerator Control (Pedal) Position, Percent Full		☑	☑	☑	☑	☐	☐	☑	☑	☑	☑	8	I	I	
6.44	Time from Event X to X+1		☑	☑	☑	☐	☑	☑	☑	☑	☑	☑	9	I	I	
6.45	Traction Control System Status		☑	☑	☐	☐	☐	☐	☐	☑	☐	☐	3	II		
6.46	Turn Signal Switch Status		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0	III		
6.47	Vehicle Identification Number		☑	☑	☑	☑	☐	☑	☐	☐	☑	☑	7	II		
6.48	Vehicle Mileage		☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	1	III		
Total			41	36	30	27	26	24	25	28	20	22				

Plans for Installations in Vehicles Between 8,500 and 10,000 lbs. GVWR

Currently, Part 563 only applies to vehicles with a GVWR of 8,500 lbs. or less and an unloaded weight of 5,500 lbs. or less. Of the OEMs that we interviewed, only Chrysler, Ford, and GM manufactured vehicles between 8,500 and 10,000 lbs. GVWR. Ford told us that they install ACMs in vehicles weighing more than 8,500 lbs., but these EDRs generally have fewer data elements than lighter weight vehicles. GM indicated that its C/K pickups (i.e., models 1500 to 3500) have the same SDM across the line as they use a single, common air bag design. One supplier told us that they usually develop a family of modules without any exceptions in that family. They were not aware of excluding EDRs in vehicles greater than 8,500 lbs. simply because the vehicle crossed the 8,500 lbs. GVWR boundary.

Plans for Additional Events That Trigger Recording

Pedestrian impact triggers in future EDRs

For future EDRs beyond MY 2013, the suppliers told us that several OEMs are working to record pedestrian impacts. One supplier told us that for pedestrian impacts, some OEMs with hood-lifters or windshield bags might record this as a separate event. A separate EDR is being developed to record pedestrian protection systems. This dedicated event slot would just be for pedestrians. There would be no sharing of slots between pedestrian impacts and non-pedestrian impacts. This segregation of events is being pursued because of the worry that recording a pedestrian event may interfere with recording a non-pedestrian 5 mph event. They expressed concern about how to record restraint deployments, which occur in parallel (not restricted to pedestrian events), and about how to handle linked events. They want to avoid the need for a complicated hierarchy of event importance to dictate overwriting.

The suppliers told us that many OEMs are trying to redesign their vehicles to capture pedestrian impacts. However, with the existing vehicle sensors, they feel that the minimum vehicle delta V threshold to trigger other events is too large for reliable detection of pedestrian impacts. As an alternative, some suppliers are using a contact switch of sorts, which detects pressure behind bumper fascia to decide whether to deploy pedestrian impact countermeasures. This will be a possible trigger threshold for future EDRs. For pedestrian impacts, recording would be independent of the event magnitude, but would instead be triggered only if the vehicle deployed a pedestrian countermeasure like a pop-up hood.

SAE J1698 future work

With the recent publication of the J1698 series, the J1698 committee has refocused its efforts on new technology and advanced data elements associated with the technology. The first technology being reviewed is Pedestrian Protection. This new group started in mid-2013 and thus far has not developed a comprehensive list of data elements.

Plans for Adding New Data Elements

The OEMs and suppliers were asked about near-term plans to add new data elements to Part 563-compliant EDRs that are either in Part 563 Table II or go beyond Part 563 Table II. Beyond Part 563 Table II, there was interest in adding:

- Higher sampling frequency and longer recording interval for pre-crash data, i.e., sampling frequency better than 1/10 of a second,
- System fault information,
- Information to facilitate reconstruction of deployment decision (which sensors contributed to decisions, which sensors failed). Some of this data may not be revealed in Bosch CDR report, e.g., internal deployment decisions information,
- Stability control sensor data: more and more electronic stability control sensors are stored in the ACM,
- A dedicated event for rollover,
- Satellite sensors,
- Begin to record non-deployment rollover data,
- Active Safety Elements, e.g., adaptive cruise control,
- Hybrid/Electric vehicle elements,
- Diagnostics that record the occurrence of data clipping,
- Brake pedal position,
- Unintended acceleration diagnostic parameters, e.g., brake light switch, commanded throttle, and actual throttle, if crash data is recorded,
- Brake override switch, and
- Hybrid battery diagnostics.

The data transmission speed on the vehicle's CAN bus is one limiting factor to getting high sampling frequency for dynamic data. Another limitation is ACM processing speed. Higher speed CAN buses, e.g., Flex-Ray, may permit acquisition of pre-crash data at higher sampling frequencies.

EDR Imaging Strategies

This section describes newly available or planned data imaging strategies for reporting of EDR data. All suppliers and OEMs stated that their EDRs can be read both by connecting through the OBD-II connector or directly to the module.

Download tool availability for MY 2013 modules

Part 563 requires that manufacturers make a tool available but does not specify which tool. For MY 2013 and later modules, most OEMs, including BMW, Chrysler, Ford, GM, Honda, Mazda, Nissan, Toyota, and Volvo, are using the Bosch CDR tool. Daimler is planning to use the Bosch CDR tool for MY 2014 vehicles. Six manufacturers, however, are known to use a tool provider other than the Bosch CDR System. This section summarizes each of these tools.

Bosch CDR tool

For MY 2012 EDRs, this tool supports Chrysler, Ford, GM, Honda, Mazda, Toyota, and Volvo. For MY 2013 EDRs, support was expanded to include Nissan and BMW. The complete CDR Tool Kit (Part #: CDG3333-1), which contains all cables, the download module, and power supply, costs $8,999. A less expensive package, which permits download from the OBD-II, only costs $1,500. In addition, the annual software license costs $899. The tool requires user input of the VIN and produces a CDR file, in addition to CSV and PDF formats. The CDR file contains the hex data and updates with software changes, eliminating the need to read the module again.

Hyundai

MY 2013 Hyundai EDRs can be read using a derivative of its dealership scan tool made by the GIT Tool Company. The Hyundai tool is sold by GIT America (Part G0ZHDMN001) and, as of June 2013, costs $3,950 and includes an additional MY 2014 cable.

The Hyundai kit includes software for Vehicle Communication Interface (VCI; the derivative of the dealer scan tool), a OBD-II connector cable and six OBD-II-to-module adapters. The tool comes with a printable instruction manual and is relatively easy to use. Purchasers are notified via e-mail if software updates are required and receive the first year of updates as part of the hardware purchase. GIT indicates that the software subscription must be renewed annually for $195.

The tool requires input of the model and model year. The tool indicates that only MY 2013 is supported; however, our experience is that MY 2010-2012 NCAP crash test Hyundai EDRs could be read. Hyundai does not publish which models are supported.

The readout can only be saved as a PDF file and there is no raw hexadecimal electronic file saved for possible later reinterpretation if a software conversion error is discovered. The module would have to be re-read to learn if any later software changes affected the data. In addition, the program does not require input of a VIN to run, and the report does not contain the VIN or module serial number so being able to attribute a file to a specific vehicle and crash must rely on physical documentation.

Hyundai ACMs are made by Bosch, Delphi, Continental, and Autoliv, but the EDR contents appear to be standardized. The report format does not resemble Bosch CDR reports. Instead, each parameter is displayed on a separate graph with a separate data table. The overall information, however, is similar to that found in a Bosch CDR system report.

Kia

Kia and Hyundai share product development, and some common vehicle models use identical ACMs. However, Kia and Hyundai have a "firewall" between their two dealer organizations and service tools, thus pricing for Kia is different than for Hyundai. The Kia tool must be ordered from Kia (part GIT0ZKDMN001). The original price in March 2013 of $3,767 has been raised to $4,380 as of June 2013.

The Kia kit comes with software, VCI, an OBD-II cable, and 6 direct-to-module cables. The VCI has a red applique but is otherwise identical to the Hyundai VCI with a blue applique. The Kia software lists only Kia models, but operates in the same fashion as the Hyundai software. The Kia software and VCI will read some Hyundai modules but would label the report with the Kia model selected during the software setup. Of the six direct-to-module cables, three are common to the Hyundai kit, and three are unique. There are 10 cables in all to cover both Kia and Hyundai. Once both systems have been purchased to get both software packages, it is possible to use each kit to read both brands, as long as a unique module cable is not required. If the vehicle electrical system is compromised, the user must supply power to both the ACM fuse and the OBD-II fuse for the VCI to get power from the interface (there is no provision to insert power directly into the VCI without using a direct-to-module cable). There are additional cables required for MY 2014, but they are common to the Hyundai cables already in the Hyundai kit.

Subaru

Subaru uses its dealer scan tool exactly as is. The tool can be purchased for $2,835 plus $1,835 for an annual software subscription. For low-volume users, it may be possible to hire a dealer to do the readout with the dealer's tools. The scan tool plugs into the vehicle OBD-II port and is powered by the OBD-II connector. There is no direct-to-module cabling available. The software has a drill-down menu for diagnostics, and the EDR function is found under the ACM. Our team worked with a dealer technician to try to access the EDR data in a new vehicle, using his laptop and the scan tool. Communication with the EDR was successful, but the vehicle had not been in a crash and thus no data was recorded, which prevented the file from saving. The dealer technician was under the impression that a dedicated laptop may be required along with the scan tool, but when we contacted Subaru to ask about purchasing the tool, this claim was not supported.

Mitsubishi

Mitsubishi uses its dealer scan tool exactly as is. The software comes loaded on a dedicated Panasonic Toughbook laptop and the total cost is $9,050 (part MIT540031-EDR). The tool is made by the former Owatonna Tool Company, subsequently purchased by SPX, subsequently purchased by Bosch in 2012. There is currently no information suggesting integration with the CDR tool. It is also not known if the tool covers only MY 2013 or covers some back models. A 2013 SAE paper featured EDR data from a 2009 Mitsubishi Lancer, which had the Mitsubishi tool pictured (Vandiver et al., 2013). There was no provision for attaching directly to the module. Communication with the EDR was through the OBD-II port.

Jaguar/Land Rover

Jaguar/Land Rover (Tata Motors, India) uses its dealer scan tool. Jaguar/Land Rover personnel provided a paper order form indicating a dedicated Panasonic Toughbook laptop loaded with software is required, at a cost of approximately $5,000. The file retrieved is a hexadecimal file, and no interpretation is available at the time of the readout. The hexadecimal file must be sent to engineers in England for decoding. As of this writing, the authors are not aware of anyone who has read a file and requested the interpretation. Like the Mitsubishi tool, toolmaker OTC/SPX was purchased by Bosch in 2012.

Saab

Saab uses a dealer scan tool similar to Subaru. The authors received information that the hardware is the same as Subaru, but Saab requires its own software with a $1,835 annual renewal fee.

We are under the impression that a different dedicated Panasonic Toughbook is needed for each manufacturer using that platform because the devices are purchased preloaded with software and are configured such that the software cannot be transferred to another computer. Thus, it is a security feature to prevent purchasers from sharing bootleg copies of the software with other repair shops.

European Projects and Groups

<u>CrashCube</u>

The CrashCube project aims to develop a data reading tool, called CrashCube, intended to collect stored crash information from vehicles that are not equipped with EDRs, as well as develop a second tool, called VINCube, to extract the VIN of all parts in a vehicle. The project vision is to promote the mandating and legislation of EDRs in Europe, motivated by Part 563. The CrashCube Project was developed by the Netherlands' Rotterdam-Rijnmond Police Force and supported by the Netherlands Forensic Institute (NFI), RDW/LIV (Driver and Vehicle Licensing Agency), Directorate-General for Public Works and Water Management (Rijkswaterstaat; RWS), and Launch Tech Co. Ltd. China.

The CrashCube is a handheld device that uses the OBD-II port to readout freeze frame data via the CAN bus following a crash. Early project goals were to use all important vehicle modules, particularly the ABS/ESC unit, engine control unit, air bag control unit and drive train control unit. This would be supplemented with the instrument panel information. Vehicle speed, seat belt usage, time of accident, steering angle, moment of brake application, engine RPM, and engine temperature are among a few of the elements given by the tool. Moreover, CrashCube was designed to merely be a "forensic tool", incapable of deleting fault codes or changing parameters. Anti-tampering measures were also intended to be placed on the output data extracted.

The first test phase provided the device to 200 Dutch police officers throughout the Netherlands, initially supporting only Volkswagen, Seat, Škoda, BMW, Audi, and Mercedes. Early reports from this phase described the data readouts to be unstandardized across vehicles. As a result, a second test phase in the Netherlands was conducted with a software update. On November 30, 2011, it began a third test phase across the European Union in Ireland, Slovenia, Spain, Switzerland, and the United Kingdom. The EU test phase was completed September 11, 2012, and supported Volkswagen, Mercedes, Audi, BMW, Peugeot, Citroën, Volvo, Škoda, Ford, Nissan, Opel, Fiat, Toyota, Renault, Jaguar, Land Rover, Saab, and Seat.

Since that time, recent updates indicate that the CrashCube is compatible with all light vehicles of MY 2006 and greater. Support for commercial vehicles is not yet available, but is an intended function of the tool and RWS is aiding CrashCube in this area. Beyond the tool itself, the CrashCube group has enlisted the help of the University College of Dublin Computing and Cybercrime Investigation program to create online training courses for the tool.

Updates from October 2012 indicate that the CrashCube is not on sale, but the project is being transferred to a third party. Early validation results conducted by TÜV-Rheinland TNO Automotive International compared speed data from CrashCube and Ross-Tech VCDS[5] in a frontal, right-hand side, 50 percent overlap test of a 2006 Volkswagen Golf at 70 kph (43 mph). CrashCube reported 68 kph (42 mph), similar to VCDS (Spek & Bot, 2012).

European AK-LV37 working group

In Germany, the informal organization, Arbeitskreis (AK, "working group"), comprising Audi, BMW, Daimler, Porsche, and Volkswagen, is developing a statement of recommended practice for EDRs. AK's work is similar to SAE's in that it, too, recommends automotive practices. AK addresses safety electronics. Its unpublished practices are called AK-LV, working group delivery specifications. The five German OEMs regulate themselves by appending the practice to their internal procedures. However, each OEM is not bound to the guidelines discussed as a group and may implement internal deviations.

AK is responsible for a set of guidelines called AK-LV37 that address EDRs. AK-LV37 was created to elaborate upon Part 563 and provide a table-based approach to detailing implementation of EDRs. The practices specified by AK are compatible with Part 563 and are largely congruent to the data element requirements of SAE J1698-1. The intent of AK-LV37 is to more carefully define some parts of Part 563 and prevent divergent implementation. For some data elements, AK-LV37 provides stricter specifications (e.g., capturing six events as opposed to two). Beyond Part 563, AK-LV37 offers a protocol for diagnosis-requests to read the EDR via the CAN bus and guidelines for software uniformity with the United States and other regions. It also addresses event handling, aligning of time zero, and pedestrian detection (Platte, 2011, and personal communication with Cunningham, A., Volkswagen Group of America, Inc., July 1, 2013).

[5] Diagnostic Software for VW-Audi Group Cars, Ross-Tech, LLC, http://store.ross-tech.com/shop/VPULTRA.html.

Findings

Near-Term Enhancements to EDR Data Elements

- Many car makers have already incorporated additional data elements beyond data elements specified in Part 563, Table I and Table II. Both Chrysler and GM, for example, record well over 100 data elements beyond Part 563.
- The recent revision of SAE J1698 provides another method to assess automaker perspectives in plausible near-term enhancements for EDRs. J1698 provides a list of 84 data elements categorized into Classification 1 (currently in EDRs), Classification 2 (in some but not all EDRs), and Classification 3 (potential future EDR data elements). Many current EDR data elements, not in Part 563, are in Classification 2, and are currently being recorded.

Plans for Installations in Vehicles Between 8,500 and 10,000 lbs. GVWR

Several of the OEMs that we interviewed told us that their manufactured vehicles with a GVWR of 8,500 to 10,000 lbs. currently have EDRs. Neither the automakers nor suppliers that we interviewed were aware of excluding EDRs in vehicles weighing more than 8,500 lbs. simply because the vehicle crossed the 8,500 lbs. GVWR boundary.

Plans for Additional Events That Trigger Recording

Several OEMs and suppliers are developing the capability to record pedestrian impacts in EDRs. In general, this EDR capability would support assessment of pedestrian impact countermeasures in some current vehicles and those being developed for other vehicles. Note that there is concern that the vehicle delta V associated with a pedestrian collision may be too small for reliable detection of pedestrian impacts. Automakers are developing other approaches to detect pedestrian impacts and trigger EDR recording.

Plans for Adding New Data Elements

OEMs and suppliers are considering adding data elements and/or data element recording capabilities that go beyond Part 563 Table II. Examples of new data elements include dedicated events for rollover events and pedestrian impacts, higher sampling frequency and longer recording intervals for pre-crash data, active safety system data elements, and specialized hybrid/electric vehicle data elements.

EDR Imaging Strategies

Part 563 requires that manufacturers make an imaging tool available but does not specify which tool. Most OEMs, including BMW, Chrysler, Ford, GM, Honda, Mazda, Nissan, Toyota, and Volvo, are using the Bosch CDR tool for MY 2013 vehicles. Daimler is planning to use the Bosch CDR tool for MY 2014 vehicles. Six manufacturers, however, are known to have chosen to use a tool provider other than the Bosch CDR System.

European Projects and Groups

The CrashCube Project, developed by the Netherlands' Rotterdam-Rijnmond Police Force, aims to (1) develop a data reading tool, called CrashCube, intended to collect stored crash information from vehicles that are not equipped with EDRs and (2) develop a second tool, called VINCube, to extract the VIN of all parts in a vehicle. The project vision is to promote the mandating and legislation of EDRs in Europe, motivated by Part 563.

The AK-LV37 working group is developing a statement of recommended practice for EDRs. The practices specified by the AK are compatible with Part 563 and largely congruent to the data element requirements of SAE J1698-1. The intent of AK-LV37 is to more carefully define some parts of Part 563 and prevent divergent implementation. For some data elements, AK-LV37 provides stricter specifications (e.g., capturing six events as opposed to two). The AK-LV37 provides an indication of likely near-term enhancements to EDRs that will be pursued by German OEMs.

4. Task 3 — Assessment of Potential Updates to Light-Vehicle EDR Technologies

Objective

The goal of this task was to conduct an assessment of potential updates to EDR installations and technologies for light passenger vehicles and LTVs, i.e., those with GVWRs of 10,000 lbs. or less. Specific objectives include reviewing the costs and benefits of alternate data ports for collecting future EDR data, reviewing the factors related to increased recording time, examining additional data elements for inclusion in future EDRs, and determining the standardization needs for future EDR data collection and access.

Approach

The research team explored these objectives through several avenues including:

1) OEM and supplier interviews,
2) NASS/CDS data analyses,
3) Review of current OEM and supplier EDR readers,
4) Review of past NHTSA and other automotive cost studies, and
5) Discussions with companies and universities who collect and store large databases.

OEM and Supplier Interviews

The research team conducted five OEM interviews and three supplier interviews. During these interviews, we asked questions regarding the objectives in this task. All OEMs and suppliers asked that their specific data be considered confidential; hence, we are presenting summaries of the answers, and do not attribute any answer to any particular company. These interviews were instrumental in determining their strategies associated with EDR memory and additional data channels.

Our approach also used a data driven method to determine the least damaged areas of an automobile (e.g., under dash, trunk, under driver seat) in a motor vehicle crash. This allowed us to assess alternate connector locations.

The research team leveraged previous NHTSA cost studies to obtain an estimate of the costs associated with adding technology such as alternate port types (e.g., OBD-II and USB) as well as wireless connection technology. Benefits for these systems are estimated and include reductions in required EDR reading paraphernalia.

The approach for storage of EDR field data in a database, database retrieval policy updates, and public access to an EDR database is based on interviews of companies who do similar work and costing a standalone system, similar to NHTSA's Fatality Analysis Reporting System.

Alternative EDR Data Access Port Locations

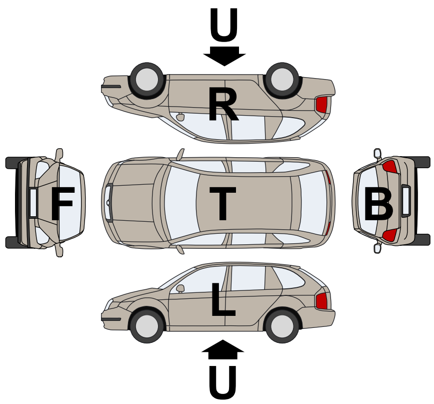
Currently, access to EDR data is obtained either through the OBD-II connector or by directly plugging into the ACM or the PCM. These connectors are typically located towards the front of the vehicle. Specifically, the standardized OBD-II connector is located near the steering wheel, as specified by SAE J1962. Among ACMs and PCMs that are supported by the publically available Bosch CDR tool v.10.2, the most common placements are in the center stack and engine compartment, respectively. However, EDR placement is not exclusive to these locations (e.g., early EDRs were installed under one of the front seats).

In a small percentage of real-world crashes, however, EDRs cannot be read due to vehicle damage. This could refer to direct damage to the modules or indirect damage that prevents access to the OBD-II or modules. Mitigation of this problem could take several forms: (1) alterative locations for a connector, e.g., car trunk, (2) alternative port types, e.g., USB, Ethernet, and (3) implementation of wireless connection. A standardized connection would moreover eliminate the current burdensome need for the investigator to carry large numbers of download cables.

The research team asked the OEMs and suppliers if they incorporated any alternate connector locations, beyond those typically used, i.e., the OBD-II port and direct connection to the EDR. All those who answered indicated there were no additional connectors.

The OEMs and suppliers stated that wiring costs could be high, depending on the distance from the access port to the EDR enclosure. Additional space in the current connectors would be required, as well as a potential connector at the location of the port. Finally, there would be no guarantee that data would be retrievable via an alternate port if it was not accessible via the OBD-II port.

With no OEM guidance to investigate, the research team focused on quantifying the locations and extents of deformation during a real-world crash to establish regions that are less susceptible to damage. This information can be extracted from NASS/CDS, a database containing a random sample of crashes from which trained crash investigators analyze and collect data. Our dataset was comprised of cases that occurred between the years 2005 and 2010. Each year included approximately 5,000 cases. Each case contains a weighting factor that allows us to estimate the national frequency of similar cases.



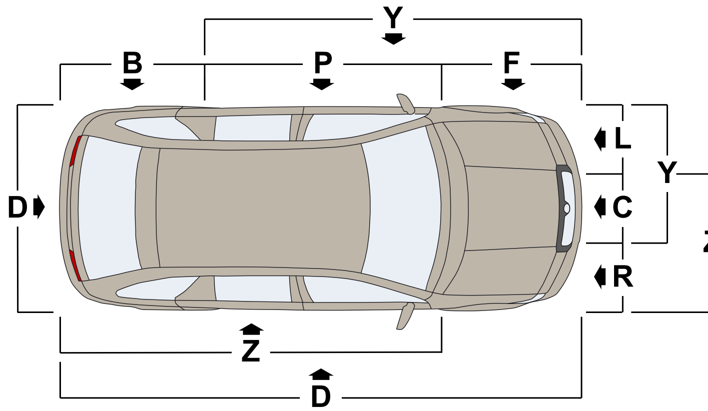


Figure 2. General area of damage (GAD).

Figure 3. Specific longitudinal locations (SHL) of deformation.

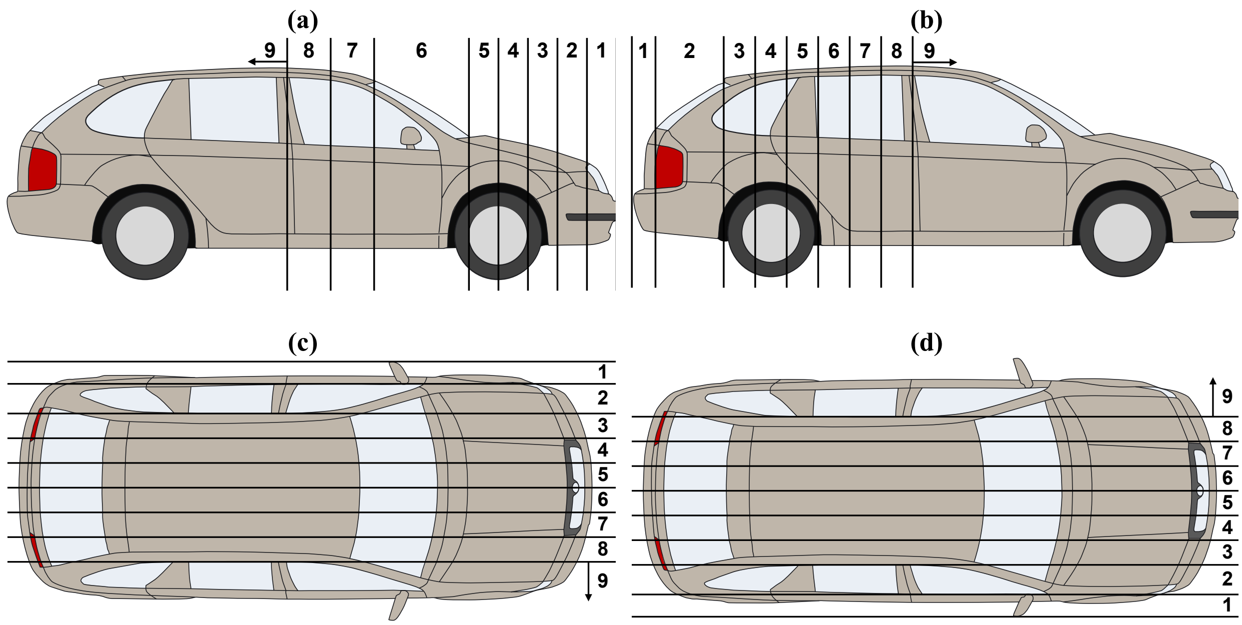


Figure 4. Zones of deformation extent based upon vehicle landmarks for (a) frontal, (b) rear, (c) left, and (d) right damage.

The cases were first selected by their general area of damage ("GAD1"), shown in Figure 2. This study analyzed frontal (GAD = F), side (GAD = L, R), and rear (GAD = B) crash mode damage exclusively. NASS/CDS additionally uses SAE J224 guidelines to indicate the specific longitudinal or lateral location (sometimes called "specific horizontal location," "SHL1") and the corresponding extent of deformation ("Extent1"). These regions are detailed in Figure 3. As the grouped regions are independent of direction (SHL = Y, Z, D), this information allows us to determine which sub-regions were damaged. The extents are shown in Figure 4 (a-d). Note that the zones of extent are based upon the vehicle landmarks of the body type and not equally divided. For frontal deformation, the first five zones are equally spaced. The end of the fifth zone is located at the lower edge of the front windshield. For side deformation, zone 1 ends at the maximum side protrusion and base of the side window glass. Zone 2 ends at the top of the side glass. Zones 3 through 8 are equally spaced, and the end of the fifth zone divides the vehicle into equal halves. Rear deformation varies with the vehicle type. Hatchbacks, vans, and station wagons are defined in the same way as side deformation. The first two zones are defined by the backlight and zones 3 through 8 are equally spaced. For other vehicle types, such as sedans and pickups, rear deformation is defined in the same manner as front deformation.

Within our dataset, we determined the weighted frequency and percentage of frontal, rear, and side crash modes. For each general area of damage, a distribution of extent is given for each SHL.

Results

Alternative EDR Data Access Port Locations

Our dataset contained 30,118 case vehicles, which, after the weighting factors, produced 12,496,634 weighted vehicles for inclusion in the analysis, as seen in Figure 5. The majority of vehicles analyzed (7,458,039 vehicles or 60%) were frontally damaged. Vehicles damaged on the side made up 27 percent (or 3,352,759 vehicles), and vehicles damaged in the rear made up 13 percent (or 1,685,836 vehicles) of our dataset.

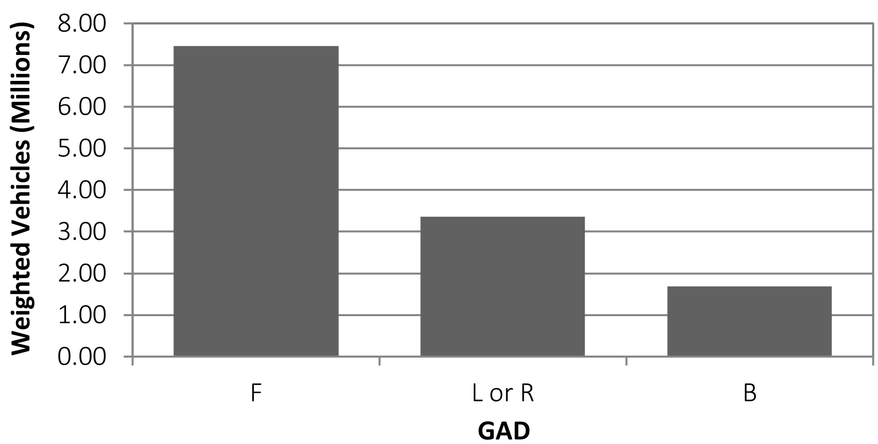


Figure 5. Distribution of vehicles by general area of damage (GAD), where F = Front, L or R = Side, B = Rear.

General area of damage: Front

For each SHL, Figure 6 shows the cumulative percentage of vehicles in a frontal crash for a given damage extent. In this crash mode, almost 50 percent (or 3,551,080) of weighted vehicles had damage across the entire front of the vehicle (SHL = D). The grouped regions (SHL = D, Y, Z) exhibited similar trends in cumulative percentage with increasing damage extent: more than 50 percent of vehicles showed zone 1 damage; 90 percent showed, at most, zone 2 damage; and over 95 percent of vehicles showed, at most, zone 3 damage. Zone 3, in this context, is located approximately midway to the front windshield. Offset, frontal damage (SHL = L, R) also exhibited similar trends, which were more severe than damage solely to the center (SHL = C).

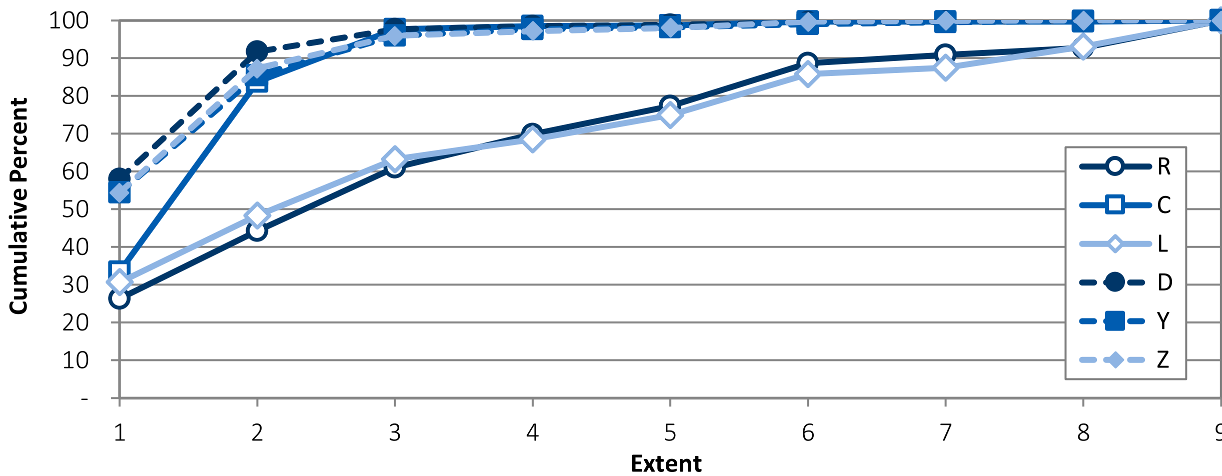


Figure 6. Weighted distribution of SHL by extent for frontal deformation.

A distribution of grouped zone damage extent by SHL is shown in Table 14. Less than 10 percent of vehicles involved in a frontal collision showed deformation beyond zone 5. Only 2 percent of vehicles in this crash mode show deformation that extended to zone 9, made up almost exclusively of offset locations (SHL = L, R). In contrast, 99 percent of center damage (SHL = C) does not extend beyond the front windshield (zone 5), showing that the center of the vehicle is less susceptible to deformation compared to the sides in a frontal crash mode.

Table 14. Weighted distribution of specific longitudinal location for frontal deformation

	B	C	D	F	L	P	R	Y	Z	Sum
Percentage of Total	-	1.46	47.61	-	14.13	-	11.88	12.28	12.63	100.00
Extent = zone 1-4	-	1.44	46.95	-	9.69	-	8.29	11.99	12.28	90.64
Extent ≥ zone 5	-	0.02	0.67	-	4.44	-	3.59	0.29	0.35	9.36
Extent ≥ zone 6	-	0.02	0.52	-	3.55	-	2.70	0.21	0.24	7.24
Extent ≥ zone 7	-	0.00	0.21	-	2.00	-	1.35	0.11	0.04	3.72
Extent ≥ zone 8	-	0.00	0.11	-	1.76	-	1.08	0.06	0.01	3.02
Extent ≥ zone 9	-	0.00	0.09	-	0.98	-	0.87	0.02	0.00	1.96

General area of damage: Side

A cumulative percentage of vehicles in a side crash for a given damage extent is shown in Figure 7. In a side crash mode, the most commonly damaged region was across the front and passenger compartment of the vehicle (SHL = Y); however, the damage extent does not vary much according to the region. Across all SHL, approximately 30 percent of vehicles showed zone 1 damage; 75 percent showed, at most, zone 2 damage; and more than 95 percent of vehicles showed, at most, zone 3 damage.

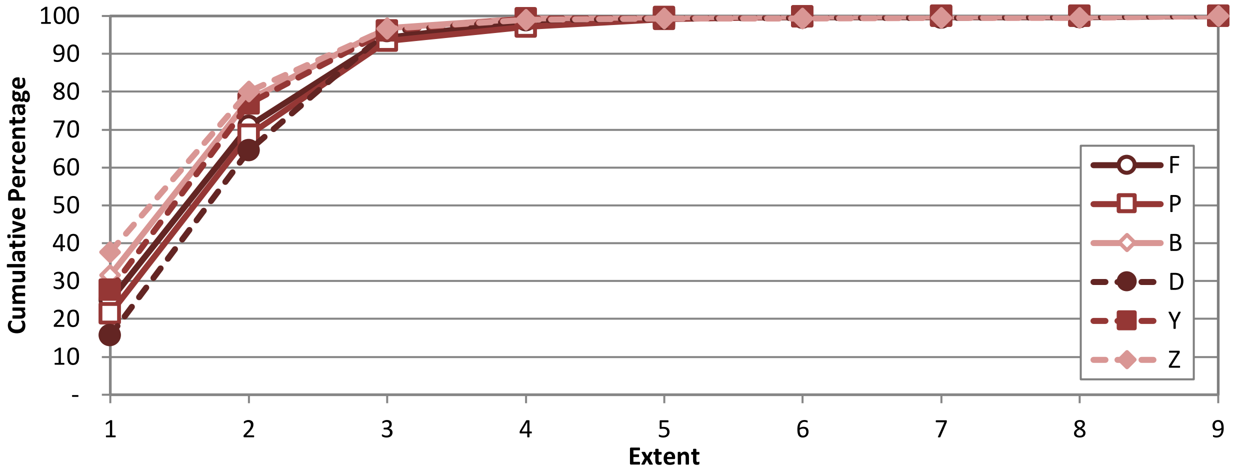


Figure 7. Weighted distribution of SHL by extent for side deformation.

Table 15 shows a distribution of grouped zone damage extent by SHL. Less than 2 percent of these vehicles showed deformation beyond zone 4. Regardless of SHL, 99 percent of the damage extent did not exceed zone 4. Therefore, deformation exceeding the vehicle centerline (zone 5) is rare, occurring in 1 percent of vehicles in side crashes.

Table 15. Weighted distribution of specific longitudinal location of side deformation

	B	C	D	F	L	P	R	Y	Z	Sum
Percentage of Total	6.71	-	13.37	19.09	-	12.21	-	28.90	19.72	100.00
Extent = zone 1-4	6.67	-	13.22	18.84	-	11.87	-	28.68	19.53	98.80
Extent ≥ zone 5	0.04	-	0.18	0.26	-	0.34	-	0.22	0.19	1.20
Extent ≥ zone 6	0.02	-	0.09	0.11	-	0.10	-	0.12	0.13	0.57
Extent ≥ zone 7	0.01	-	0.07	0.06	-	0.02	-	0.04	0.12	0.31
Extent ≥ zone 8	0.01	-	0.06	0.06	-	0.01	-	0.02	0.11	0.26
Extent ≥ zone 9	0.01	-	0.05	0.05	-	0.00	-	0.01	0.11	0.23

<u>General area of damage: Rear</u>

Figure 8 shows the cumulative percentage of vehicles in a frontal crash for a given damage extent. In a rear crash mode, more than 50 percent (957,997 vehicles) indicated damage across the entire rear of the vehicle (SHL = D). The grouped regions (SHL = D, Y, Z) exhibited similar extent trends, where 95 percent of vehicles showed damage between zones 1 and 5. Zone 5 is defined as the start of the rear backlight or midway in the trunk depending on the vehicle. Offset, frontal damage (SHL = L, R) was often more severe than damage solely to the center (SHL = C), similar to the frontal collision distributions.

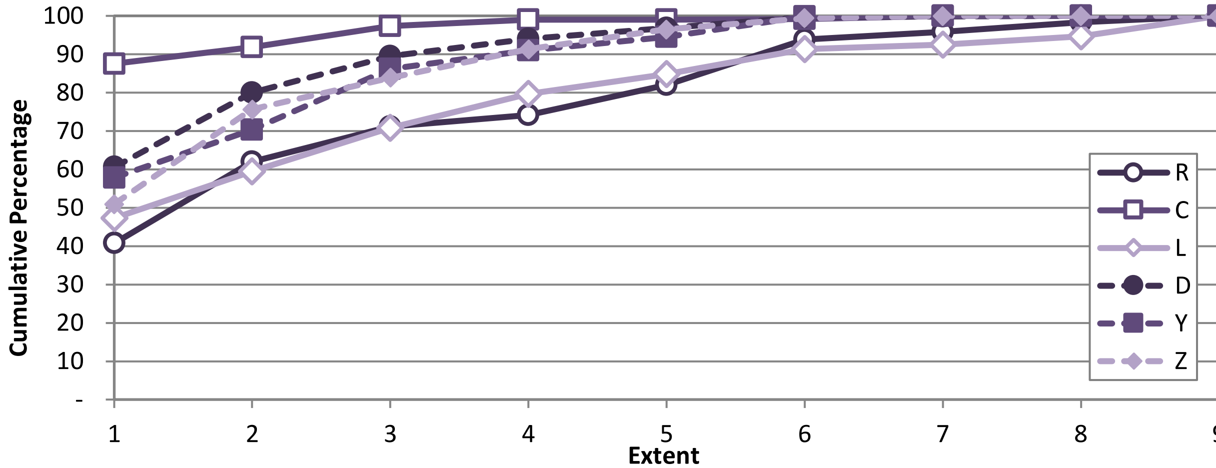


Figure 8. Weighted distribution of SHL by extent for rear deformation.

A distribution of grouped zone damage extent by SHL is shown in Table 16. Similar to vehicles in a frontal crash, less than 10 percent of vehicles in a side collision showed deformation beyond zone 4. Less than 1 percent of vehicles showed deformation that extended to zone 9, composed primarily by offset locations (SHL = L, R). Note, that 99 percent of the damage to the center did not exceed zone 5, showing again that the center of the vehicle is less susceptible to deformation compared to the sides in a rear crash mode.

Table 16. Weighted distribution of specific longitudinal location of rear deformation

	B	C	D	F	L	P	R	Y	Z	Sum
Percentage of Total	-	1.54	56.83	-	7.88	-	6.40	16.03	11.34	100.00
Extent = zone 1-4	-	1.52	53.38	-	6.28	-	4.74	14.58	10.35	90.84
Extent ≥ zone 5	-	0.01	3.44	-	1.60	-	1.66	1.45	0.99	9.16
Extent ≥ zone 6	-	0.01	1.76	-	1.20	-	1.15	0.89	0.40	5.41
Extent ≥ zone 7	-	0.01	0.22	-	0.69	-	0.39	0.02	0.07	1.40
Extent ≥ zone 8	-	0.00	0.08	-	0.59	-	0.26	0.01	0.00	0.94
Extent ≥ zone 9	-	0.00	0.01	-	0.42	-	0.10	0.00	0.00	0.54

Summary

Centrally located OBD-II connectors, ACMs, and PCMs are unlikely to be damaged by deformation during a collision as only 5 percent of vehicles in a frontal crash experience damage between zone 7 and 9. In a side crash mode, however, 20 percent of vehicles experience damage greater than zone 2. Therefore, EDRs located underneath either front seat (i.e., driver and passenger) are more susceptible to damage than their centrally located counterparts.

Looking beyond the front passenger compartment, suggestions have also been made to place the EDR access connector in the trunk. Although rear crashes occur less frequently than frontal crashes, the rear deformation profile is similar to the frontal deformation profile; 95 percent of vehicles experience damage between zone 1 and 5, meaning there is a greater likelihood that a trunk connector would be damaged in a rear impact because the trunk is generally in these zones. However, if a connector was placed centrally in the rear passenger compartment, our results show the likelihood of damage caused by deformation is equivalent to placement in the front passenger compartment. Hence, in the most severe crashes, which may be the ones of most interest, there is no guarantee a rear-placed port will be any more accessible than the current front-placed ports.

Alternative EDR Data Access Port Types

OEM and supplier input

As with alternate connector locations, the OEMs and suppliers indicated they did not have any information regarding alternate EDR data access ports. To date, all interviewees said they primarily try to use the OBD-II port. They indicated they have developed sophisticated MMMY strategies to allow access of the data via the OBD-II port. In rare cases where the OBD-II port is damaged, the OEMs indicated they used direct read technology. This was also used to read EDR data when the enclosures were shipped to their companies for data download. With these two methods, several car companies said that it is extremely rare when the data could not be captured.

Generally, car companies cited costs, compliance, and manufacturing complications as drawbacks associated with adding any new connectors, and said the benefits are almost nonexistent because nearly all EDRs can be read using current technology.

Some car companies have made strides toward reducing the cost of future direct connect data downloads by standardizing the interface connector across as many of their MMMY variations as possible. This should reduce the number of interface cables needed in the future within a given OEM.

Cost estimate of additional connector

To get an estimate of cost for a connector, the research team leveraged prior NHTSA cost studies. We could not find a direct comparison for a connector but did find two samples of simple electronic components that should provide insight. Because the connector has similar components (e.g., wire, mechanical locks, pins, waterproofing), this project has assumed a connector upgrade would be similar in scope and cost as a simple telltale or switch. The recent tire pressure monitoring system cost study found a telltale to be $1.58 in 2001$ (Office of Regulatory Analysis and Evaluation and National Center for Statistics and Analysis, 2005), adjusting to 2012$ this is about $2.05. The ESC cost study found a simple switch to be $1.75 in 2006 dollars (Ludtke & Associates, 2006), adjusting to 2012 dollars this is approximately $1.96. Hence, with 15,000,000 light vehicles produced annually, the team estimates that the total cost of installing a simple connector, such as a USB, would be $30 million annually. There could be some additional cost for programming and input/output support of the USB format.

Possible low cost solution to expansion of interface cables

One interviewee proposed a unique solution to the expansion of interface cables. They suggested that several pin orientations, possibly 4, be specified to be the same in all OEMs MMMY variations. This would allow for a special 4-pin connector that could be easily designed to fit all future vehicles, eliminating the need for crash investigators to buy specific cables with full-sized connectors for each MMMY. This type of connector would likely cost about the same as the current direct connect cables that Bosch sells; single cables with EDR direct connect connectors cost approximately $150.

Telematic EDR Data Access Strategies

Telematic solutions to gather EDR data have been discussed for many years, especially by the emergency medical service community. Their goal is to collect crash data quickly to aid in occupant triage decisions. To date, several OEMs have offered telematic systems that may notify EMS, if appropriate, when a collision has occurred. Recent improvements by some OEMs have included the addition of a measure of severity, based on a few crash parameters. Thus far, OEMs are not transmitting the full EDR record.

Generally, there are two families of telematic solutions: short- and long-range. The current systems (i.e., GM's OnStar, BMW's Assist, and Ford's SYNC) are all long-range solutions, using existing cellular connections to connect the vehicle to emergency resources. Most cars and LTVs also have short range systems such as Bluetooth, dedicated short-range communication and Wi-Fi. These systems power communication technology such as connecting your mobile phone to the vehicle for hands-free operation, connecting your car's TPMS (located in the tire) to the vehicle, connecting a computer to the web via the Wi-Fi and cell signal, and connecting your key fob to the vehicle to allow remote lock and vehicle start.

Telematic issues

Telematic systems, both long- and short-range, have critical technical, legal, and policy challenges associated with their use in this way that could potentially be difficult to overcome. Some of the technical issues include the high cost of additional hardware. These include a computer to manage the system and store the data prior to transmission, a transmitter to send the signal, a power supply to keep the system running after the crash starts, which could sever the battery connection, and an antenna. Besides these hardware issues, there are technical, legal, and policy issues, such as data security, that would need to be resolved as well.

Additionally, telematic systems would need to be robust because they need to work during a crash where the vehicle is experiencing up to 50 G's, potential deformations, and possible violent rollover.

- **Computer**: This component must be stronger than the current EDR system because it would need to continue to work after a high-severity crash, during a fire, and under submersion conditions. Memory would also need to be robust.
- **Transmitter**: This device would need to be as crash resistant as the computer.

- **Power Supply**: This system must be capable of transmitting data for a few minutes for the long-range solution and possibly days for the short-range solution (needs to be operating during the early phases of rescue and later phases of crash investigation); hence, some type of possibly substantial battery would be needed, which could have maintenance issues.
- **Antenna**: As these need to be outside the vehicle's steel bodywork and are prone to damage from day-to-day use of the vehicle, they may require maintenance. Rollovers present difficulty, in that the system may be called upon to transmit data with the antenna crushed, buried, during a fire, or submerged. Some conditions may require the OEMs to install more than one antenna.
- **Security**: Current EDRs provide data security by maintaining the data within the vehicle, requiring access to the vehicle to gain access to the data. Telematic systems broadcast the data based on a crash event and have no ability to know who is receiving the data. Hence, telematic systems might need to incorporate some encryption processes to protect the data or possibly limit the data transmitted.

Another problem is evaluating the performance of such a robust system. Consider the type of test that would need to be developed to ensure operation of a broadcast system under the most severe rollover.

In telematics systems, the amount of data also must be considered. Of course, this is dependent on the telematics scheme, either automatic or semi-automatic. The two general types of telematics solutions for EDR data collection are long- and short-range.

Long-range systems send signals via the cell system. The current model for this type of system is a CAN system offered by many car companies. With this system, the telematics system automatically sends a signal if a certain pre-defined condition occurs, such as an air bag deployment. Potentially large amounts of data could be generated, as discussed below in the cost section. A variant of this system would await a call, possibly from an investigative source, and then respond semi-automatically by transmitting the data. This produces less data but does not reduce the cost of the equipment. It also requires the maintenance of a database of all the vehicles' identification numbers and their associated phone numbers.

The short-range system provides data semi-automatically and telematically, but only within a short distance of the vehicle. The system responds to an onsite interrogation from an investigator, police officer, or other approved official.

Telematic costs

We have reviewed the costs of two basic systems to frame possible costs for these systems.

Long-range solution

In 2011 GM started offering "OnStar For My Vehicle" to owners of vehicles not equipped with OnStar systems (discontinued at the start of 2014). FMV was a full add-on system and contained many of the services needed to transmit EDR data during and after a crash. FMV was installed in a customer's vehicle, typically by a third party. The customer payid for the device and installation plus a monthly service to activate the cellular connection and fund the services provided. Internet prices range from the suggested retail price of $300 to as low as $100. Monthly services start around $19 per month, but discounts existed for bulk purchasing, such as three years for $499 ($13.86 per month). Using the lowest price for installation and service, and averaging the installation cost over the useful life (estimated at 15 years), the annual cost would be approximately $173 per vehicle.[6] With an 15,000,000 light-vehicle annual sales fleet, the annual cost of this system would be $2.6 billion.[7]

Beyond these costs, some type of infrastructure would be needed to collect the data. If every vehicle were equipped with this technology, we can estimate the number of EDR calls based on a typical crash year. From *Traffic Safety Facts 2011*, there were 29,757 fatal crashes and 1,530,000 injury crashes (National Center for Statistics and Analysis, 2013). In a long-range automatic system, large amounts of data would be generated as it would be programmed to submit data every time conditions were met. Thus, if each of these crashes generated an EDR record, NHTSA would need the capability to collect more than 1.5 million events per year, or approximately 4,100 per day. This would require a significant investment in manpower and equipment by the government.

Short-range solution

We have looked at the cost study (Office of Regulatory Analysis and Evaluation and National Center for Statistics and Analysis, 2005) prepared for the TPMS rulemaking for guidance for a short-range system. These systems require a control unit, sensors, antenna, and miscellaneous material for assembly. The cost study looked at three systems: Beru, SmarTire, and Johnson Controls. The results are summarized in Table 17. We found that the average cost is approximately $64.

Unlike the automatic telematic system described above, the short-range system does not require a transmission fee, and NHTSA would have control on the number of EDRs read, concentrating on those applicable to improving automobile safety. Because the signal is near the vehicle, crash investigators could collect the telematic data, using a special reader. We have selected the Bosch basic tool to get an estimate cost for a telematic reader. The Bosch CDR OBD-II base kit (Part #: F00K108943) is described as the minimum hardware needed to retrieve crash data from vehicles through the vehicle's OBD-II port. It has an MSRP of $1,500, plus software of approximately $900 per year. In comparison to the current wired system, the Bosch CDR Premium Tool Hardware Kit (Part #: CDG3333-1) is described as the complete hardware CDR tool with all cables, adapters, power supply, and modules current through the current hardware release. It has an MSRP of $9,599, plus software of approximately $900 per year. The cost for the short-range unit is applied to each automobile and LTV. The download kit and its software are only borne by the crash investigators, which is a much smaller population. Using the same 15 million annual

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[6] $\$13.86 \times 12 + (100 \div 15) = \$172.99$.

[7] A variant of this approach would be a transmit-once call service that does not require a monthly cell connection fee; a service that now exists for 9-1-1 calls. This would reduce the cost of this approach significantly, but would require a Memorandum of Understanding to be developed between the cell companies and DOT.

fleet as in the long-range solution, the vehicle portion would have an annual cost of about $960 million. If a life expectancy of the base kit of 5 years is assumed, the annual cost would be $1,200.[8] While the current population of EDR readers is unknown, using an annual acquisition rate estimate of 1,000 units, the annual cost would be $1.2 million.

Table 17. Cost study of short-range systems

System	Control Unit	Sensor[1]	Antenna[1]	Assembly	Total	Total Adjusted to 2012$[2]
Beru	$44	$8.00	$2.75	$10	$64.75	$83.94
SmarTire	$30	$7.50	--	$11	$48.50	$62.88
Johnson Controls	$19	$7.50	--	$9	$35.50	$46.20

[1] These unit costs were divided by four because the TPMS system needs a sensor and antenna for each tire.
[2] This study was conducted in 2001, the Customer Price Index (CPI) ratio from 2001 to 2012 is 1.296.

Telematics benefits

The benefits from telematics are minimal from a crash investigation standpoint. Basically, the crash investigators would be switching out one set of equipment (i.e., cables compatible with various EDR modules) for a different set of equipment (i.e., transceivers). But, it is anticipated that some crashes will be so severe that the data will not transmit; hence, a solution for backup collection for the most severe crashes would need to be developed. This may mean that some sets of cables and connectors will still be needed.

Development of Standardized EDR Data Readers

Status of OEM EDR readers who use non-Bosch systems

Part 563 requires that manufacturers make a tool available but does not specify which tool. A majority of the OEMs have selected the Bosch CDR tool. Six manufacturers are known to have chosen to use a different tool provider. Details of each of these OEM's tools are presented in the Task 1 report. Table 18 provides a summary of these six OEMs plus the Bosch premium CDR system for comparison.

The companies that make some of these tools have recently been acquired by Bosch. Because Bosch is the main provider, there is a possibility that those tools will be incorporated into the main CDR family. These include the Mitsubishi tool, which is made by the former OTC, subsequently purchased by SPX, subsequently purchased by Bosch in 2012. Like the Mitsubishi tool, the Jaguar/Land Rover toolmaker OTC/SPX has been purchased by Bosch.

As shown in Table 18, not all EDR download tools are compatible for directly connecting to the EDR module. And of interest, the Jaguar/Land Rover tool produces a file that is not interpreted

[8] $\$900 + (1{,}500 \div 5) = \$1{,}200$.

into engineering units, but provides a hex file that needs to be sent to England for decoding and generation of the Part 563 format output.

Table 18. Summary of available download tools

OEM	OBD-II Connect	Direct Connect	Current est. purchase cost	Annual est. software cost	Notes
Hyundai	Y	Y	$3,950	$195	
Kia	Y	Y	$4,380	Unknown	
Subaru	Y	N	$2,835	$1,835	
Mitsubishi	Y	N	$9,050	Unknown	Includes laptop computer
Jaguar/Land Rover	Y	Unknown	~$5,000	Unknown	No engineering data, hex file sent to England for decoding
Saab	Y	N	$2,835	$1,835	
Bosch premium CDR	Y	Y	$8,999	$899	Reads many different OEM's vehicles

Other notable differences include that each of these tools do not produce a Bosch CDR like output file, but generally follow the Part 563 outline, perhaps because they were likely developed specifically for Part 563 compliance. Additionally, not all of the tools produce a hex file, which could be problematic for users of the data if a software problem is discovered.[9] The EDR enclosure would need to be preserved in order to reread the file with the updated software. This has occurred several times with the Bosch CDR tool software, so one might expect that it could occur again.

It appears that the costs of the six standalone systems are higher than the Bosch CDR equipment when compared on a MMMY application type rate. While the Bosch premium CDR kit costs more, it contains many direct connect cables and can read many more MMMY vehicles.

Additional Data Elements and Sensors

OEM input

During the interview process, most OEMs indicated it was not difficult to add data elements to the EDR, given the data are available on the vehicle's data bus structure, sufficient time was given to make the changes during logical model makeovers, and the EDR has sufficient memory reserve.

Regarding sensors, OEMs said they would likely not add sensors solely for the purpose of collecting additional EDR data. There was general agreement that if a sensor was being added for some other purpose, then adding its associated data stream to the EDR could be

[9] As dictated in the Bosch CDR reports, hexadecimal data is data "that the vehicle manufacturer has specified for data retrieval… [It] may contain data that is not translated by the CDR program." Thus, inclusion of hexadecimal data requires mere rerunning of the file and does not necessarily require download from the physical module after a software update.

accomplished. Examples of new sensors include those associated with new technologies, such as ESC, forward collision warning, and others.

Costs and benefits for new data elements

The main driver for data element cost is the sensor. If the sensor exists, then it can be added to the EDR data array with minimal cost. If the sensor does not exist, then the costs will be much higher.

The research team turned to the Final Regulatory Impact Analysis for ESC (NHTSA, 2005). The incremental costs of sensors were developed in support of this project, as shown in Table 19.

Table 19. Estimated cost of various sensors

Component	Cost ($2005)	Est. current cost ($2012) 1.176 factor
ABS Speed sensors ($60.32 for 4)	$15.08	$17.73
ESC Yaw Rate/Lateral Acceleration Sensors	$60.24	$70.84
ESC Steering Wheel Sensor	$27.55	$32.40

Thus, the cost for adding a sensor varies from a little less than $20 to over $70. The cost seems partially dependent on the complexity of the sensor, with the complicated electronic yaw and lateral acceleration combination sensor costing the most in this set. The cost for a 15 million annual sales fleet for new similarly valued sensors would vary from $300 million to $1,050 million.

The benefits for a new sensor are the better understanding of vehicle crashes, leading to further improvements in the safety of current and future vehicles. Hence, it is not possible to directly estimate a cost benefit ratio.

Increased Recording Duration

From the Task 1 review of MY 2012 EDRs, many car companies are recording data in the format specified in Part 563. This includes pre-crash data as well as crash data. Furthermore, some OEMs are also recording acceleration, a data element that requires significant memory.

Part 563 Table I and Table II memory requirements

Different data elements require different amounts of memory. Static data, such as a switch status, need the smallest amount of memory, as little as one or two bits. Data that have many possible ranges, such as acceleration, which may vary from 0 to 100 Gs, with a resolution of a 0.5 G, will require a byte or two (depending on resolution) for each sample. If one sampled at 500 Hz for 1.0 sec, then 500 to 1,000 bytes would be needed.

Part 563, Table I does not require significant amounts of memory. Table 20, generally reproduced from NHTSA's Final Regulatory Evaluation (FRE); Event Data Recorders (EDRs); July 2006, indicates that the Table I data can be collected in approximately 72 bytes per record. This amount of memory would be duplicated for each event, and some redundancy may be needed.

A similar analysis was conducted in the EDR FRE for Table II data elements and is presented in Table 21. The estimated memory size for Table II is 857 bytes. Of course, more samples could be collected for acceleration, which would quickly increase the file size.

Table 20. Total bytes required for each Part 563 Table I data element

Element #	Data Element	No. of Samples	Bytes per Sample	Total Bytes
1	Delta V, Longitudinal	26	1	26
2	Maximum delta V, Longitudinal	1	1	1
3	Time, Maximum delta V, Longitudinal	1	1	1
4	Speed, vehicle indicated	11	1	11
5	Engine throttle, % full	11	1	11
6	Service brake, on/off	11	1	11
7	Ignition cycle, crash	1	2	2
8	Ignition cycle, download	1	2	2
9	Seat belt status, driver	1	1	1
10	Frontal air bag warning lamp	1	1	1
11	Frontal air bag deployment time, Driver (1st, multi)	1	1	1
12	Frontal air bag deployment time, RFP (1st, multi)	1	1	1
13	Multi-event, number of events	1	1	1
14	Time from event 1 to 2	1	1	1
15	Complete file recorded	1	1	1
Total bytes				72

Table 21. Total bytes required for each Part 563 Table II data element

Element #	Data Element	No. of Samples	Bytes per Sample	Total Bytes
1	Lateral acceleration	126	2	252
2	Longitudinal acceleration	126	2	252
3	Normal acceleration	126	2	252
4	Delta V, Lateral	26	1	26
5	Maximum delta V, Lateral	1	1	1
6	Time, maximum delta V, Lateral	1	1	1
7	Time, maximum delta V, Resultant	1	1	1
8	Engine RPM	11	1	11
9	Vehicle roll angle	11	1	11
10	ABS activity	11	1	11
11	Stability control	11	1	11
12	Steering wheel angle	11	1	11
13	Seat belt status, RFP	1	1	1
14	Frontal air bag suppression switch status, RFP	1	1	1
15	Frontal air bag deployment, time to nth stage, Driver[1]	1	1	1
16	Frontal air bag deployment, time to nth stage, RFP[1]	1	1	1
17	Frontal air bag deployment, nth stage disposal, Driver[1]	1	1	1
18	Frontal air bag deployment, nth stage disposal, RFP[1]	1	1	1
19	Side air bag deployment time, Driver	1	1	1
20	Side air bag deployment time, RFP	1	1	1
21	Curtain/tube air bag deployment time, Driver	1	1	1
22	Curtain/tube air bag deployment time, RFP	1	1	1
23	Pretensioner deployment time, Driver	1	1	1
24	Pretension deployment time, RFP	1	1	1
25	Seat position, Driver	1	1	1
26	Seat position, RFP	1	1	1
27	Occupant size classification, Driver	1	1	1
28	Occupant size classification,	1	1	1
29	Occupant position classification, Driver	1	1	1
30	Occupant position classification, RFP	1	1	1
Total				857

OEM memory capability

From interviews with the OEMs and suppliers, our research team was told that most companies are replacing the older memory technology, like EEPROM, with flash type memory located on the microprocessor. These newer memory systems are manufactured in increments of two, e.g., 1k (1024), 2k (2048), 4k (4096). We also found that this memory is used for several functions within the ACM, such that the EDR maybe uses ⅓ to ½ of the memory. Of significance to the question of additional data recording capacity is how close the current memory capacity is to full capacity. For example, if an ACM had a 4k chip and was only using 3k of its capacity, then 1k could be used for additional data collection before the company would need to upgrade to an 8k chip.

Cost of memory

Computer memory has made amazing strides in cost reduction over the past several decades. Based on data from Trefis (2013), the market research firm, flash memory in 2013 costs approximately 0.072¢ per megabyte, as seen in Figure 9. Trefis also made cost projections for flash memory until 2020.

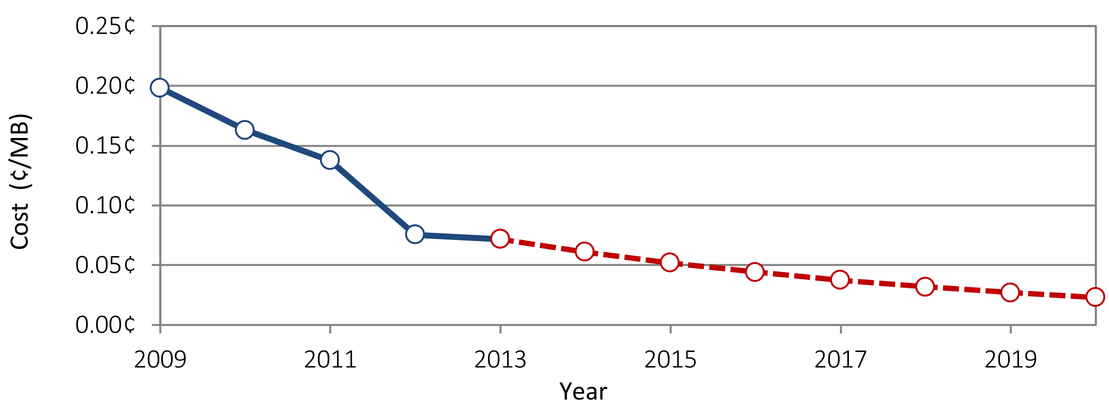

Figure 9. Flash memory costs per GB with respect to time (Trefis, 2013).

Because memory costs are minimal, the major cost elements come from exceeding the storage capacity of the current chip. This requires the installation of a larger memory chip, as well as design time, lead time, and possible redesign of the printed circuit board to accommodate a larger unit.

Example case

To illustrate the effect on EDR memory by changing the recording requirements, consider a revised Table I that included 10 pre-crash data elements, each collected at a rate of 10 Hz for 10 seconds and 10 crash data elements, each collected at 1,000 Hz for 0.5 seconds. The estimated total bytes for each set of data elements are shown in Table 22.

Table 22. Bytes needed for 10 pre-crash elements (10Hz for 10 sec) & 10 crash elements (1,000Hz for 0.5 sec).

Data Element	No. of Samples	Bytes per Sample	Total Bytes per Channel	Channels	Total Bytes
Pre-crash	100	1	100	10	1,000
Crash	500	2	1,000	10	10,000

Additional costs are required to manage the collection of these data, as well as RAM to store them until a trigger is encountered.

Future Standardization Needs

Self-driving cars

The chairman of the National Transportation Safety Board recommended that all autonomous, or "self-driving cars," be equipped with EDRs. Beyond the typical need for data during automotive crash investigations, autonomous vehicles require data to identify the source of error, i.e., vehicle or human. Self-driving cars such as Google's vehicles already capture performance information primarily used to refine and monitor the vehicle (Bosker, 2013).

Both Nevada (Nevada Administrative Code, n.d.) and California (California Senate Bill No. 1298, 2012) require specialized EDRs for these vehicles. Essentially both states require that 30 seconds of pre-crash information be recorded in the event of a crash. This data must be stored for three years after the recording date in a device separate from the EDR. Both states explicitly indicate these requirements must be separate from existing federal EDR requirements. Neither law specifies what should be recorded or how the data should be downloaded after a crash.

OEM and supplier input

None of the interviewees indicated they knew of any national EDR databases. Several indicated they kept track of individual cases applicable to their own company's needs.

Scope of potential EDR database

The current NHTSA EDR database system used the NASS structure. A new system might be developed to collect even more data. To explore the potential number of possible EDR records, we assumed records for all injury and fatal crashes might be collected. As mentioned earlier in this Task 3 report, *Traffic Safety Facts 2011* (National Center for Statistics and Analysis, 2013), shows 29,757 fatal crashes and 1,530,000 injury crashes. If each of these crashes generated an EDR record, NHTSA would need the capability to collect more than 1.5 million events per year, or approximately 4,100 per day. This would generate a case load on the agency of more than 10-

fold beyond the current annual collection of cases by NHTSA.[10] But these cases would generally have much less data.

Additionally, NHTSA would need to develop a method of pairing the EDR records with the current crash case files in a way consistent with NHTSA privacy policy and applicable laws. Currently, the EDR record does not include any identifying information. Date, time, and location are not required by Part 563 and are not known to be recorded by any EDR.

Storage of EDR field database

Current process

EDR data storage is currently being done at NHTSA in a couple of places. Data systems that have NHTSA-based investigation teams, such as the Special Crash Investigations, NASS/CDS, and the Crash Injury Research and Engineering Network (CIREN), are collecting EDR data as part of their normal crash investigative process. These teams have collected thousands of EDR records over the past decade. All of these records are part of each systems' data structure. EDR records associated with NCAP vehicles have been read by Virginia Tech as part of a support task. The records are read and provided to NHTSA for inclusion in the NCAP data structure.

Potential new storage systems

A national EDR storage collection site could be established. This system could be open for anyone to submit EDR records, including NHTSA, industry, insurance companies, researchers, law enforcement, and others.

Public access to an EDR database

Current process

NHTSA currently makes its EDR files available to the public at no cost. For the national databases like NASS/CDS and SCI they are part of the database structure and can be downloaded like any other crash variable. Other data is published in research reports and Enhanced Safety of Vehicles papers, or made available on the NHTSA web site, typically found in the Vehicle Safety Research portion of the web site at www.nhtsa.gov/research. These are also available at no cost to the requester. Other researchers have collected EDR data and published the data in automotive industry journals and at associated conferences. Some of these are copyrighted, and a fee may be required to obtain a copy.

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[10] Currently NHTSA collects approximately 40,000 fatal crash records in its FARS system, 5,000 cases in its NASS-CDS system, 60,000 in its NASS/GES system, a few hundred in its SCI system, and up to 1,000 in its CIREN system.

Costs associated with each identified need

Collection of EDR data in NHTSA's NASS/CDS, SCI, and CIREN data systems

The costs associated with NHTSA's current approach are generally low because the investigators are already going to the crash scenes. Adding the EDR to the investigation likely adds one to two hours of effort on the part of the investigator, considering training, downloading, possible need for back powering the EDR module during the download process, uploading the data report, and quality control of the information. If the loaded labor rate was $50 per hour, this would add approximately $100 per case for EDR collection. Additionally, the investigators need a download system, such as the Bosch CDR. The current cost of these systems is $8,999 for the full system with cables and an $899 annual fee for software. If each investigator conducted 50 cases per year, the annual software cost would be approximately $18 per case. If the main system could be used for 4 years, or 200 cases before a major replacement, the cost per case would be $45.[11] Thus, our general estimate for collecting EDR data in an individual case is $163.[12] The estimate for SCI and CIREN EDR data collection may be higher because they tend to process fewer cases per year.

Database Format

This section describes a potential standardized database format designed to store the data elements and events defined in Part 563 Table I and Table II data element definitions. We envision the EDR as one component of a more comprehensive electronic crash data record system. EDR data provide unique insights into the factors associated with a crash but are only one component of a crash record. The proposed Part 563 EDR database has been designed with the intent that the data will be linked to existing electronic crash records, including police accident reports, national database records, e.g., FARS, NASS/CDS, or National Automotive Sampling System/General Estimates System (NASS/GES), and state crash record databases.

The proposed structure, which follows, is designed as a relational database composed of the four database tables presented in Table 23 and diagrammed in Figure 10.

[11] ($8,999 ÷ 200) = $45.

[12] $100 (labor) + $45 (equipment) + $18 (software) = $163.

Table 23. Description of Part 563 database tables

Table	Description	Number of Entries	Identifying Keys
System	Summary of all records in the module	1 record for each EDR	• CaseID • Vehno
Event Summary	Summary of each recorded event	1 record for each event recorded	• CaseID • Vehno • Eventno
Event Time Series Parameter	Data for each of the time series parameters stored for each event	1 record for each time series parameter recorded for each event	• CaseID • Vehno • Eventno • Param_Code
Restraint	Summary of the restraint performance deployed for each occupant in each event	1 record for each occupant for each event	• CaseID • Vehno • Eventno • Occno

This set of tables can be merged using the identifying keys shown in Table 23.

- **Case ID**: unique case identifier assigned by the agency. The CaseID would be an identifier already used in an existing crash record database, e.g., FARS, NASS/CDS, or State crash records. Examples of CaseIDs would be police accident report case numbers, NHTSA crash test numbers, or NASS Caseyear-PSU-Caseno case identifiers.
- **Vehno**: integer key assigned to each vehicle in the case starting with vehno=1.
- **Eventno**: integer key assigned to each event in which a vehicle encountered in the crash. Sequentially assigned for each CaseID-Vehno combination starting with eventno=1.
- **Occno**: integer key assigned to each occupant seated in a vehicle that was involved in a given the crash. Sequentially assigned for each CaseID-Vehno-Eventno combination starting with occno=1.
- **Param_Code**: integer parameter code assigned to each time series array stored in a particular event. The parameter codes for each type of time series data element are defined in the discussion that follows.

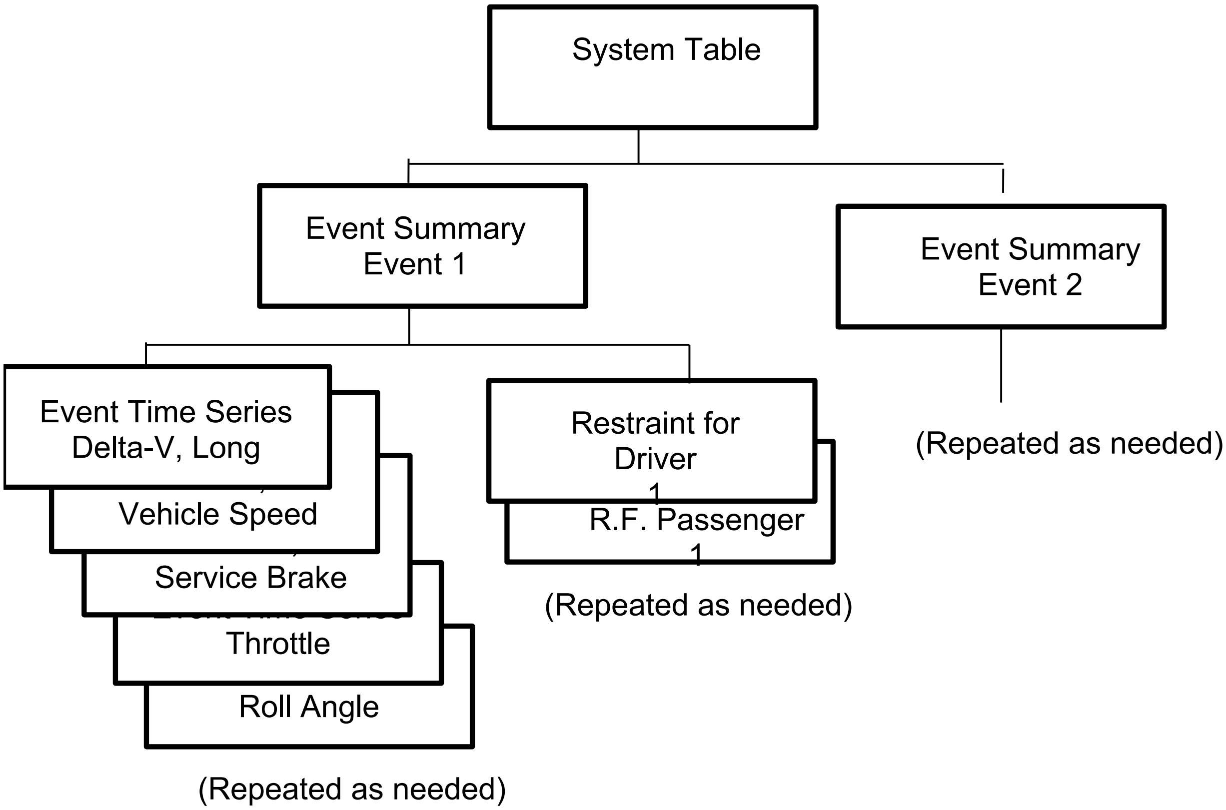

Figure 10. Schematic of Part 563 database structure.

Following is the structure of each of these tables. These tables have been designed using the following assumptions:

- Equal intervals between values recorded in a time series,
- Database can accommodate variable length arrays, and
- All frontal air bags have only up to two stages.

Table 24. Description of system table

Variable Name	Description	Data Type
caseid	Case Identifier (defined by agency) *	
vehno	Vehno Number (1,2...)	Integer
VIN	Vehicle Identification Number *	Character field
Num_events	Number of recorded events (derived from database entries)	Integer
igcycle_download	Ignition cycle, download	integer

** Not required by Part 563.*

Table 25. Description of event summary table

Variable Name	Description	Data Type	Units/Values
caseid	Case Identifier (defined by agency)		
vehno	Vehno Number (1,2...)	Integer	
eventno	Event Number (1, 2...)	Integer	
dvlong_max	Maximum delta V longitudinal	Real	kph
dvlong_tmax	Time, maximum delta V	Real	ms
dvlateral_max	Maximum delta V, lateral	Real	kph
dvlateral_tmax	Time maximum delta V, lateral	Real	ms
dvresult_tmax	Time for maximum delta V, resultant	Real	ms
igcycle_crash	Ignition cycle, crash	Integer	
air bag_lamp	Frontal air bag warning lamp	Coded	On/Off
tevent	Time from this event to next event	Real	Seconds
event_complete	Complete file recorded	Coded	Yes/No

Table 26. Description of event time series parameter table

Variable Name	Description	Data Type	Units/Values
caseid	Case Identifier (defined by agency)		
vehno	Vehno Number (1,2...)	Integer	
eventno	Event Number (1, 2...)	Integer	
pcode	Time Series Parameter code	integer	Tabulated in Pcode table
nelem	Number of elements in array*	Integer	
tstart	Time of first array element	Real	seconds
tinterval	Time interval between elements	Real	seconds
parray	Array of Time Series Values	Function of Pcode	Function of Pcode

* Derived from elements in this record

Table 27. Parameter codes (pcodes) for time series parameters in Part 563

Pcode (Parameter Code)	Parameter Description	Data Type	Units	Part 563 nelem)	Part 563 Tinterval (sec)
1	Delta V, longitudinal	Real	kph	25	0.01
2	Delta V, lateral	Real	kph	25	0.01
3	Lateral acceleration	Real	G	25	0.01
4	Longitudinal acceleration	Real	G	25	0.01
5	Normal acceleration	Real	G	25	0.01
6	Speed, vehicle indicated	Real	kph	10	0.5
7	Engine throttle (or accelerator pedal)	Real	%	10	0.5
8	Service brake, on/off	Coded	on/off	10	0.5
9	Engine rpm	Real	rpm	10	0.5
10	Vehicle roll angle	Real	degrees	60*	0.1
11	ABS activity	Coded	Engaged/Not Engaged	10	0.5
12	Stability control	Coded	On/Off/ Engaged	10	0.5
13	Steering input	Real	%	10	0.5

** Assuming Part 563 recommended duration of -1 to 5 seconds for Roll Angle.*

Table 28. Description of occupant restraint table

Variable Name	Description	Data Type	Units/Values
caseid	Case Identifier (defined by agency)		
vehno	Vehno Number (1,2...)	Integer	
eventno	Event Number (1, 2...)	Integer	
occno	OccNo (1=driver, 2=right front passenger)	Integer	
belt_status	Seat belt status	Coded	Buckled/Not Buckled
abfront_timdep1	Frontal air bag deployment, time to deploy (stage 1)	Real	ms
abfront_timdep2	Frontal air bag deployment, time to deploy (stage 2)	Real	ms
abfront_suppress	Frontal air bag suppression switch status	Coded	On/Off/Auto/NA
abfront_disposal1	Frontal air bag deployment, stage 1 disposal	Coded	Yes/No
abfront_disposal2	Frontal air bag deployment, stage 2 disposal	Coded	Yes/No
abside_timdep	Side air bag deployment, time to deploy, driver	Real	ms
absidecurt_timdep	Side curtain/tube air bag deployment, time to deploy	Real	ms
abpretens_timdep	Pretensioner deployment, time-to-fire, driver	Real	ms
seat_trackpos	Seat track position switch, foremost, status, driver	Coded	Yes/No
occ_size	Occupant size classification	Coded	Yes (5th female or larger)/No
occ_oop	Occupant position classification	Coded	Yes (out of position)/No

Extensions to database

Note that the proposed database structure has been designed to scale to accommodate common extensions to the minimum Part 563 specifications. Additional time series data elements, e.g., roll rate used by many OEMs, can be added by simply adding an additional time series parameter code. The higher sampling rates and longer recording duration used by some OEMs in MY 2012 EDRs can be accommodated by changing the time interval and number of points for a particular time series data element. No limit is placed on the number of events that can be accommodated in the database. The proposed database format readily accommodates the Part 563 minimum of two events as well as the five events stored by Chrysler.

Database retrieval policies

In general, EDR data identifying information should not be included in data released to the public. This practice is routinely followed for national databases *such as* FARS, NASS/CDS or NASS/GES. Specifically, all identifying information should be excluded. In addition, the investigator name, date, and location of the crash should be removed. VINs should either be excluded entirely or shortened from 17 characters to 11 characters. Finally, any printouts of the raw binary contents of an ECU, such as the hexadecimal printout currently in the Bosch CDR report, should be removed as some EDRs may store sensitive identifiers, such as full VINs, in the raw binary file. We note that NHTSA not only ensures that complete VINs are not included in any public databases, but NHTSA also requests vehicle owner permission before obtaining any EDR data.

Additionally, NHTSA has worked closely with makers of the CDR tools to ensure that printouts exclude sensitive information, like the complete VIN.

Discussion

Alternative EDR Data Access Ports

Alternative ports for access to EDR data were reviewed, including locations, type of connector, and the use of telematic data transfer. Currently, access to EDR data is obtained either through the OBD-II connector or by directly plugging into the ACM or the PCM. While the OBD-II connector is standardized, the direct connection to the EDR enclosure is not and has led to a myriad of interconnecting cables. The current premium Bosch CDR tool kit includes more than 50 direct-connect cables. The Bosch cables cost approximately $150 per cable. There are at least six other OEMs offering EDR read tools beyond the Bosch tool, and each of them has its own set of interconnect cables. One solution to this problem was provided by some of the OEMs. They indicated they had standardized the direct interconnect cable connector across product lines, hence decreasing the need for many variations of direct connect cables for future MMMYs. Another idea provided during the interviews was the establishment of common pins within the various connectors that could be fitted with a standard connector no matter the layout of the full connector. A standardization activity of this nature could be done by SAE.

On the other hand, crash investigators only need to buy these cables once and may already have a set of cables. Many car companies recently released EDRs to meet Part 563 causing a surge in CDR parts, but this should slow down now that Part 563 is effective.

Based on analysis of the NASS/CDS crash deformations, there does not appear to be any other place in the vehicle that affords better protection than the current location. Furthermore, the trunk fares poorly in rear crashes, which are quite common in the population we analyzed. The current location is practical because it allows the EDR to coincide with the ACM; hence, no additional enclosures or wiring are needed.

Alternate connectors, such as USB and Ethernet, in addition to the current ACM connector, will add costs to the vehicle. Furthermore, they do not necessarily add any additional performance over a direct connection, except for a standardized design. Alternate connectors also have issues with back powering the ACM, and are prone to crash damage, which will require direct connect to the EDR connector or removal from the vehicle.

Alternatively, a standardized wireless connection appears advantageous as it may eliminate the current burdensome need for the investigator to carry large numbers of download cables. However, there will always be those cases where the transmitter will not work, and the crash investigator would need to rely on the aforementioned cable set.

Alternative Data Elements and Sensors

Based on 143 MY 2012 EDRs we read during Task 1 of this project, OEMs are already collecting data elements well beyond Part 563, Tables I and II. On average, OEMs included more than 20 other data elements.

SAE has just finished a complete overhaul of J1698. The new version of this RP details many advanced and alternative data elements. The updated RP included many advanced technologies such as blind spot system, collision warning system, electronic stability control, electronic stop start, and lane departure system. Beyond the updated J1698, the committee is continuing its efforts to review data elements associated with advanced technology, particularly pedestrian safety.

Addition of new sensors appears relatively expensive, ranging from $20 to $70 per sensor per vehicle. But there is a good possibility these sensors will be added to the vehicle by the OEM as they install new technology. If cost is the driving factor, a solution for the agency is to add these to Table II.

Increased Recording Duration and Events

Increased recording duration for data elements can be easily accomplished. Recent reductions in the cost of computer memory have generally eliminated the cost of memory from the equation. Plus, the additional memory to expand the recording duration is fairly small. But other costs still exist, including processor capability, RAM size, increased physical size of the printed circuit board, increased energy reserve, etc. Additionally, the current EDR function is built on the back end of the microprocessor that controls the automatic restraints. Additional burden on the EDR will at some point start to affect the performance of safety systems.

Increased pre-crash durations will allow recording many events of interest, such as long duration rollover crashes and UA events (that end in a crash that is sufficient to trigger recording). Increased crash event duration may help better understand long duration crashes. And analysis of NASS/CDS indicates that approximately 20 percent of all crashes involve three or more events, which would not be captured under the current Part 563.

Future Standardization Needs

Currently, NHTSA has uploaded more than 8,000 EDR reports to its website as part of its real-world crash investigations including NASS/CDS, SCI, and CIREN, as shown in Figure 11. A jump can be seen in data collected between 2010 and 2011, where NHTSA incorporated new training to improve the field collection success rate.

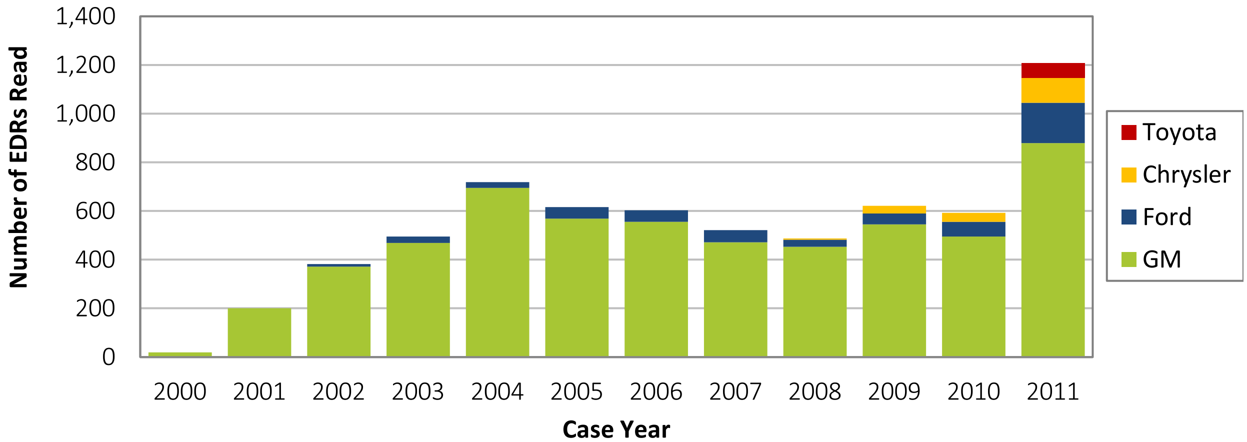

Figure 11. Real-world EDR data available from NASS/CDS investigations by case year.

Current database practices seem to be appropriate, in that each EDR data set is accompanied with a crash file. There is generally belief in the crash reconstruction community that the EDR data is only one of the investigator's tools. Collecting standalone EDR data sets without the accompanying crash investigation could tempt researchers to make judgments without all the facts.

Findings

Alternative EDR Data Access Ports

- The central location of current modules and connectors is among the least susceptible to damage from deformation.
- Trunk placement of an alternative connector does not provide additional protection; however, centrally located modules in the rear passenger compartment offer equivalent protection to the front passenger compartment.
- Additional data ports add cost and have their own crashworthiness issues.
- Short-range telematic solutions have added costs, must be crashworthy, require sophisticated receivers, require backup solutions for the worst-case crashes, and may provide little benefit without significant research on the exact data needed for the EMS community to make proper triage decisions. Long-range telematic solutions are even more expensive and pose a number of other challenges.

Alternative Data Elements and Sensors

- Based on MY 2012 EDRs, OEMs are providing a significant number of data elements.
- SAE has updated J1698 to include many data elements, including several related to advanced technologies.

- The J1698 committee is moving forward to consider other advanced technologies, currently accessing data elements associated with pedestrian protection.
- Additional sensors add cost, which likely cannot be justified on the basis of an EDR need.
- OEMs are adding new sensors as they add new technology and have shown the willingness to add these data to their current EDRs.

Increased Recording Duration and Events

- Based on current information, computer memory costs have dropped significantly in recent years, and now appear to be so low that they are not a significant part of the cost of an EDR.
- As currently configured, Part 563 requires approximately 1k of memory to capture all Table I and II data elements for each event. An EDR that records 10 pre-crash elements (at 10Hz for 10 sec) and 10 crash elements (at 1,000Hz for 0.5 sec) would require approximately 10 times as much memory.

5. Task 4 — Assessment, Specifications and Testing for Survival Hardening and Tamper Resistance

Background

NHTSA sets forth requirements for EDRs in regulation Part 563, which became effective on September 1, 2012. This regulation covers five major aspects of EDRs installed in automobiles and LTVs. These are (1) minimum data element requirements, (2) specifications of the data format, (3) data survivability requirements, (4) data retrieval tool requirements, and (5) owner's manual requirements.

Specifically, Part 563 imposes survivability requirements on EDR data. Paragraph 10, Crash test performance and survivability, of this regulation reads:

(a) Each vehicle subject to the requirements of S5, S14.5, S15, or S17 of 49 CFR 571.208, Occupant crash protection, must comply with the requirements in subpart (c) of this section when tested according to S8, S16, and S18 of 49 CFR 571.208.

(b) Each vehicle subject to the requirements of 49 CFR 571.214, Side impact protection, that meets a trigger threshold or has a frontal air bag deployment, must comply with the requirements of subpart (c) of this section when tested according to the conditions specified in 49 CFR 571.214 for a moving deformable barrier test.

(c) The data elements required by § 563.7, except for the “Engine throttle, percent full,” “engine RPM,” and “service brake, on/off,” must be recorded in the format specified by § 563.8, exist at the completion of the crash test, and be retrievable by the methodology specified by the vehicle manufacturer under § 563.12 for not less than 10 days after the test, and the complete data recorded element must read “yes” after the test.

The severity of these tests is greater than a major proportion of the crashes that occur on the nation’s highways. Of course, there are always crashes that are outside the normal distributions or under unusual circumstances. These include high-severity crashes, crashes that are associated with fire, and crashes where the vehicle is immersed in water, the latter two, generally occurring at the vehicle’s final resting point, among others.

Survivability of the EDR data also extends beyond physical damage experienced during a crash. Though data may survive a crash, ACM resetting services are easily accessible online.[13] The literature (Koscher et al., 2011) reflects growing interest in security weaknesses that ECUs may allow unintended control of the vehicle. Despite this interest, however, little is known regarding the prevalence of such data tampering.

[13] A Google query of relevant terms yielded tampering tools, send-away services, and do-it-yourself YouTube videos. The detailed approach is provided later in this task.

Objective

The goal of this task was to evaluate the needs, costs, and benefits of improved hardening of light-vehicle EDRs for environmental exposure and tampering. Specific objectives were to determine the scope of fire, immersion, and high severity and need for hardening beyond the current Part 563 requirement; estimate the costs and benefits of heat, fire, immersion, and impact resistance of the EDR beyond the current Part 563; conduct component tests of pre MY 2013 EDRs, such as fluid immersion, heat exposure, and high static crush; and evaluate tampering of EDR data; summarize literature discussing EDR and electronic security; and evaluate the efficacy of ACM reprogramming services.

Approach

This research used a problem identification approach and relied on existing transportation solutions to guide the study's research direction. NHTSA crash data files were used to assess the scope of heat/fire, water immersion, and high impact on EDR data outcome. A literature study was conducted to investigate tampering and potential prevention. Existing aviation standards for flight data recorders were used to guide the development of specifications to test the automobile EDRs. A well-established aviation FDR development and testing company was used in this task to guide the conversion of FDR standards to appropriate target levels for automobiles and then conduct the test program.

Scope of the Problem

This subtask consists of two separate analyses:

(a) Determination of the frequency of real world fire, immersion, and high-severity crashes.

(b) Identification of vehicles in which EDRs survived these events as well as vehicles in which EDRs could not be downloaded after these events.

<u>Frequency of fire, immersion, and high-severity events</u>

Three databases were used in the following analysis to determine the cases where fire occurred, immersion was present, or the crash resulted in a high crash delta V.

The FARS is a nationwide census of motor vehicle traffic crashes including a fatality. Each case includes information describing the crash, the vehicle, and the people involved. Our analysis examined the most harmful event ("M_Harm") from 2009 and 2011 annual subsets.[14] Vehicles

[14] In addition to the most harmful event, FARS also reports fire occurrence ("Fire_Exp") as an alternative method to identify vehicle fires. This variable identifies all fire occurrences and is used in the traffic safety facts annual report (National Center for Statistics and Analysis, 2013). For the purposes of this study, however, the most harmful event is a better indicator of possible damage to the EDR.

in which the most harmful event was “fire/explosion” or “immersion” were included in the analysis.

The National Motor Vehicle Crash Causation Survey includes a total of 6,949 crashes that were investigated between January 1, 2005, and December 31, 2007. A nationally representative sample of 5,470 cases allows weighted percentages to be calculated, allowing extrapolation of results to a national scale. Vehicles involving vehicle fires in the database were identified using the variable, “fire,” which indicated the presence of fire in a particular vehicle. Immersion is not an explicit variable included in the NMVCCS database. Crash narratives were therefore examined for variables indicative of sources of water (i.e., pond, lake, and ocean) and manually perused for relevance. The severity of each case was evaluated from on-scene photographs and classified into one of three categories. “No risk of submersion” was characteristic of a shallow body of water. “Risk for submersion” identified a significant body of water but no apparent water in the occupant compartment. Last, “submerged” designated water in the occupant compartment. Relevant vehicles were identified in the database from which weighted and unweighted frequency distributions were generated. Designators of “risk of submersion” and “submerged” were combined into a single value of “immersion” for ease of comparison with FARS.

The NASS/CDS database is a nationally representative, probability sample of crashes from which trained crash investigators analyze and collect data; this includes retroactive photographs, damage measurements, interviews, as well as EDR information when available. NASS/CDS vehicles involving vehicle fires occurring between 2005 and 2008 were identified using the variable, “fire”, which indicates the presence and severity of a fire in a particular vehicle. Element values of “major fire” and “minor fire” were combined into a single value of “fire” for ease of comparison among datasets. Vehicles subjected to high-severity crashes were identified through the variable “dvtotal,” total vehicle change in velocity, or delta V, in the most harmful event. Part 563 requires that EDRs survive and be readable after Federal Motor Vehicle Safety Standard (FMVSS) No. 208 frontal crash tests and FMVSS No. 214 side crash tests. For the frontal impact test, total delta V ranges from 56-64 kph (35-40 mph) depending on the rebound velocity from the rigid wall. For NHTSA side movable deformable crash tests, total delta V ranges from approximately 34-48 kph (21-30 mph). The high-severity threshold was set at 56.7 kph (35 mph) for frontal events and 34 kph (21 mph) for side impacts. Frontal impacts were identified by GAD1 = “F’ in the most harmful event. Side impacts were identified by GAD1 = “L’ or “R’ in the most harmful event.

Identification of EDRs subject to fire, immersion, and high severity

Fire, immersion, and high delta V crashes are relatively rare. To further refine these measurements, a case level study was performed using NASS/CDS (2005-2011) and NMVCCS datasets. The dataset was limited to GM vehicles of MY 1995 and greater. GM EDRs of this model year range could be read by the publicly available Bosch CDR tool at the time of the crash. NASS/CDS records whether the EDR was read and, if not read, the reasons why the EDR could not be read.

GM, like most automakers, installs its EDRs in the occupant compartments. Approximately 95 percent of Bosch CDR v.10.2 supported GM EDRs are installed underneath the driver seats, underneath the front passenger seats, or in the center tunnel. As described below, for vehicle fire or immersion, we examined crash summaries and photos of the occupant compartment to determine if the EDR location suffered any visible damage from these events.

Risk of fire damage to EDR

NASS/CDS identifies vehicle fires using the variable "fire," which indicates the presence and severity of a fire in a particular vehicle. Vehicles exposed to fire were extracted from the database and inspected for evidence of fire via photographs and crash summaries from the NASS/CDS online case viewer. The risk of heat exposure to the EDR was determined from the severity of occupant compartment damage, as indicated by photographs. Each case was categorized into one of three values, as shown in Table 29, describing the risk of EDR damage: "no risk from vehicle fire," "risk from vehicle fire," and "unknown." Additional variables of fire origin and success of EDR information download were extracted from NASS/CDS. In vehicles where the EDR information was not successfully downloaded, the reason was documented. Our study created frequency distributions for each of these data elements.

Table 29. Rating scheme to determine the risk of EDR damage because of vehicle fire

	No risk from vehicle fire	Risk from vehicle fire	Unknown
Example Image	 NASS Case ID: 762013627	 NASS Case ID: 768011337	 NASS Case ID: 613009786

NMVCCS further provides fire ignition time, fire origin, and whether EDR information could be downloaded by crash investigators. For vehicles for which EDR information was not obtained, the NMVCCS investigator's reasons for not downloading the EDR were tabulated in frequency distributions. Photographs are presented for representative vehicles in which EDR data could or could not be downloaded.

Risk of immersion damage to EDR

Immersion was not an explicit variable included in the NMVCCS database. However, this database was a good source for this study in the determination of immersed vehicles as investigators were on scene with police and EMS agencies and thus were able to obtain a good assessment of the crash characteristics. The database includes crash narratives, photographs, schematic diagrams, vehicle information, as well as EDR data when available. Crash narratives were therefore examined for variables indicative of sources of water (i.e., pond, lake, and ocean) and manually perused for relevance. The severity of each case was evaluated from on scene photographs and classified into one of three categories. "No risk of submersion" was characteristic of a shallow body of water. “Risk for submersion” identified a significant body of water with no apparent water in the occupant compartment. Last, “submerged” designated water in the occupant compartment. Relevant vehicles were identified in the database from which weighted and unweighted frequency distributions were generated for immersion, severity, and obtainment of EDR information.

Table 30. Rating scheme to determine the risk of EDR damage because of submersion

	No risk from submersion	Risk from submersion	Possible risk
Example Image			
	NASS Case ID: 159010285	NASS Case ID: 437010067	NASS Case ID: 174008900

Similarly, the NASS/CDS database does not include an explicit variable to indicate immersion. Crash summaries were searched for terms, which indicated sources of water, e.g., river, lake, or canal, and were then manually perused to determine if the vehicle entered the body of water. Another challenge to this analysis was the absence of photographs of the vehicle at the crash site. Because NASS investigators visited the crash site many days after the crash, the vehicle had been removed from the scene prior to the visit, and no photos were available showing the degree to which the vehicle was immersed. Our approach was to rate the probability of immersion based upon water depth estimated from the site photographs. These vehicles were then classified into one of three categories, as seen in Table 30. “No risk from submersion” was characteristic of a shallow body of water. “Risk from submersion” identified a significant body of water with potential to enter the passenger compartment. Last, “possible risk” reflected the inability to determine the risk. Relevant vehicles were identified in the database from which frequency distributions were generated for immersion, risk, and retrieval of EDR information. For vehicles from which EDR information was not obtained, the online case viewer provided a variety of causes that were gathered and outlined in similar frequency distributions.

Risk of high delta V damage to EDR

High-severity crashes were identified in NASS/CDS through the variable “dvtotal,” total vehicle change in velocity, or delta V, in the most harmful event.

Vehicle crashes were determined to be of high severity if their delta V surpassed 56 kph (35 mph) for frontal crashes and 34 kph (21 mph) for side crashes. Frontal impacts were identified by GAD1 = “F” in the most harmful event. Side impacts were identified by GAD1 = “L” or “R” in the most harmful event.

Test EDRs to Potential Specifications for Hardening

The RFP specified a minimum set of tests, including thermal and immersion. Based on the crash data study described previously, the research team selected heat (crash fire), immersion (or submersion), and crush (high impact force) as the three focus areas for the test program. The program consisted of four main areas, development of the test levels and protocols, EDR selection, a pilot test, followed by production tests.

Test development

Test development used the crash data study as a guide for selection of the three types of tests, heat, immersion, and crush, but there were no readily available test methods for automobile EDRs. Similar devices in other transportation areas have component test specifications, but they are overly conservative for automobile use. First, automobile crashes are less severe than airplane crashes. Also, with EDRs, it may not be imperative to develop a module that can withstand the most severe crash outcomes because increasing survivability to include these rare events will greatly increase unit cost, potentially outweighing the benefit. The aviation industry has several standards or prototype specifications for flight data recorders:

(a) Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems (EUROCAE ED-112, 2003) "is meant to define the minimum specification to be met for all aircraft required to carry flight recorders."

(b) Minimum Operational Performance Specification for Lightweight Flight Recording Systems (EUROCAE ED-155, 2009) "is meant to define the minimum specification to be met for aircraft [that elect] to carry lightweight flight recording systems."

(c) The L-3 Communications, Aviation Recorders Division (L3ARD) lightweight data recorder is a small, lightweight package providing crash-protected recording of audio, image and flight data on small general aviation helicopters and fixed-wing aircraft.

A brief summary of the requirements of these standards is found in the Table 31.

Table 31. Airborne recorder test requirement summary

Survivability	ED-112		ED-155		LDR	
Impact	3,400 G	6.5 ms	1,000 G	5 ms	1,000 G	5 ms
Penetration	¼ in. pin, 500 lb	10 ft	N/A		¼ in. pin, 250 lb	10 ft
Static Crush	5,000 lb	5 min	1,000 lb	5 min	1,000 lb	5 min
Low Temp Fire	260 °C	10 hr	N/A		260 °C	5 hr
High Temp Fire	1,100 °C	1 hr	1,100 °C	15 min	1,100 °C	15 min
Sea Water Immersion		30 days	N/A			30 days
Deep Sea Pressure	20,000 ft	24 hr	N/A		20,000 ft	24 hr
Fluid Immersion	Various fluids	48 hr	N/A		Various fluids	48 hr

The research team reviewed each document for three test areas: heat, immersion, and crush, deemed applicable from the crash test data. Further, we refined the load condition to those applicable to automobile crashes.

Heat load condition

In the airborne recorders, very high heat for an extended time is used; this is because the aircraft can carry very large amounts of jet fuel that can sustain a fire for a long period of time. In addition, fuel-fed aviation fires can burn at high temperatures. In an automobile, based on the crash test data, the research team determined that lower temperatures and shorter durations were associated with automobile fires than allotted for in the FDR test requirements Shipp & Spearpoint, 1995. Based on the current EDR structures, the research team expected the EDRs to be capable of withstanding heat more than 100 °C but less than several hundred °C.

Immersion load condition

Airborne recorders are designed to withstand immersions to the deepest ocean depths and for an extended period of time, to allow for recovery of the recorder. Based on the crash data, automobile recorders are not immersed at depths of 20,000 feet (4 miles) of water and are generally removed in a short time period. However, like aircrafts, automobiles can crash into either fresh or saltwater. The final test protocol was three types of water at 3 meter of depth for 48 hours, followed by drying.

Static crush condition

Airborne recorders are designed to withstand large load conditions. In current automobile testing and crash research, there are no direct measures of load conditions, especially on individual components like an EDR housing. Generally, delta V, acceleration profile, exterior crush, and interior intrusion are gathered to quantify the physical characteristics of a crash. None of these provide any direct relationship to loading on EDR housing. In lieu of direct measurement, vehicle weight was considered a marker for the magnitude of loading on the EDR enclosure. The direction of the load is also unknown; hence, the final design of the test was to test the EDR module under a loading condition in three orientations.

EDR selection

ACMs containing EDRs from MY 2011 and MY 2012 light vehicles were examined and divided into three categories distinguishable by module material: metal, plastic, and a combination of metal and plastic. Specific EDR models were chosen that were supported by the Bosch public download tool. In all, 27 modules were tested (12 from MY 2011 vehicles and 15 from MY 2012 vehicles) from GM, Ford, Chrysler, and Toyota vehicles. The combination metal-plastic type module was only found among MY 2012 EDRs.

Pilot testing

The pilot tests were developed to target actual test specifications for the production tests. In particular, there were no clear data on the performance of the current EDRs in high temperature environments. Additionally, it was unknown how much load a typical EDR enclosure could withstand without significant crushing.

The pilot tests used two box types for temperature testing.

- Unit 1 – MY 2007 Chrysler Jeep Wrangler (Plastic Housing).
- Unit 2 – MY 2004 Chevrolet Tracker (Aluminum Housing).

These boxes were subjected to oven temperatures of 150 °C, 200 °C, and 250 °C for one hour. The pilot load used a metal type construction EDR from a MY 2012 Toyota Sienna, NHTSA no. QC5100, tested at various loads.

Production testing

The 27 MY 2011 and MY 2012 EDR production tests are described below. The EDRs that were subjected to load testing were fitted with the mating connector in case the connector provided any additional structural strength. All tests were conducted with the modules disconnected from power.

Heat load condition

The EDR modules for these tests are shown in the appendix. The high temperature tests were divided into three testing conditions: 100 °C, 150 °C, and 200 °C. The EDR modules were heated in an oven with a temperature rise rate not less than 2 °C per minute, to a minimum temperature specified and maintained for at least 1 hour. At the conclusion of the 1-hour exposure period, the EDR modules were removed from the oven and allowed to cool naturally. The EDR modules were then returned to Virginia Tech to check the survivability by attempting to retrieve data.

Immersion load condition

The EDR modules for this test are shown in the appendix. EDR modules were submerged to a depth of three meters for 96 hours in either distilled, tap, or saltwater. The tap water was collected from the L3ARD laboratory's connection to the local public water system without any additional additives or filtering. The saltwater was typical of that of the Gulf of Mexico. At the end of the test, EDR modules were placed in an oven to dry at 65 °C for 1.5 hours and then returned to Virginia Tech to check operational status.

Static crush condition

The EDR modules for this test are shown in the appendix. The external connectors to these modules were included during the test. The static crush tests were divided into three conditions that varied by the location that the load was applied: (1) parallel and (2) perpendicular to the mounting flange onto the main housing, as well as (3) parallel to the mounting flange onto the electrical connector. In each case, a static crush force of 2,500 pounds was applied for 5 minutes by a hydraulic press equipped with a pressure gauge. The EDR modules were returned to Virginia Tech to check the survivability of the data.

Following verification of successful data download (survivability measurement) and case integrity (measured by significant case yielding), the EDRs were returned to L3ARD for additional testing. The EDR modules and their respective orientations were identical to those previously designated for the first round of testing. Modules were loaded with increasing force until they showed signs of significant yielding.

Basis for Costs/Benefits of Heat, Fire, Immersion, and Impact Resistance Hardening

The approach for assessing cost is based on three levels of performance: the existing technology as measured by MY 2011 and MY 2012 EDR enclosures, an enhanced EDR enclosure that would meet the performance of the tests conducted as part of this project, and a robust EDR that is sufficiently strong to meet the lower threshold levels of airborne recorder requirements. The benefits for the three levels of EDR enclosures are based on the crash data analyses.

Typical EDR enclosures (circa MY 2012 and earlier)

Based on interviews with OEMs and suppliers, most MY 2011 and MY 2012 EDR enclosures are designed to meet the requirements of ANSI-IEC 60529-2004, using the interior enclosure specification IP51. This specification provides guidance for dust protection and protection against vertically dripping water. Additionally, OEMs and suppliers stated that electronics were designed to withstand heat associated with transportation and end use of the devices, which was generally around 100 °C.

The performance level of typical EDR enclosures can be quantified by their performance in the survivability tests discussed in the results section of this report. Generally, all EDRs tested passed the performance tests, but some had little or no margin beyond the goals of the test program.

The EDR modules in our sample, and similarly those found in the databases reviewed as part of this research pre-date the requirements of Part 563. Survivability requirements for EDRs meeting 563 state they must remain operational and report a set of data after a frontal or side crash test.

Enhanced EDR enclosures

This term is defined as an EDR enclosure that meets the current design specifications, described in the previous paragraph, plus will pass a suite of component tests similar to those performed in the project. These EDR enclosures are expected to provide additional survivability over the current design.

Enhanced EDR enclosures would be designed to pass with reasonable margin above the goals. Hence, their expected performance would be such that they should be able to capture and store data after exposure to fire, immersion, and high impact crashes, but not necessarily after all hazardous events.

Robust EDR Enclosure

This term is defined as an EDR that would meet a lower level threshold for an airborne recorder. The test procedure for a robust EDR would be as follows: impact shock, penetration, static crush, and high temperature fire tests (with the aforementioned tests to be performed in the above order and on a singular same unit). These EDR enclosures would be expected to almost never fail, hence nearly 100 percent survivability. Table 32 illustrates the magnitudes of the tests to be performed on the unit.

Table 32. Test requirements for a robust EDR enclosure

Test	Acceleration Weight Force Temp	Duration Distance	Basis	Notes
Impact Shock	1,000 G	5 ms	ED-155, 2009	
Penetration Resistance	250 lb	10 ft	ED-112, 2003	Uses ¼ in. pin Original weight reduced 50%
Static Crush	2,500 lb[1]	5 min	ED-155, 2009	
High Temp Fire	1,100 °C	15 min	ED-155, 2009	

[1] *Crush force was increased to be aligned with vehicle weight.*

Tampering

The recorded data in EDRs are stored internally on an EEPROM chip or flash memory and can be retrieved with various tools, e.g., Bosch CDR. This information helps manufacturers and researchers. However, there are numerous services on the market that claim to alter EDR data and reset the device to its original settings.

This study (1) explores the potential outlets of EDR tampering, (2) discusses anti-tampering countermeasures, and (3) presents the effectiveness of several send-away ACM reprogramming services. For the purpose of this study, tampering is defined as the intentional alteration or erasure of EDR data by parties outside of the owner and the owner’s consent.

Potential Tampering Services and Tools

The Google search engine was used to search for real world cases of EDR tampering. Search terms included “EDR tampering,” “erase crash data,” “event data recorder reset,” “hack crash data,” “delete crash data,” “EDR hack,” and “EDR court cases.” These searches gave a list of EDR tampering tools and services. The company information and the services offered were recorded. In addition, a collection of YouTube tutorials on EDR tampering were surveyed.

Tampering countermeasures

A search for current security standards was conducted using Google Scholar and The Engineering Village search engines. Search terms included "EDR security," "EDR standards," "secure event data recorders," and "tamper resistant EDR." A total of seven standards and three other journal articles were reviewed. Additional countermeasures were searched using Google Patent for current tamper-resistant EDR technology.

EDR reprogramming

A study by Chuck Veppert (2009), of Valley Technical Services, assessed the effectiveness of a reprogramming service. Four modules, each containing a deployment event, were extracted and submitted to the same service. The returned modules were exposed to a benchtop event to assess the EDR functionality. Data was downloaded at three points: after extraction, after received from the service, and after exposure to the simulated event. The results are summarized in Table 33.

Despite the advertised outcomes, Veppert's study showed that reprogrammed ACMs had inconsistent results even though they were all treated by the same service. Only one seemed to have been fully reset and functional, and the others had partial to no functionality after they were reprogrammed (Veppert, 2013). Even though websites may claim to reset air bags to "Like New" conditions, it may not be the case. The SIR system light may turn off when the reprogrammed module is placed back into the vehicle. However, that does not necessarily mean that the EDR or the ACM module is fully functional. Vehicle owners are limited to the information given by the SIR indicators and have no way of confirming if their ACM is operating properly.

Table 33. Results of Veppert study on reprogrammed ACMs

ACM	OEM	Returned Status	EDR Functionality
1	GM	• Unchanged; all event data present	• Cannot record new events
2	GM	• All event data present • Current ignition cycle reset to zero • Ignition cycle at download set to 1 • Frontal deployment level counter reset to zero	• Recorded non-deployment event • Recorded deployment event & deployment level event counter went from 0 to 2
3	Chrysler	• Unchanged; all event data present • Visible evidence of opening	• N/A – no additional event slots
4	GM	• Events recovered became "NONE" • Erased all previous event data • Visible evidence of opening	• Two deployment events

As a follow-up study, the research team sought services providing ACM reprogramming and chose three U.S. businesses: SRSModule; Airbag Systems, Inc; and MyAirbags. A 2012 Ford Mustang ACM was sent to each service. These modules were extracted from NCAP crash test vehicles and contained one deployment-level event. The housing of these modules was an aluminum case fastened by screws and sealing adhesive. This module type provides easier access to the printed circuit board (PCB) with fewer obstacles to discern tampering compared to plastic units that would require damage to the housing. However, aluminum housing modules were chosen as the crash test information written on them could be removed with greater ease than with a module of plastic housing. Prior to shipment, the data from each ACM was downloaded, and the housing was photographed to establish the pre-tampered state. Serial numbers and other unique identifiers were recorded. Crash test information written on the housing was then removed and sent to each service with an alias unaffiliated with Virginia Tech. Upon the return of each module to a third-party address, each module was read with Bosch CDR v.10.2, and the reports were compared to the reports prior to tampering. Each module was then examined for physical signs of tampering, and progressive photographs were taken of the housing and interior.

Results

Scope of the Problem

The frequency of vehicle fire, immersion, and high-severity crash scenarios in the target scope is quite small. Analyses show each of these scenarios represents generally less than 1 percent of the crash problem, except for side high severity, which is approximately 4 percent.

Frequency of fire, immersion, and high-severity events

Fire

The frequency of vehicle fires was reported in all three datasets: NASS/CDS, NMVCCS, and FARS. NASS/CDS reported vehicle fires in 238 out of 25,733 vehicles between 2005 and 2008. Note the total vehicle population excludes 115 vehicles with unknown fire exposure and vehicle fire is the sum of "major fire" and "minor fire." There were 61 out of 12,731 NMVCCS case vehicles involving fire. Similarly, the population of 12,731 vehicles excludes 47 vehicles that did not specify fire exposure. This comparison is made in Table 34.

Table 34. NASS/CDS (2005-2008) and NMVCCS comparison of fire frequency (unweighted)

	NASS/CDS	NMVCCS
No Fire	25,495	12,670
Fire†	238	61
Total‡	25,733	12,731

† "Major fire" and "minor fire" were combined to create "fire" for NASS/CDS.
‡ Total NASS/CDS and NMVCCS populations do not include vehicles if "fire" involvement unknown.

FARS values are compared with weighted NASS/CDS and NMVCCS values in Table 35, where vehicles of unknown fire exposure are omitted. NASS/CDS reported that approximately 0.2 percent of vehicles involved fire (27,447 out of 11,848,831). In contrast, NMVCCS reported 0.7

percent of vehicles involved fire (26,285 out of 3,880,818). In FARS 2009-2010, approximately 1 percent of vehicles involved vehicle fires (1,008 out of 90,253).

Table 35. NASS/CDS (2005-2008), NMVCCS, and FARS (2009-2011) comparison of fire frequency (weighted)

	NASS/CDS		NMVCCS		FARS	
	#	%	#	%	#	%
No Fire	11,821,384	99.77	3,854,533	99.32	132,692	98.88
Fire†	27,447	0.23	26,285	0.68	1,506	1.12
Total‡	11,848,831	100.00	3,880,818	100.00	134,198	100.00

† "Major fire" and "minor fire" were combined to create "fire" for NASS/CDS.
‡ Total NASS/CDS and NMVCCS populations do not include vehicles if "fire" involvement unknown.

Immersion

Vehicle immersion was also a rare event, as shown in Table 36. In NMVCCS, only 16 of 13,304 vehicles suffered immersion. The weighted data are 3,868 out of 4,031,075, or 0.09 percent. For immersion FARS data indicate 408 out of 90,253, or 0.43 percent.

Table 36. NMVCCS and FARS (2009-2011) comparison of immersion frequency

	NMVCCS			FARS	
	Unweighted #	Weighted #	Weighted %	#	%
No Immersion	13,288	4,027,207	99.91	133,618	99.57
Immersion†	16	3,868	0.09	580	0.43
Total	13,304	4,031,075	100.00	134,198	100.00

† "Risk of submersion" and "submerged" were combined to create "immersion" for NMVCCS.

High severity

A total of 4,471,089 vehicles suffered frontal damage in the most harmful event in the NASS/CDS database from 2005 to 2008. NCAP frontal crash test delta V varies from 56-64 kph (35-40 mph). As shown in Figure 12, the delta V in 0.32 percent of vehicles (14,412 out of 4,471,089) exceeded the lower threshold of 56.7 kph, or 35 mph. There were 1,900,623 vehicles where the general area of damage was the left or right side in the most harmful event. Total delta V in NCAP and FMVSS side crashes varies from 34-48 kph (21-30 mph). By using a delta V of 34kph (21 mph), an upper bound on the potential number of vehicles experiencing high side impact severity is estimated. Of these vehicles, 77,651 vehicles, or approximately 4.1 percent, exceeded a delta V of 34 kph, or 21 mph, as shown in Figure 13.

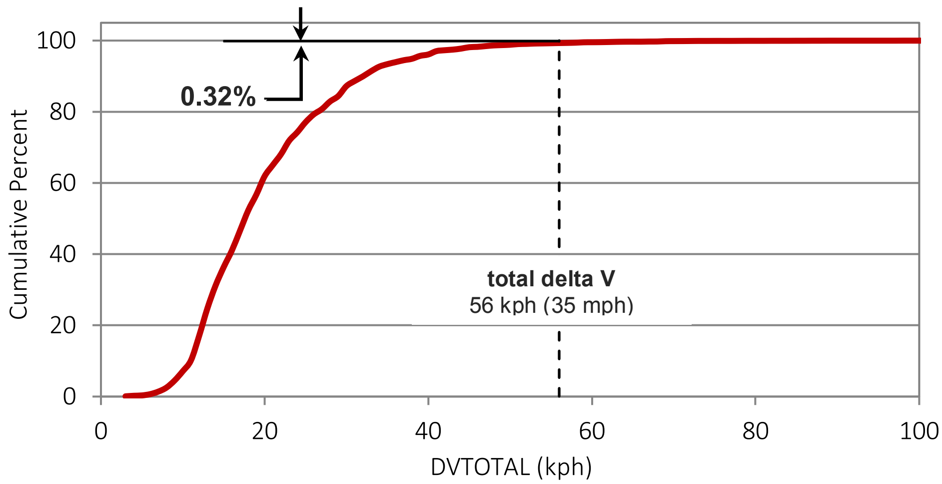

Figure 12. Distribution of vehicles in a frontal crash by total delta V (NASS/CDS 2005-2008).

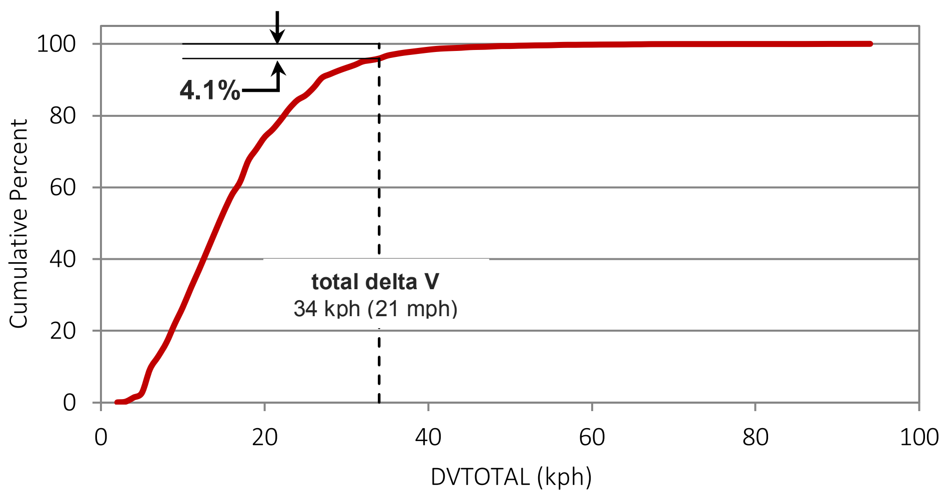

Figure 13. Distribution of vehicles in a side crash by total delta V (NASS/CDS 2005-2008).

Identification of EDRs subjected to fire, immersion, and high severity

This analysis was based on GM vehicles because at the time of the report, this group in the crash population was most likely equipped with a readable EDR. Their EDRs were read by the NHTSA crash investigators for the NASS/CDS and NMVCCS programs.

Data download limitations

From the NASS/CDS database, an unweighted total of 15,215 vehicles were GMs of MY 1995 and later. In all of these vehicles, the EDRs should have been readable. The Oracle version of the NASS/CDS database reports whether the EDR could be downloaded and the reason if the EDR could not be downloaded. Note that NASS/CDS does not indicate if an EDR download was attempted just that the data was not collected. As shown in Table 37, NASS/CDS reported that in 34 percent of vehicles (5,109 of 15,215) investigators successfully read the EDRs. However, 6,678 vehicles of 15,215 (44%) were not read. In 23 percent of vehicles (3,428 out 15,215), this information was not provided in the Oracle database and the vehicles were indicated as "data not available." Note that these download rates are for all vehicles, regardless of whether the vehicle was involved in a fire, immersion, or a high-severity crash.

This study uses "vehicle damage prevents accessing EDR data" status in many of the analyses. It does not identify why a download could not be completed. This status could be selected for any number of reasons, including: (1) vehicle damage interrupted power or communication to the system, preventing downloading, (2) vehicle damage prevented access to both the OBD-II connector and the EDR, or (3) the download tool did not collect data because of vehicle damage. Potential refinements that may assist future studies include: (1) whether the Bosch CDR reader was connected to the vehicle, (2) if so, whether the EDR could be downloaded either through the OBD-II port or by direct connection.

Table 37. EDR download outcomes in GM vehicles of model year 1995 and greater (NASS/CDS 2005-2012)

	2005	2006	2007	2008	2009	2010	2011	2012	Sum
EDR information obtained	653	712	598	527	565	515	894	645	5,109
EDR information not obtained	658	805	1,008	1,193	1,195	1,124	485	210	6,678
Vehicle not equipped with EDR	206	185	0	0	0	0	0	0	391
Vehicle not supported by software	61	93	0	0	0	0	0	0	154
Vehicle make/model not supported by software or hardware	0	0	269	320	229	151	84	30	1,083
Vehicle damage prevents accessing EDR data	146	205	158	158	174	151	69	30	1,091
Permission not received	237	315	317	387	425	450	202	60	2,393
Other reasons	0	0	219	251	317	327	104	73	1,291
Unknown	0	0	0	0	1	1	2	1	5
Software issue	0	0	28	42	37	33	19	6	165
Hardware issue	0	0	17	35	12	10	5	9	88
EDR submitted to manufacturer	0	0	0	0	0	1	0	1	2
Unknown if vehicle equipped with EDR	8	7	0	0	0	0	0	0	15
Data not available	278	377	462	411	421	442	399	638	3,428
Total	1,589	1,894	2,068	2,131	2,181	2,081	1,778	1,493	15,215

This study was limited to GM vehicles and used the "vehicle damage prevents accessing EDR data" data variable as the measurement of opportunity for more cases. Further it was limited to rare cases, including fire and immersion. This resulted in very few cases being selected, giving low confidence to the benefit estimates.

The most common reason (2,393 of 6,678 EDRs where information was not obtained, or 16 percent of all EDRs) for not being able to read GM EDRs was not damage but lack of download permission from the vehicle owner. Note that all GM vehicles in our sample contained an EDR readable by the Bosch CDR tool. However, in nearly 550 vehicles NASS investigators stated the "vehicle was not equipped with EDR" or "vehicle not supported by software." The table lists a number of other reasons for lack of download success. However, as our objective was to determine how vehicle damage may affect EDR download, we focused the analysis, which follows, on only the two categories "EDR information obtained" and "vehicle damage prevents accessing EDR data." While "vehicle damage prevents accessing EDR data" makes up 7 percent (1,091 ÷ 15,215) of the overall EDR data set, together, this analysis gives a download success rate of 82 percent (5,109 ÷ (5,109 + 1,091)) for all vehicles – regardless of whether the vehicle was involved in a fire, immersion, or a high-severity crash. We next investigated how download success rates varied with exposure to each of these risk factors.

EDRs subjected to vehicle fire

As shown in Table 38, only 89 of the 15,215 subject GM vehicles in our sample were subjected to fire. This constituted a weighted population of 8,014 vehicles out of 6,767,494 or 0.12 percent. These exposures to fire were further categorized as 28 minor fires and 61 major fires. Similarly, only 13 out of 2,656 NMVCCS vehicles experienced a vehicle fire. This constituted a weighted population of 2,351 vehicles out of 868,818 or 0.27 percent.

The EDRs were not read in 73 of the 82 NASS/CDS vehicles exposed to fire. In 9 out of 13 NMVCCS vehicles exposed to fire, the EDRs were not read. The most prevalent cause given by NASS investigators for unreadability was "vehicle damage prevents accessing EDR data," constituting 51 vehicles of the total 82. Only 2 out of 13 NMVCCS vehicles were not read because of vehicle damage.

Table 38. Distribution of vehicle fire vehicles among GM vehicles after model year 1995

	NASS/CDS (2005-2012)			NMVCCS		
	Unweighted #	Weighted #	Weighted %	Unweighted #	Weighted #	Weighted %
No Fire	11,612	4,788,390	70.76	2,656	845,876	97.36
Fire†	89	8,014	0.12	13	2,351	0.27
Unknown	3,514	1,971,090	29.13	90	20,591	2.37
Total	15,215	6,767,494	100.00	2,759	868,818	100.00

† "Major fire" and "minor fire" were combined to create "fire" for NASS/CDS.

We next examined the crash photos to determine if the fire involved the area in the occupant compartment containing the EDR. The majority of the vehicle fires originated in the engine compartment. In NASS/CDS, this accounted for 55 out of 89 vehicles, and in NMVCCS, this accounted for 11 out of 13 vehicles. Based on our examination of vehicle photographs, 53 of the NASS/CDS vehicle fires suffered sufficient fire damage to the interior, which could have posed a threat to the EDR, as seen in Table 39.

Table 39. Distribution of heat exposure severity for GM vehicles (NASS/CDS 2005-2012)

	Frequency	EDRs read	EDR not read because of	
			Vehicle Damage*	Non-Damage reasons
No risk from vehicle fire	26	7 + 1†	5 + 3†	10
Risk from vehicle fire	53	1 + 1†	34 + 5†	11 + 1†
Unknown	10	2 + 1†	3 + 1†	3
Total	89	13	51	25

** NASS/CDS explanation - "vehicle damage prevents accessing EDR data."*
† vehicles involved with fire and high-delta V.

Using the same strategy described earlier, that is, computing the success rate based on two factors: (1) successful EDR download cases with fire present and (2) cases with vehicle damage, this data set shows two successful downloads and 39 cases with vehicle damage preventing download.[15] Hence, the estimate for successful downloads is two out of 41, or a 5 percent success rate. In the general crash population of GM vehicles, the EDRs were read approximately 82 percent of the time in the same comparison. While the download rate was lower when fire was present, it is unknown if the fire prevented access to the EDR or actually destroyed the EDR data, with the latter set being the only ones that would benefit from a more robust EDR enclosure.

EDRs subjected to vehicle immersion

Vehicle immersion was relatively rare in the NASS/CDS and NMVCCS databases. Seventeen GM NASS/CDS vehicles suffered water exposure, as shown in Table 40. This constitutes a weighted population of 7,743 vehicles out of 6,767,494 (0.1%). NMVCCS reported similar results, where an unweighted population of 9 GM vehicles out of 2,759 vehicles indicated water exposure; this constituted a weighted population of 4,726 vehicles out of 864,092 (0.54%).

Table 40. Distribution of vehicle immersion vehicles for GM vehicles

	NASS/CDS			**NMVCCS**		
	Unweighted #	Weighted #	Weighted %	Unweighted #	Weighted #	Weighted %
No water exposure	15,198	6,759,751	99.89	2,749	863,944	99.44
Water exposure	17	7,743	0.11	10	4,874	0.56
Total	15,215	6,767,494	100.00	2,759	868,818	100.00

Among the GM vehicles exposed to water in NASS/CDS, 7 of 17 were categorized as "risk from submersion" from post-crash photographs, as seen in Table 41. Two cases identified vehicle damage as the primary reason preventing EDR data accessibility. The remaining 10 vehicles were deemed as "possible risk" from the post-crash photographs. Three EDRs were read successfully. Of the 7 EDRs not read, one cited vehicle damage as the reason for inaccessibility to the EDR data; however, this vehicle additionally met our criteria for high-severity exposure.

Table 41. Distribution of water exposure severity for GM vehicles (NASS/CDS 2005-2012)

	Frequency	**EDRs read**	**EDR not read because of**	
			Vehicle Damage*	**Non-Damage reasons**
Risk from submersion	7	0	2	5
Possible risk	10	3	1‡	6
Total	17	3	3	11

* *NASS/CDS explanation - "vehicle damage prevents accessing EDR data."*
‡ vehicles involved with immersion and high-delta V.

[15] Case counts are being used because the sample is extremely small.

In a similar fashion, a frequency distribution of risk in NMVCCS immersion vehicles is shown in Table 42. Recall that the categories of risk are more explicit for NMVCCS because this dataset provided images at the scene of the crash. “No risk of submersion” was assigned to 4 vehicles (out of 10), where one EDR was successfully read and data for 3 EDRs was not retrieved because of vehicle damage. In the only case rated as “risk of submersion” the EDR data was not retrieved because of non-damage issues. Five vehicles were designated “submerged,” where 1 EDR was successfully read, 1 EDR was not read because of damage, and 3 were not read for non-damage reasons.

Table 42. Distribution of water exposure severity for GM vehicles (NMVCCS)

	Frequency	EDRs read	EDR not read because of	
			Vehicle Damage*	Non-Damage reasons
No Risk of Submersion	4	1	2	1
Risk of Submersion	1	0	0	1
Submerged	5	1	1	3
Total	10	2	3	5

** NASS/CDS explanation - "vehicle damage prevents accessing EDR data."*

Using the same technique as for the fire cases, we can estimate the percentage of successful downloads. Combining both “risk of submersion” vehicles from NASS/CDS and “Submerged” vehicles from NMVCCS data, because of the small case counts, this dataset shows 1 successful download and 3 cases with vehicle damage preventing download. The estimate for successful downloads based on only 4 cases is 25 percent.

EDRs subjected to high-severity crashes

Of the 15,215 GM vehicles of MY 1995 and later in NASS/CDS, 1 percent of vehicles (171 of 15,215) were involved in frontal crashes and experienced a delta V of 56 kph (35 mph) or greater. Weighted, this population is equivalent to 11,783 out of 6,767,494 vehicles (0.2%). Additionally, 2 percent of vehicles (282 of 15,215) were side crashes of delta V 34 kph (21 mph) or greater. This constituted a weighted population of 31,387 vehicles out of 6,767,494 or 0.5 percent. This is shown in Table 43.

Table 43. Distribution of GM vehicles in high-severity crashes (NASS/CDS 2005-2012)

	Unweighted #	Weighted #	Weighted %
Not High Severity	14,762	6,724,324	99.36%
High-severity Frontal Crash	171	11,783	0.17%
High-severity Side Crash	282	31,387	0.46%
Total	15,215	6,767,494	100.00%

As shown in Table 44, 55 EDRs in frontal high-severity crashes were read, 59 were not read because of vehicle damage, and in another 57 vehicles, the download was not completed for non-damage reasons, e.g., lack of owner permission. For side crashes indicated as high severity, 98 EDRs were read, 83 were not read because of vehicle damage, and in another 101 vehicles the download was not completed for non-damage reasons.

Table 44. Distribution of GM vehicles in high-severity crashes (NASS/CDS 2005-2012)

	Frequency	EDRs read	EDR not read because of	
			Vehicle Damage*	Non-Damage reasons
High-severity Frontal Risk	171	53 + 2†	50 + 8† + 1‡	56 + 1†
High-severity Side Risk	282	97 + 1†	82 + 1†	101

** NASS/CDS explanation - "vehicle damage prevents accessing EDR data."*
† vehicles involved with fire and high-delta V.
‡ vehicles involved with immersion and high-delta V.

Using the same technique as for the fire and submersion cases, these data sets show 55 successful download cases and 59 cases with vehicle damage preventing download for high-severity frontal risk and 98 successful download cases and 83 cases with vehicle damage preventing download for high-severity side risk. Hence, the estimate for successful downloads is 48 percent in frontal and 54 percent in side. In the general crash population of GM vehicles, the EDRs were read approximately 82 percent of the time in the same comparison.

Overlapping damage modes

There were 13 GM EDRs that were involved with both vehicle fire and high delta V crashes, and there was one EDR that was involved with a vehicle immersion and high delta V case, as shown in Table 45.

Table 45. Overlapping damage in GM vehicles (NASS/CDS 2005-2012)

Case ID	Veh. #	EDR Information Obtained	Exposure Severity		GAD
			Heat	Water	
158009849	2	Vehicle damage prevents accessing EDR data	Risk from vehicle fire	—	F
158009849	1	Vehicle damage prevents accessing EDR data	Unknown	—	R
159010285	1	Vehicle not equipped with EDR	Risk from vehicle fire	—	F
168010081	1	Vehicle damage prevents accessing EDR data	Risk from vehicle fire	—	F
173008825	1	Vehicle damage prevents accessing EDR data	Risk from vehicle fire	—	F
173009973	1	Vehicle damage prevents accessing EDR data	No risk from vehicle fire	—	F
360003857	1	Vehicle damage prevents accessing EDR data	—	Possible risk	F
520016014	1	EDR information obtained	No risk from vehicle fire	—	F
520016113	5	EDR information obtained	Risk from vehicle fire	—	L
663015122	1	EDR information obtained	Unknown	—	F
666014600	1	Vehicle damage prevents accessing EDR data	No risk from vehicle fire	—	F
762014603	2	Vehicle damage prevents accessing EDR data	Risk from vehicle fire	—	F
768011519	1	Vehicle damage prevents accessing EDR data	No risk from vehicle fire	—	F
877011668	1	Vehicle damage prevents accessing EDR data	Risk from vehicle fire	—	F

Supplier and Automaker Interview Responses

Survivability

OEMs and suppliers have encountered EDRs that have been readable after various events, i.e., vehicle fire, immersion, and high-severity crashes. Interest was expressed in establishing a standard industry protocol and an update to ANSI procedures with EDRs; however, these were accompanied by concerns of the cost implications to more extensive environmental requirements. Our survey also found that several OEMs and suppliers will read these modules on a request basis for a fee, although it may not be advertised. Dependent upon the extent of damage, one supplier estimated chip swapping to cost $400 per hour and to take more than a day. Although each interviewee indicated internal specifications, the consensus of the industry is that these events are rare, and little cost/benefit analysis has been done.

Vehicle Fire

The majority of the OEMs and suppliers interviewed have encountered vehicle fires from which the EDR data could be read. There were few instances when OEMs and suppliers encountered EDRs that could not be read. One OEM estimated that it only encountered 6 instances over its entire experience with EDRs where the EDR could not be read. These cases of vehicle fire and heat occasionally require desoldering of the chip and placing it into another module by manually inserting pins, a process that is estimated to take up to one hour. There were, however, a variety of responses regarding the importance and difficulty of protecting against these events. One OEM stated that they were not concerned with temperature and fire exposure. Other OEMs discussed their concerns and specifically addressed various factors, e.g., interior damage and module placement, which affect the extent of damage and the survivability of the data. Our survey indicated that the industry focuses primarily upon heat, rather than the fire exposure, through oven tests. Often the module was required to be functional between 80 °C and 85 °C, where one OEM indicated 1,000 hours of guaranteed operation under these conditions. Storage temperature specifications were given to be between 105 °C and 110 °C. Brief tests at temperatures between 120 °C and 150 °C were also described for modules of plastic and metal housing, although these conditions approach the melting point of silicone and the plastic connectors. One OEM described that protection was provided by additional layers to act as a heat shield; however, they also expressed concerns whether there was sufficient room in the module if there was a need to add more layers for heat protection.

Vehicle immersion

Anecdotally, most of the companies interviewed have encountered real world EDRs that have been readable after a water exposure. One OEM reported that they experience an immersion only once in nine years, although there was a lower prevalence of EDRs during that time. These include instances of complete submersion, corrosion, and post-accident rain. Procedurally, one OEM specified a drying time of 24 hours near a heat source to allow the module to dry before attempting to download the data. Occasionally, one OEM specified back-powering as a needed method to read the module. Indicated by several OEMs, extraction of the microprocessor and EEPROM to put into a host module is required in rare cases. Several suppliers indicated that sealed units manage water challenges. Overall in the industry, immersion does not appear to have priority over other conditions, i.e., fire; however, a variety of water tests were alluded to, such as heavy splash, light water spray, drip, and submersion. One OEM indicated that these immersion tests were only performed on vehicles where the customer usage profile suggests that the ACM would be exposed to water. For those that detailed their submersion tests, the connector remains connected to the module such that the wires must stay out of the water or be sealed on the end. The most extreme test described involved a 14-day submersion at approximately 6 inches below the surface.

High-severity crashes

We heard little regarding high-severity crashes, and none of the interviewees described cases where the EDR could not be read. The industry consensus was that the small module size coupled with the centralized location of the EDR protects it in even the most extreme crashes. Less than 10 percent of crashes require chip swapping. One OEM described that the impact itself, not the severity of the crash, causes damage. Moreover, damage from the crash was primarily seen among the wiring and additional damage, if any, was attributed to module extraction. Few specifics were given regarding the level of protection required of the modules although crush tests and connector pull force tests were briefly alluded to by one OEM. Only one crash test, run at 80 kph, was described. The bracket broke, and the readability of the EDR was not disclosed.

Tampering

The industry is aware of various services that attempt to tamper with EDR data.[16] One OEM indicated that it does not have many specific countermeasures for tamper resistance, arguing that little can be done by those without knowledge of electronics. This OEM relies primarily upon the microprocessor that prevents overwriting of data and does not have any physical countermeasures. Other responses included current and future plans to incorporate encryption, modules seals, checksum, password protection, fasteners and welds, cyclic redundancy checks (CRC) in memory, prevention of erasing through standard diagnostic tools, and conformal coatings of the chip. ISO 26262 was described as the driving force in electronic security, e.g., 128-bit encryption. Those industry representatives who were interviewed and consider tampering a “legitimate and growing concern” also expressed interest in guidance from the SAE J1698 task force. The SAE Vehicle Electrical System Security Committee was also mentioned as an anticipated source for further direction in this area.

Test EDRs to Potential Specifications for Hardening

This section describes the results of the pilot and production testing. In all, three boxes (two subjected to heat and one to various load tests) were tested in the pilot program. The production test program matrix consisted of 3 box types (plastic, metal, and combination metal/plastic) x 3 test types (heat, immersion, load) x 3 load conditions for each test type = 27 EDRs tested.

[16] NHTSA, in its thousands of EDR data retrievals during crash investigations, has not seen any evidence of attempts to tamper with EDR data.

Pilot testing

Oven pilot tests

Two box types were tested in the oven at three temperatures. During the 150 °C test, both units mechanically appeared to survive. During the 200 °C test, both units' housings mechanically appeared to survive, but there were board level components that became unsoldered and rattled around inside the module. During the 250 °C test, one unit completely melted. With the second unit, its external aluminum housing was intact, but the connector and other non-metal parts melted. Figure 14 depicts these results.

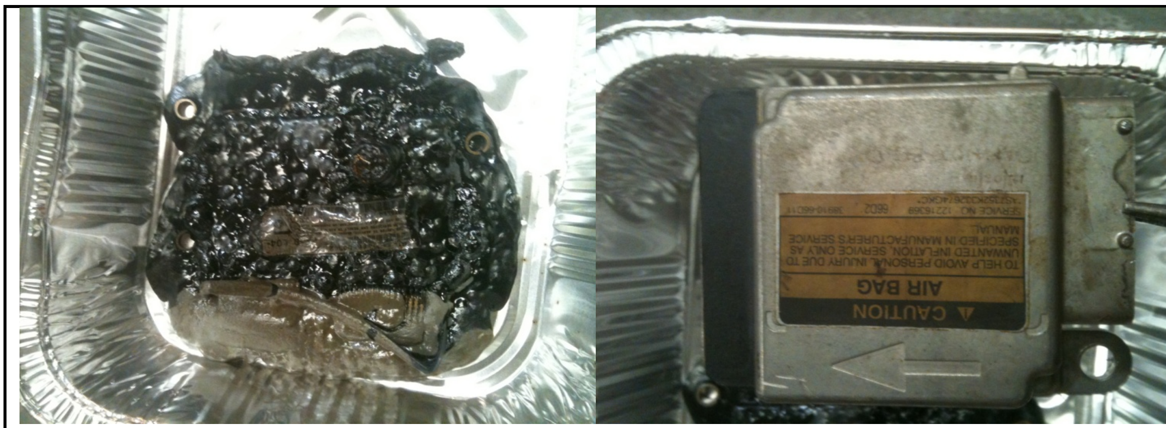

Figure 14. Final test results of the pilot oven test conducted at 250 °C.

Load pilot tests

The load test consisted of testing an aluminum type construction EDR enclosure. This EDR was from a Toyota Sienna tested in NHTSA test no. QC5100. The EDR was tested with various loads to determine its ability to resist crush forces that might be associated with high speed crashes. Figure 15 shows deformation starting at 3,600 lbs.

Figure 15. Selected result from pilot load tests, load = 3,600 pounds.

Pilot test impact on production tests

The pilot tests were critical in setting the final test criteria. Based on the oven test, the final oven temperatures were selected to be 100 °C, 150 °C, and 200° C. Regarding the load test, it was decided to run the test in two phases. First the enclosures were loaded to 2,500 pounds, observed for deformation, and assessed for EDR download operational status. This was followed by loading the box until it significantly yielded, measuring the corresponding load, and then assessing EDR download operational status for a second time.

Production testing

The EDR tests were conducted at L3ARD's Florida facility. To minimize travel of the research staff, EDR modules were returned to Virginia Tech to determine if the data had survived the test. Using the Bosch CDR tool and the then current version of software, Virginia Tech attempted to retrieve the data from each module. The results are shown in the appendices and summarized below:

Oven production tests

All 9 EDR modules that underwent controlled heat testing were successfully read.

Submersion production tests

Using the established test procedure, that is submersion followed by a prescribed drying cycle, six of the modules were successfully read upon receipt from L3ARD. The three plastic modules, from 2011 Chevrolet Tahoe vehicles, could not be immediately read. After an additional week of drying at ambient temperature, the tests were repeated, and two of Tahoe modules could be read. The module from the saltwater submersion test could not be read. Salt deposits were clearly visible on the pins of the connector. When the module was opened, as seen in Figure 16, water droplets were still present. Virginia Tech contacted GM, who agreed to read the Tahoe module.

GM cleaned the connector, and the box was then successfully downloaded. In summary, nine of nine modules were successfully read after exposure to the immersion tests.

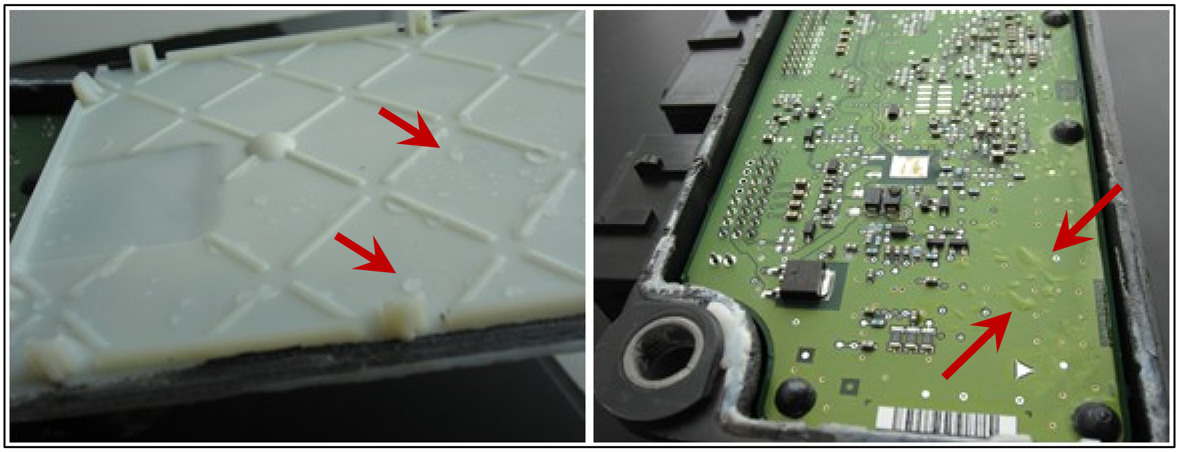

Figure 16. Water droplets found within plastic module (2011 Chevrolet Tahoe, MC0120) more than one week after saltwater immersion test.

Static crush production tests

Eight EDR modules that underwent the 2,500-pound static crush test were successfully read after the tests. One Ford Focus module (MC0202) exhibited cracks and deformation of the connector housing, as shown in Figure 17. After removal of the main housing connector, the damaged Focus module was downloaded successfully. In summary, 9 of 9 modules were successfully read after the first round of static crush tests.

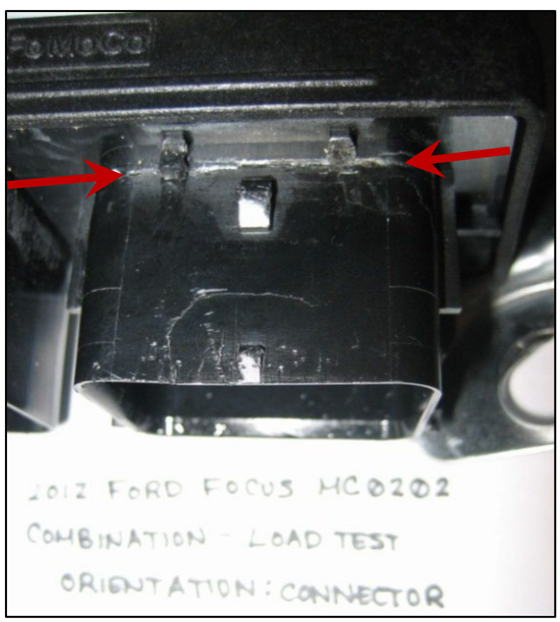

Figure 17. Broken connector on Ford Focus (MC0202) that hindered initial downloading attempt.

Because of extensive damage to the connector housing for the Ford Focus module from test MC0202, it was considered that it had been loaded to significant failure; hence, it was excluded from the second phase of the testing. The remaining eight modules were returned to L3ARD for further testing. As seen in the appendices, these eight modules were subjected to increasing static load tests until significant signs of yielding were observed. These modules were returned to Virginia Tech to test for survivability of the data.

Five of the eight EDRs maintained their ability to download stored data. Three of modules could not be downloaded. Top loaded boxes withstood loads up to 9,000 pounds. All three side loaded boxes failed to download after the loads were applied. The side-loaded Toyota Yaris module (MC5107) showed significant deformation at a force of 6,000 pounds. Figure 18 shows the significant bending of the printed circuit board of the module that likely prevented downloading. The side-loaded Cadillac CTS module (MC0122) yielded at a force of 3,400 pounds. Figure 19 shows the detached component found within the module that was likely accountable for the inability to download. Figure 20 shows the cracked printed circuit board found within the side-loaded Ford Focus (MC0201). This module endured a final force of 8,000 pounds. Note that the damage described in these figures may not be the sole component responsible for the unsuccessful download of the EDR information.

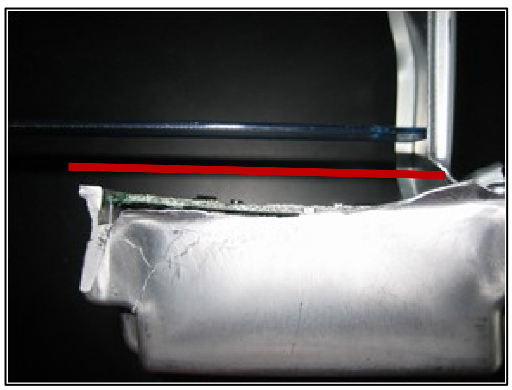

Figure 18. Side-loaded 2012 Toyota Yaris (MC5107) with bent PCB (peak force 6,000 lbs).

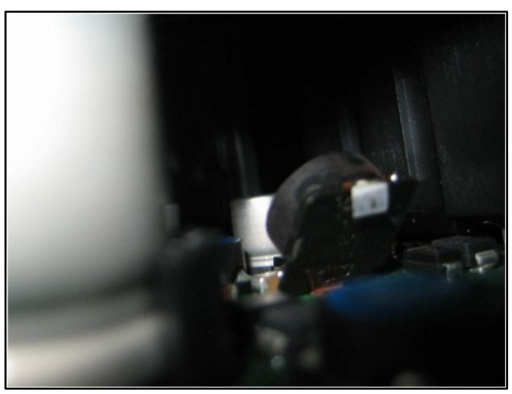

Figure 19. Side-loaded 2012 Cadillac CTS (MC0122) with detached interal component (peak force 3,400 lbs).

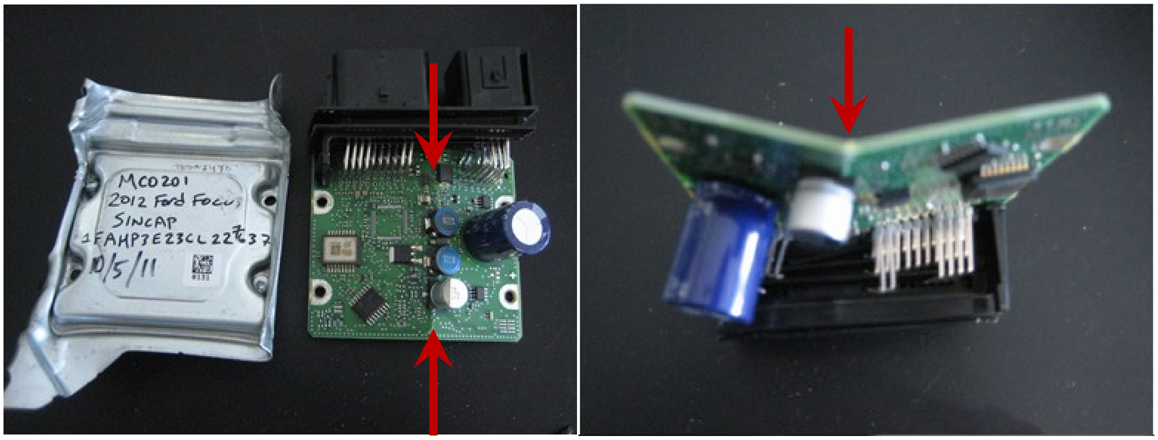

Figure 20. Side-loaded Ford Focus (MC0201) with cracked PCB (peak force 4,900 lbs).

In summary, 9 of 9 of the boxes were capable of producing data after being loaded to 2,500 lbs. Five of the boxes continued to perform successfully after high loads were applied, and those that failed did so at high loads, typically multiple times the weight of the vehicle.

Basis for Costs/Benefits of Heat, Fire, Immersion, and Impact Resistance Hardening

<u>Costs</u>

Typical EDR Enclosure

The typical EDR enclosure was considered the baseline and for this analysis has no associated additional cost. It would be representative of those EDRs from pre-MY 2013.

Enhanced EDR Enclosure

The enhanced EDR enclosure will have additional cost over current enclosures. This cost is likely low because the data in most of the current EDRs survived the three component tests.

While the test program did not find any EDR modules that lost their data, the margin for passing the tests is low in some, and the pilot oven tests showed an additional 50 °C would result in total failure of plastic and melt components within the metal housings. Thus, the enclosures would have to be redesigned or have additional content added in order to ensure that they survived the tests.

Summary of possible actions and estimated costs to meet the component tests:

- **<u>Heat</u>**: Nine of 9 survived. The oven temperatures were 100 °C, 150 °C, and 200 °C. Of note, at 250 °C in the pilot tests, there was total failure. In order to achieve a compliance margin above the passing temperature of 200 °C and the failure temperature of 250 °C observed in the pilot tests, OEMs could increase the heat resistance capability of EDRs by adding some level of insulation between the components and the housing. This would require a somewhat larger and metal housing. The estimated cost for a larger housing is $10,[17] and the estimated cost for insulation is $20.[18]

- **Immersion**: Nine of 9 survived. Three modules required extra drying and cleaning, but the data survived. During this project the, modules were tested with the connectors removed. During interviews with OEMS and suppliers, it was suggested that the connectors are water-tight to dripping water in a crash. If the protocol was changed to require connectors, the estimated cost for the improved connectors is $5,[19] which includes costs for strengthening (i.e., preventing dislodgment to break the waterproof seal) and waterproofing (i.e., 3 meters deep for 4 days).
- **Impact**: Nine of 9 survived the basic test of 2,500 lbs. in three different orientations. It was determined that one box had no margin beyond the 2,500 lbs. Five of nine were also able to be downloaded after significant yielding of the enclosure. The current housings are generally robust as measured by these tests. Additional housing performance could be obtained from the design when incorporating the aforementioned heat improvements in the oven test, hence no additional cost.

Robust EDR Enclosure

Robust EDR Test Procedure. The tests that comprise each sequence all correlate to specific conditions a flight recorder may experience during a worst-case scenario crash. Some, but not all, of these scenarios can reasonably be expected in a worst-case scenario automobile accident. The test procedure for a robust EDR is as follows: impact shock, penetration, static crush, and high temperature fire tests.

Design Changes to Existing EDR. The design changes needed are based on an engineering analysis of the existing automobile EDRs and are predicated on L3ARD's proven methods and design practices that allow its recorders to perform well in all of them.

After inspecting a current EDR in contrast with the recently developed LDR, there are three design enhancements suggestions that should allow a robust EDR to survive the test procedure. These enhancements are: an improved crash survivable housing, the addition of special

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[17] OEMs would likely combine design strategies when making enhancements. Because enclosure improvements may be needed to allow more room for insulation and improve load resistance, this cost combines the larger enclosure costs with the costs associated with enhancements to the strength of the enclosure to improve performance. The distribution of these costs would likely be determined by the OEM's design strategy.

[18] These cost estimates are scaled from the cost estimate of the robust EDR. Those estimates were performed by L-3 Communications Corporation, Aviation Recorders Division. (L3ARD, now L3Harris Technologies, Inc.), an aircraft flight data recorder designer and manufacturer (see L-3 Communications Corporation, Aviation Recorders Division, n.d.). See the next section for details.

[19] A review of recent cost studies performed for NHTSA did not find any estimates for a connector upgrade. Because the connector has similar components, (e.g., wire, mechanical locks, pins, waterproofing, etc.), this project has assumed a connector upgrade would be similar in scope and cost as much as a simple telltale or switch, but because it is much larger, it could cost approximately 2.5 times as much. The recent TPMS cost study found a telltale to be $1.58 in 2001$, adjusting to 2012$ this is approximately $2.05. The ESC cost study found a simple switch to be $1.72 in 2006$, adjusting to 2012 this is approximately $2.00. Hence, the cost estimate for the more robust waterproof connector is $5.00.

insulation material and the inclusion of a flat flex cable to thermally isolate the sensitive memory of the EDR. The FA 2100, an FDR (Figure 21), and the LDR (Figure 22) are pictured at the top of the next page for reference.

Figure 21. L3ARD FA2100 flight data recorder.

Figure 22. L3ARD lightweight data recorder.

<u>Crash Survivable Housing.</u> The first design enhancement would be a more substantial housing to enclose the crash survivable portion of the EDR. L3ARD has designed housings used on a variety of FDR, which have been proven to be able to survive these tests. The housings typically consist of a top housing, which is mechanically fastened to a base plate or cover. Table 46 outlines the materials used in, as well as the approximate cost of, a few of the crash survivable housings currently used by L3ARD.

Table 46. Existing L3ARD housings, with materials and costs

Housing	Material	Housing Cost (USD)	Cover Cost (USD)	Total Cost (USD)
A	Stainless Steel	≈ 120	≈ 40	≈ 160
B	Titanium	≈ 500	≈ 200	≈ 700
C	Aluminum	≈ 375	≈ 75	≈ 450

USD: United States Dollar

The model housing pictured in Figure 23 is representative of what would be required by the augmented EDR. Because these materials are capable of meeting the requirements, stainless steel would most likely be selected based on its low cost. The housing would be designed to be mechanically fastened to a tightly fitting base that would work together with the specified insulation material to ensure that the unit would be able to survive the impact shock and penetration resistance tests.

Figure 23. View of assembled robust EDR crash survivable housing, including upper housing, base plate and existing automotive type connector.

Insulation. The next design enhancement, shown in Figure 24, is meant to address the high temperature fire test criteria. L3ARD uses an extremely effective material to insulate the crash survivable portions of its recorders. The insulation material is capable of being molded into the upper portion of the crash housing as well as molded into an individual piece that can be used as a cover, once the crash survivable media is placed inside the housing with insulation.

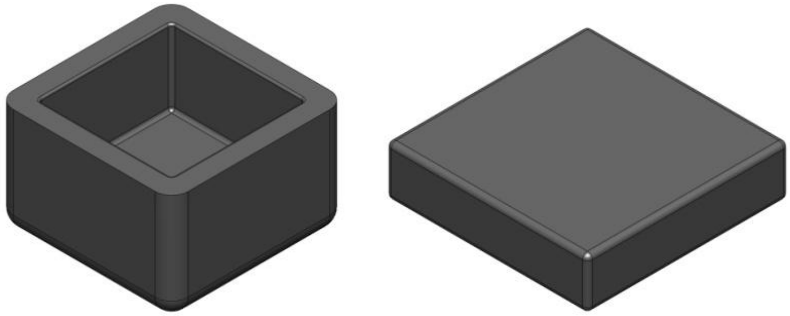

Figure 24. View of insulation pieces used in robust EDR, main upper housing and cover.

Data I/O. The final design enhancement is also aimed at helping the augmented EDR pass the high temperature fire test. The experience gained by L3ARD during the development of several recorder products has shown that the amount of copper directly leading to the crash survivable memory plays a significant role in determining whether or not the unit will pass the high temperature fire test. As a result, L3ARD has worked to develop a special cable solution designed to limit the total cross sectional area of copper leading into the memory portion of the housing. This cable integrates low profile cross sectional copper traces along with a specially designed copper ground plane that allows for high-speed, high-integrity controlled impedance differential pairs to transfer data. This cable is built using flat flex technology and would require the existing connectors to be mounted to a separate circuit card that is thermally isolated from the memory.

Cost Analysis. Each of the above design enhancements is an adaptation of techniques currently employed by L3ARD and as such the cost of each one can be estimated. The stainless steel housing that would be designed would closely resemble housing A, referenced above. The use of this housing would also require a cover. The total cost of the housing with cover is estimated at $160 for this application. The molded insulation and insulation cover will be estimated by volume. The upper insulation and insulation cover are approximately 50 cubic inches and 20 cubic inches, respectively. Examination of previous installations of this material shows that a cost of approximately $4 per cubic inch can be expected. With an estimated total volume of 70 cubic inches of insulation, the estimated cost of the insulation to be used on this project is $280. The final enhancement is the use of a minimal copper flat flex data cable. This application would require a special circuit card to accept the current connectors and output their signals to the flat flex cable. Also, the memory itself would require an updated connector to accept the flat flex cable. Table 47 provides an estimate of the total cost of the suggested design enhancements.

Table 47. Anticipated Cost by design enhancement

Enhancement	Purpose	Anticipated Cost (USD)
Upper Housing	Protect EDR from Impact Shock and Penetration	$120
Housing Cover	Compress Insulation	$40
Upper Insulation	Allow Unit to Pass High Temp Fire Test	$200
Insulation Cover	Allow Unit to Pass High Temp Fire Test	$80
Flat Flex Cable	Minimize Conduction of Heat to Memory	$40
Special Connectors	Interface with Flat flex Cable (Interior & Exterior)	$20
Total		**$500**

Assumptions. It was assumed that the four tests would be able to be survived. There are other tests used in aerospace industry (such as those in DO-160G, EUROCAE, 2011); however, they represent situations not typical of many automobile crashes. Additionally, it was assumed that the entire circuit assembly of the current EDR would need to be protected for these four tests. This would eliminate any redesign of the current electrical components and allow the assembly to use the current connectors for normal interface needs. It was assumed that the existing connectors would be destroyed in a fire scenario; however, the data would be preserved and able to be accessed with special methods.

This report did not consider the initial cost associated with these modifications, including engineering charges, new tooling costs, research and development charges, testing, and any new manufacturing costs. It was also beyond the scope of this analysis to analyze the installation of the modified EDR as well as the cost of support equipment needed for repairs and maintenance of the augmented EDR or to retrieve data from the EDR in the event of an accident.

Summary

The costs of the three EDR enclosures are as follows.

- Current - No additional cost
- Enhanced - $35 additional cost
- Robust - $500 additional cost

Benefits

In this analysis, we are defining benefits as an increase in the number of successful downloads for those cases where vehicle damage prevented download.

Benefits with current technology, no additional cost to OEM. Two strategies are explored here: (1) improve the collection rate of EDR data from existing EDRs through improved NASS/CDS collection rates and (2) collection of special cases via special handling techniques.

NASS/CDS EDR data collection opportunities and improvements. Benefits can be obtained at different levels within the EDR data collection process. Reviewing the specific cause data from NASS/CDS in Table 48, we see NASS/CDS reports slightly more than 34 percent of the EDRs (5,109 out of 15,215 vehicles) are successfully downloaded. Of the nearly 70 percent not downloaded, 16 percent (2,393 out of 15,215 vehicles) are not downloaded because the owner did not give permission to download the data. The remaining approximately 50 percent of the cases have potential for collecting additional EDR data with little additional cost.

Table 48. EDR download outcomes in GM vehicles of model year 1995 and greater (NASS/CDS 2005-2012)

	2005	2006	2007	2008	2009	2010	2011	2012
EDR information obtained	653	712	598	527	565	515	894	645
EDR information not obtained	658	805	1,008	1,193	1,195	1,124	485	210
Vehicle not equipped with EDR	206	185	0	0	0	0	0	0
Vehicle not supported by software	61	93	0	0	0	0	0	0
Vehicle make/model not supported by software or hardware	0	0	269	320	229	151	84	30
Vehicle damage prevents accessing EDR data.	146	205	158	158	174	151	69	30
Permission not received	237	315	317	387	425	450	202	60
Other reasons	0	0	219	251	317	327	104	73
Unknown	0	0	0	0	1	1	2	1
Software issue	0	0	28	42	37	33	19	6
Hardware issue	0	0	17	35	12	10	5	9
EDR submitted to manufacturer	0	0	0	0	0	1	0	1
Unknown if vehicle equipped with EDR	8	7	0	0	0	0	0	0
Data not available	278	377	462	411	421	442	399	638
Total	1,589	1,894	2,068	2,131	2,181	2,081	1,778	1,493

Of interest is the significant change from NASS/CDS years 2010 to 2011. According to NHTSA, NASS investigators were given training to improve their download success rate.[20] The number of EDRs downloaded in NASS/CDS 2011 almost doubled from previous years (515 read in NASS/CDS 2010 vs. 894 read in NASS/CDS 2011). Simultaneously, the number of EDRs from which data was not collected decreased from 1124 in NASS/CDS 2010 to 485 in NASS/CDS 2011. This trend is also evident for NASS/CDS 2012, although the effect is not as dramatic because of the smaller number of GM vehicles and larger number of cases where the EDR data is not available. In NASS/CDS 2012, 645 EDRs were read compared to the 515 EDRs read in NASS/CDS 2010. The number of EDRs not read, however, is far less in NASS/CDS 2012 (only 210 EDRs not read) compared to NASS/CDS 2010 where 1,124 EDRs were not read. Table 49 shows the significant change in EDR capture rates between 2005-2010 and 2011-2012. EDR information obtained increased from 30 percent to 47 percent.

Table 49. EDR download outcomes in GM vehicles of model year 1995 and greater for NASS-years 2005-2010 and 2011-2012

	NASS/CDS 2005-2010		**NASS/CDS 2011-2012**	
EDR information obtained	3,570	30%	1,539	47%
EDR information not obtained	5,983	50%	695	21%
Vehicle not equipped with EDR	391	3%	0	0%
Vehicle not supported by software	154	1%	0	0%
Vehicle make/model not supported by software or hardware	969	8%	114	3%
Vehicle damage prevents accessing EDR data.	992	8%	99	3%
Permission not received	2,131	18%	262	8%
Other reasons	1,114	9%	177	5%
Unknown	2	0%	3	0%
Software issue	140	1%	25	1%
Hardware issue	74	1%	14	0%
EDR submitted to manufacturer	1	0%	1	0%
Unknown if vehicle equipped with EDR	15	0%	0	0%
Data not available	2,391	20%	1,037	32%
Total	11,944	100%	3,271	100%

The NASS/CDS 2012 increase in vehicles without EDR data available prompted additional investigation into the level of inspection (NASS/CDS variable INSPTYPE). Figure 25 shows the year-to-year change in complete, partial, and non-inspections for the same population (GM vehicles MY 1995 and greater). From NASS/CDS calendar year 2011 to 2012 there was a 160 vehicle decrease in complete inspections and 343 vehicle decrease in partial inspections. This was accompanied by a 239 vehicle increase in vehicles that were not inspected. Figure 25 does

[20] NHTSA provided thorough end-of-year training for NASS investigators on an easier way to back power the module to get the data. NHTSA made standard kits for each field office and trained investigators in their proper use. This reduced the numbers because they did not need the keys and/or the vehicle did not have to have power (two challenges they previously faced).

not include the inspection types “Non-CDS Vehicle” and “Vehicle Repaired,” which were only 81 and 419 vehicles out of the total 15,215 vehicles analyzed.

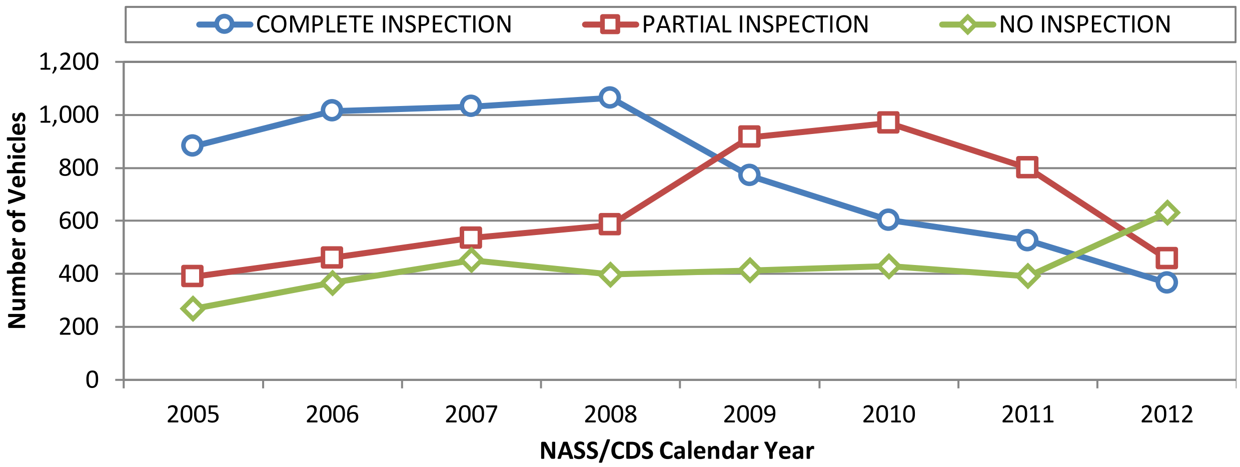

Figure 25. Annual NASS/CDS changes in inspection type for GM vehicles of MY 1995 and greater.

Figure 26 also shows inspection type, but only considers the subset of 3,428 vehicles where the EDR download outcome was “Data not available.” Non-inspected vehicles make up 88 percent (3,032 out of 3,428) of all vehicles in this subset. Similarly, an increase of 234 vehicles is seen from NASS/CDS year 2011 to 2012.

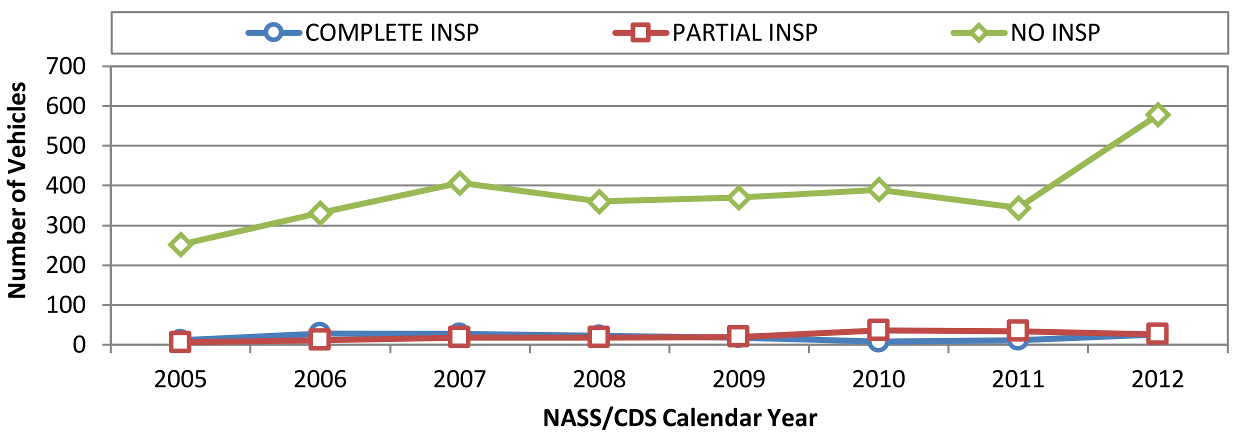

Figure 26. Annual NASS/CDS changes in inspection type for GM vehicles (MY 1995+) that received a “data not available” EDR download outcome designator.

However, the population of non-inspected vehicles does not completely coincide with the population of “data not available” vehicles. For the 15,215 GM vehicles of model year 1995 and greater, there were 3,245 non-inspected vehicles. As previously discussed, 3,032 vehicles (out of 3,245; 93%) had an EDR outcome of “data not available.” Of the remaining vehicles, 4 percent (125 out of 3,245) the EDR information was not obtained. Unexpectedly, 3 percent (88 out of 3,245) of these GM vehicles were non-inspected but EDR data was successfully downloaded.

NASS/CDS EDR data collection via special handling. One strategy that could be employed would be the development of a special capability to read the problematic EDRs. The cases would likely be selected by NHTSA to collect data from the currently non-readable EDRs in NASS, SCI, and CIREN, or to support other NHTSA activities in research or defect investigations. The data collected would benefit the public through publication via the current methods, be it current data bases or public reports.

In interviews with OEMs and suppliers, they all stated they were almost always able to capture EDR data from the automobile EDR, even after structural damage, fire, and immersion. This suggests that the data is almost always available if the right processes are employed to capture the data.

Car companies and suppliers have used different strategies, but for the most problematic modules, generally chip swapping always yielded the data. This is accomplished by removing the appropriate chip from the EDR module and installing it in an exemplar unit, which could then be read. While the time varied from OEM and suppliers, typically a chip could be removed and installed in another unit and read with one man-day of effort by a qualified technician. Other strategies are less invasive, such as using clip leads to connect to a broken connector, cleaning connectors of corrosion, or using a special drying chamber to remove moisture.

If one person was hired to do this work exclusively, and allowing for some training and time to acquire exemplar units, one man-year of effort could yield 100 to 200 successful reads of problematic EDR modules. While the read cost would be somewhat high, ranging from $500 to $2,000 per read (assuming manpower and lab equipment would cost $100,000 to $200,000 per year), there would be no additional costs to manufacturers and suppliers because there would be no need to make EDRs more resilient, where every $1 added to the cost of an automobile costs 15 million dollars (varies by annual production) per year. This process would allow NHTSA to target the most valuable problematic EDR data, whether for inclusion in a national database, to support a research goal, or even support the defect programs.

Scope for modifying each EDR (make stronger approach), additional cost to OEM.
NHTSA’s Traffic Safety Facts 2010 estimates that 9,567,000 vehicles are involved in crashes of all magnitudes. Table 50 summarizes the crash data from the previous sections (based on multiple years and multiple data systems), presents an overall estimate, and an annual count for the target populations.

Table 50. Projected populations with fire, immersion, and high impact

Area	Data	NASS Weighted	NMVCCS Weighted	FARS	Overall Estimate[21]	Annual Count
Fire	Percent	0.2	0.7	1.1	0.6	
	Count	27,447	26,285	1,506		~60,000
	Total Count	11,848,831	3,880,818	134,198		
Immersion	Percent	---	0.1	0.43	0.2	
	Count	---	3,868	580		~20,000
	Total Count		4,031,075	134,198		
High Impact Frontal	Percent	0.3	---	---	.03	
	Count	14,412	---	---		~30,000
	Total Count	4,471,089				
High Impact Side	Percent	4.1	---	---	4.1	
	Count	77,651	---	---		~390,000
	Total Count	1,900,623				

Benefits with enhanced and robust EDR enclosures, additional cost to OEM. The first step in this analysis is the understanding the potential from improved EDR enclosures. Recalling the EDR download analyses, there are three major categories: (1) EDR information obtained, (2) EDR information not obtained, and (3) data not available. Further recall that category 2 was subdivided into several subcategories, most of which would not benefit from a more robust EDR enclosure. This analysis assumes the more robust EDR enclosure will help in subcategory: vehicle damage prevents accessing the EDR data. This represents approximately 7 percent of the EDR population. As discussed earlier, "vehicle damage prevents accessing EDR data" is not necessarily limited to EDR damage cases only, e.g., inability to power the EDR because of a compromised vehicle electrical system; hence the estimates presented here are an upper bound.

Based on the selected GM population equipped with EDRs, the general download rate is approximately 82 percent when only considering EDRs successfully read and those not read because "damage prevents accessing EDR data." As discussed previously, a similarly based download rate for fire was 5 percent, for submersion it was 25 percent, and high impact had a rate of 48 percent for front and 54 percent for side, or approximately 52 percent on average. The opportunity population for each condition is the difference in the expected and observed downloads. These data are presented in Table 51.

[21] Authors' estimate based on combining NASS. NMVCCS, and FARS based on past experience with these data systems.

Table 51. Expected and observed downloads for fire, submersion, and high impact

Area	Target population	Expected population with vehicle damage prevents accessing EDR data (7%)	Expected downloads (rate = 82%)	Observed download rate	Observed downloads	Opportunity population
Fire	60,000	4,200	3,444	5%	172	3,272
Submersion	20,000	1,400	1,148	25%	287	861
High Impact (front + side)	420,000	29,400	24,108	52%	12,536	11,572

The next step is to estimate the improvements of each EDR enclosure. For this analysis, the current EDRs are considered baseline. For the enhanced EDR, considering fire is difficult to defend, it is assumed that this EDR will improve collection of fire cases by 10 percent, but because the immersion depths are minimal in most automobile crashes, and with the addition of waterproof connectors, it is estimated the enhanced EDR will improve capture and store 50 percent of the lost cases. Fifty percent was also used for the high Impact condition. Finally, if all EDRs were designed to meet airborne recorder criteria, we estimate that data could be collected from 100 percent of the opportunity population.[22] These data are presented in Table 52.

Table 52. Opportunity population and outcomes for enhanced and robust EDR housings by condition

Area	Opportunity Population	Effectiveness of Enhanced EDR	Additional Vehicles with Enhanced EDR	Effectiveness of Robust EDR	Additional Vehicles with Robust EDR
Fire	3,272	10%	327	100%	3,272
Immersion	861	50%	431	100%	861
High Impact (front+side)	11,572	50%	5,786	100%	11,572
Total cases			6,544		15,705

Cost/Benefits for stronger EDRs. The cost and benefit ratios associated with each solution are shown in Table 53. They are based on an annual vehicle production of 15,000,000.

[22] The estimates for improved performance of the enhanced EDR enclosure were based on an analysis of the margin of performance of the current EDRs compared to the testing. The oven estimate was set low because current EDRs melted at a temperature slightly above the highest oven temperature. The submersion estimate was set mid-point because there was more margin of the current enclosures over the tests conducted in the program, and the report suggests two additional changes to the test, (1) testing with the connector attached, and (2) more robust drying after the test to remove water. The high impact estimate was also set mid-point because of the significant performance over the nominal test threshold, especially by several of the enclosure designs.

Table 53. Cost and benefits for enhanced and robust EDR

EDR type	Unit Cost	Fleet Cost	Additional cases	Cost per case*
Enhanced	35	$0.53 B	6,544	$ 80,990
Robust	500	$7.50 B	15,705	$477,566

* *A sensitivity analysis of the enhanced enclosures shows changing the estimates by +/-10% reduces the cost per case estimate to $65k per case for the +10% estimates and increases the cost per case estimate to $107k per case for the -10% estimates. As with the nominal estimate of performance for the enhanced enclosure, these are also high.*

There was a big change in the data that formed the basis for this analysis. Between NASS-years 2010 and 2011, there was an improvement in the EDR data collection rate on the order of a factor of 2. If this continues, the above analysis would need significant adjustment. Also, remember that the "vehicle damage prevents accessing EDR data" outcome could have resulted from more than damage to the EDR; hence, these estimates are the upper bound.

Tampering

Methods of EDR data tampering

Table 54 lists the query results of U.S. services and tools that claim to alter or erase deployed ACMs. Note, there were similar services based in Europe that were not included. Most businesses claimed to aid the consumer in erasing the data, with two tools (i.e., AirPro and Enigma tool), which offered to modify the data. All of these services and tools advertise that their methods save the consumer time, money, and hassle compared to manufacturers' and dealerships' methods. However, OEMs such as GM have stated that they do not support the use of used or salvaged EDRs (Veppert, 2009).

Table 54. Commercially available ACM tampering services and tools

Tampering Method	Claims
Services	
karmanauto.com	Clears crash data & resets air bag module
myairbags.com	Clears crash data, repairs, resets, & reprograms modules
airbagsystems.com	Clears codes & repairs air bag system to "like new" condition
srsmodule.com	Repairs module, loads original dealer settings, & removes crash data
Tools	
Enigma Tool	(Device + Software) Recodes & reuses already deployed air bag ECUs
Audi-VW Air Bag Reset Tool	(Device) Erases car crash data via an OBD-II connector
AirPro	(Device + Software) Reads, writes, & modifies EDR data
ABRepair	(Software) Deletes crash data

Data tampering services

All services from our query claimed to clear existing crash data and reset the ACM to its original factory state, which would clear the consumer's restraint system indicator light. A previous study observed varying levels of success to these claims. There were varying degrees of crash data erasure, from unaltered to completely erased. The functionality of the ACM also varied in simulated tests, from non-operational to restored functionality (Veppert, 2009).

Each online service required the customer to mail out the ACM, with some websites providing tutorials on how to properly locate and remove the unit. Once the device and payment were received, the device would be reset and returned to the customer in 24 hours. None of the websites provided any information regarding how the device would be reset. Additionally, none of these services were affiliated with vehicle manufacturers. Dependent upon the vehicle make and model, the price of a factory-warranted ACM replacement could range from $200 to over $1,000.[23] However, most of these businesses advertised their services for an average of $50.

Data tampering tools

The commercially available tools advertised erasure, as well as alteration of ACM data. These tools included solitary, handheld devices (i.e., Audi-VW air bag reset tool) or software-hardware packages. The devices connected to a variety of locations: the OBD-II port, the ACM by direct connection, and the memory chip within the ACM. These tools are also largely marketed for businesses, unlike the send away services that advertised primarily to owners. Additionally, the price was often not disclosed and required contacting the manufacturer of the tool. Only the AirPro indicated a base price of $700 with an additional $150 for software specific to each make, or $2,000 for all 22 makes. The Enigma tool additionally claimed to clear inspection messages, deactivate the passenger air bag, and control indicator lights available from the OBD-II port. None of the tool websites offered clear explanations or examples of their effect on the EDR data, and no studies have evaluated the claims of these tools.

Potential tampering methods

Beyond commercially available services and tools, researchers are evaluating the ability to affect ECUs while they are still equipped within a vehicle. Researchers from University of Washington and University of California San Diego investigated the security of vehicle electronic systems in response to tampering. Most modern vehicles are equipped with ECUs, computers that control vehicle subsystem functions, such as an EDR. These ECUs are often interdependent and communicate according to the standards set by the CAN protocol (National Instruments, 2011). From their experiments, the researchers determined that the entire electronic system in modern vehicles is fragile. By physically linking from the OBD-II connector to a laptop equipped with their software, CarShark, the researchers were able to gain access to all ECUs that were connected to the CAN bus. They were able to control dashboard displays, various lights, the sound system, locks, brakes, and the engine of a running car. In many cases, the researchers were

[23] Personal communication with B. Brown, Duncan's Hokie Honda, Christiansburg, VA, June 2013.

able to completely override the driver's control of the vehicle. They identified the main weakness of the system in the setup of the network (Koscher et al., 2011).

The researchers discovered that the authentication between the interconnected components was lacking. Any one ECU could be used to gain access to the other ECUs on the CAN bus. Therefore, by bypassing the security of one ECU the whole system could be compromised. In addition, the research team claimed that many of the security algorithms in use today are commonly known by the car tuning community (Koscher et al., 2011).

Although the "Inflatable Restraint Sensing and Diagnostic Module (SDM)" was addressed as a key ECU, it was not specifically evaluated in this study; however, as EDR data is obtained through communication with other ECUs, this demonstrates the potential to send inaccurate information to the EDR to record before a crash (Koscher et al., 2011). The study was specifically able to falsify speedometer readings. Additionally, the study indicated that the researchers were able to "forge a packet with the "airbag deployed" bit set to disable the engine," but it is unknown if this action affects what the EDR would record. Moreover, the vehicle SDM was identified as a low-speed communication bus component, and the researchers were able to compromise other ECUs of this type. Specifically, the CarShark software was capable of "loading custom code into ECUs." This suggests it may be plausible to change recorded data elements, but this was not specifically demonstrated in the study.

<u>Anti-tampering countermeasures</u>

Anti-tampering methods can be categorized into three categories: prevention, detection, and data protection. The preventive methods deny unauthorized access to the EDRs. In the event that these preventive methods are bypassed, detection methods offer a way to identify physical tampering. Detection methods, however, do not offer resistance to data tampering. Thus, data protection methods (i.e., encryption) could be implemented.

Access prevention methods

Physical obstacles are among the prevention methods suggested to prevent EDR data tampering. Thomas M. Kowalick, the IEEE 1616 and IEEE 1616a chair and president of AIRMIKA, Inc., advocated owner-controlled access to the EDR through a physical locking device that secures to the OBD-II port, called the Motor Vehicle Event Data Recorder Connector Lockout Apparatus (MVEDRCLA) (Kowalick, 2011). Access to the port is permitted with a unique key provided solely to the vehicle-owner by the manufacturer. However, tools and brute force could be used to remove the locking device. Additionally, the ACM could be accessed directly, bypassing the OBD-II port.

In conjunction, but not a prevention method in itself, IEEE-1616 recommends all actions involving crash data to be logged in detailed records in order to form a "chain of custody" — similar to a paper trail (IEEE, 2005). Similarly, ASTM E2493 (American Society for Testing and Materials, 2013) recommends that all parties involved must make a mutual agreement on procedures before any actions involving the collection of EDR data takes place. In the case where the EDR must be disconnected from the vehicle, the process must be appropriately documented. These standards are in place to ensure the integrity of the data and prevent data altering.

Detection methods

U.S. Patent No. 6,795,759 (Doyle, 2002) proposes to implement an irreversible sealing mechanism. The sealing mechanism could be mechanical, chemical, electronic, or an electromechanical seal; if broken, it would indicate and record a breach in an irreversible manner.

U.S. Patent No. 5,471,193 (Peterson & Weinert, 1995), Tamper-Resistant Vehicle Event Recorder, describes an alternative EDR design that incorporates the use of an irreversible signal if an event occurs. The design uses a plastic substrate layer that would be placed somewhere visible to the vehicle operator, such as the dashboard. The plastic substrate would be equipped with a metallic igniter that has a layer of combustible material formed on it. When the vehicle data recorder is activated by an event, it will pass a current that will heat up the igniter. The heat will cause a visible deformation on the substrate. The change may be a mechanical deformation or just a visible change in the substrate, or the two combined.

Data protection methods

SAE J1698-2 recommends all crash data to be encrypted using the standards set by National Institute of Standards and Technology (NIST) SP 800-38C. As an additional security measure, the protocol recommends crash data to be read at least three times to make sure there are no discrepancies (SAE International, 2013a, January).

The NIST SP800-38C recommends an encryption scheme for data security. It describes the use of the Counter Block Chaining-Message Authentication Code (CCM) algorithm to encrypt and decrypt data. The input data consists of three parts: payload data, associated data, and a nonce. The payload is the essential data that is carried in packages. Associated data consists of the overhead information. The nonce is a unique key that must be set beforehand (National Institute of Standards and Technology. 2004). The algorithm consists of two main stages: the "generation-encryption" stage and "decryption-verification" stage. Generation-encryption first uses all three input elements and generates a message authentication code (MAC). The MAC and payload can then be translated into an unreadable form. Decryption-verification is the reverse process of generation-encryption, which first recovers, the MAC. If the decrypted MAC value, matches the original, it can be concluded that the decrypted information is the same as the original data.

The CCM process is a stronger security measure than a checksum or an error detecting code. Checksums, and non-cryptographic methods, can only detect modifications to the overall data. On the other hand, CCM can detect modifications in every bit of the data because it verifies every data point (National Institute of Standards and Technology. 2004).

U.S. Patent No. 6,718,239 (Rayner, 2004), Vehicle Event Data Recorder Including Validation of Output, offers another method of securing data. It describes a typical EDR design modified to include a crash data validation system to indicate tampering. The device is equipped with a CPU and dynamic RAM memory that can securely store real time audio and video data. In case of a triggering event, the device also has flash memory that is used for permanent data storage. The stored data is supplanted with a validation value such as a hash function or digital signature. These values are computable in the creating of the secret code, but are difficult to reversely compute. Once the data is read, it is verified with the validation value to detect any tampering. The data may also be encrypted, but altering audio and video data requires more processing power (Automotive News, 2011 to 2013 et seq.).

The encryption methods presented by SAE J1698-2 and U.S. Patent No. 6,718,239 (Rayner, 2004) are just one of many data encryption approaches. There are numerous other data encryption schemes. Any of these methods could be implemented in EDRs. The encryption of EDR data is limited to the memory device and processing power of the circuitry.

EDR reprogramming

A matrix of basic module information was created, as seen in Table 55. Original price estimates for the 3 ACM reprogramming services ranged from $40 to $50 prior to shipping and handling (S/H). Two services (Airbag Systems, Inc. and MyAirbags) required added fees after receipt of the module to conduct further hardware changes. Airbag Systems, Inc. specifically indicated the replacement of the memory chip because it was "completely destroyed."

Table 55. Service and module information

	SRSModule	**Airbag Systems, Inc**	**MyAirbags**
Website	srsmodule.com	airbagsystems.com	myairbags.com
Address	PO Box 26, Freeville, NY 13068	1414 Comanche Dr., Allen, Texas 75013	461 Elena Vista, Winder, GA30680
Cost	$40 + S/H	$50 + $50* + S/H	$49 + $39* + S/H
Serial No.	2XF313014121	2XF312978031	2XF313146921
VIN	1ZVBP8AM4C5245599	1ZVBP8AM9C5245601	1ZVBP8AMXC5251570
Test No.	7463	7465	7475
NHTSA No.	MC0212	MC0211	MC0210

** Additional costs incurred after shipment for hardware changes.*

Housing alterations

A photograph comparison of pre- and post-altered housing is shown in the appendix. On the SRSModule ACM, there were no observable signs of altering. However, both the Airbag Systems, Inc. and MyAirbags ACMs were marked with "OK" on the top of the housing. Additionally, the sealing of the MyAirbags module was observably loose and detached.

Interior alterations

The appendix shows progressive photographs as the modules were opened. In opening the Airbag Systems, Inc. module, the sealing was not firmly adhered to the housing. Note that this module did not appear to be altered with from the exterior. In all modules, the foam padding between the housing and PCB was altered. In the SRSModule and the Airbag Systems, Inc.

modules this alteration was limited to partial peeling of the adhesive side from the PCB. However, in the MyAirbags module, the foam padding was completely detached from the PCB. There were no other observable defects on the interior, despite the indicated need to change hardware components from Airbag Systems, Inc. and MyAirbags.

Report alterations

The deployment-level events were eliminated from the Airbag Systems, Inc. and MyAirbags modules. For the data element "ignition cycle, download (first record)," both of these modules reported the value "N/A" after altering. The event record hexadecimal data was cleared, such that all hexadecimal pairs showed "FF."

However, for the SRSModule, the deployment-level event was partially present such that some data values were made invalid or reset to zero. The relevant sections of the report are shown in the original form and altered form in the appendix. The recording status indicated "No Record" where it previously indicated "Locked Record." Similarly, the value for the data element "multi-event, number of events (1,2)" became "0" when the original value was "1." Interestingly, among these modifications, the "seat belt status, driver" was changed from "Driver Buckled" to "Driver Not Buckled." All pre-crash data became invalid. Additionally, lateral and longitudinal crash pulse data was eliminated. This information was contradictory to data elements such as "Maximum delta V, longitudinal" and "Time, maximum delta V longitudinal," which still retained values. Only the deployment data section of the report remained unchanged after altering.

Discussion

Study Limitations

Data

Neither NASS/CDS nor NMVCCS explicitly code for immersion. For NMVCCS vehicles, assessment of immersion was determined by on-scene photos. For NASS/CDS the assessment of immersion risk was instead determined from photographs from post-crash photos or text in the crash summary. The on-scene photos from NMVCCS allowed a good assessment of immersion. For NASS/CDS, these assessments are only an estimate, and the evaluation of immersion risk does not have the same level of certainty as the fire and high delta V assessments.

Vehicles

This study is limited to vehicles with EDRs, which could have been downloaded between 2005 and 2011 NASS/CDS or the 2005 to 2007 NMVCCS periods from MY 1995 and greater GM vehicles. The findings on EDR survivability may or may not generalize to the EDRs of other automakers. We conjecture however, based on the component tests, that there would be little difference in EDR survivability from OEM to OEM.

Some of the EDRs discussed in this paper were developed many years ago, some even before any EDR research or rulemaking activity by NHTSA. The performance of the EDRs and preservation of their data in crashes was the result of then-current industry practices. The findings of this analysis may or may not be relevant to EDRs that are currently being designed and installed in MY 2013 and later vehicles.

Further, none of the vehicles in the study, earliest vehicles would be about MY 2011 (and possible a few MY 2012 in the last quarter), in NASS/CDS year 2011, were required to meet Part 563. Hence, this study does not measure any effect of the survivability requirements associated with Part 563 will have on future performance.

Future considerations

Component tests

Oven. All module types survived high temperature tests at 100 °C, 150 °C, and 200 °C. On the other hand, during the pilot tests, an oven test to 250 °C completely melted one EDR enclosure. OEMs and suppliers indicated that typically electronic boxes and their components are designed to survive to temperatures slightly above 100 °C. It is likely the addition of a high oven temperature test will result in OEMs and suppliers removing plastic components from the EDR housing. This could add weight to the vehicle.

Submersion. Most of the modules subjected to immersion could be downloaded immediately after the test. Some required additional drying time beyond the planned test methodology, and one required removal of corrosion from the connector pins. In the end, all EDR data were retrievable. Future considerations: (1) conduct these tests with the connectors attached, this would allow the OEMs and suppliers a method to waterproof the EDR; (2) use a dehydration vacuum combination dryer to remove the moisture after the test. The oven drying specified in the tests conducted in the research program was insufficient to remove all moisture.

Crush. All modules subjected to static crush testing were successfully read after a load of 2,500 pounds was applied in three orientations; however, the plastic connector housing on one module needed to be removed in order to be successfully read. Higher loads tended to lead to more failures with side loading appearing to generate more failures than other loading paths. Future considerations: (1) These loads may cause external or internal shorting in the EDR enclosure. Hence, a special procedure may be needed to read the modules, such as, removing the housing, removing the connector housing, etc. Thus, future variations of this test may need to specify that the test conductor is allowed to use means other than straight forward connector hook up to download the data.

Findings

This study has investigated EDR data recovery associated with fire, immersion, and high-severity crashes and reviewed tampering associated with the EDR data. Additionally, a set of component tests were developed and executed for these same three crash aspects. A literature study was conducted to assess the tampering aspects. Two new EDR housings were described that could improve the survivability of crash data collected and stored in the EDR. Finally, costs and benefits were investigated associated with the two new housing designs.

Crash Characteristics

NHTSA crash data have been reviewed to determine the frequency of real-world crashes associated with fire, immersion, and high-severity impacts. Based on the crash data reviewed, the following was determined:

- From NASS/CDS (2005 -2012) there were 15,215 GM vehicles of model year 1995 and greater. On average, GM EDRs were successfully read in 34 percent of vehicles.
- Vehicle fires are rare crash outcomes (GM vehicles: 0.12% in NASS/CDS 0.12% and 0.27% in NMVCCS; All vehicles: 0.23% in NASS/CDS, 0.68% in NMVCCS, 1.12% in FARS).
- Vehicle immersions are rare crash outcomes (GM vehicles: 0.11% in NASS/CDS and 0.56% in NMVCCS; All vehicles: 0.09% in NMVCCS and 0.43% in FARS).
- High-severity frontal crashes are rare (in NASS/CDS, 0.17% of GM vehicles and 0.32% of all vehicles), while high-severity side crashes are more common (in NASS/CDS, 0.46% of GM vehicles and 4.1% in all vehicles) than high-severity frontal, as defined in this study.

Component Tests

Component tests were developed to stress an EDR in a similar manner as fire, immersion, and high-severity impact might. Twenty-seven EDRs of three generic enclosure designs, metal, plastic, and combination, were tested in three conditions for each component test. A review of the associated findings is as follows.

- **Oven Test**: All EDRs passed tests conducted at 100 °C, 150 °C and 200 °C. The EDRs were destroyed in a 250 °C pilot test, demonstrating little heat resistance above 200 °C.
- **Submersion Test**: All EDRs passed tests in distilled, tap, and saltwater. The three plastic housing EDRs did not fully dry after the oven drying, and the saltwater module developed corrosion on the connector; however, all three were eventually read. A superior drying cycle and connector attachment are factors that should be considered for future submersion test improvement.
- **Static Crush Test**: All EDRs passed 2,500 pound tests in three loading orientations. One module sustained connector damage that required special handling to read to data. After a second, increased loading, three out of eight EDRs sustained greater damage that prevented data capture.

Cost/Benefit

Benefits

The project reviewed real-world download experience with GM vehicles in crashes exposed to fire, immersion, and high-severity impacts. The potential benefits were assessed as the additional cases that could be read after the occurrence of a fire, immersion, of high-severity impact. These were computed by comparing the overall download experience from all crashes of these vehicles to the download experience associated with fire, immersion, of high-severity impact crashes. Generally, the opportunity population is small, mainly because these conditions are rare. The overall opportunity cases are 6,544 for an enhanced EDR and 15,705 for a robust EDR.

Costs

Three generic EDR concepts were developed to conduct the analysis. Cost estimates were developed for each, as follows.

Typical EDR	• No additional costs over current production
Enhanced EDR	• $35 over typical EDR cost • Designed to withstand component tests within a reasonable compliance margin
Robust EDR	• $500 over typical EDR cost • Designed to withstand 100 percent of outcomes – improves housing, adds significant fire protection, and includes isolation techniques to minimize heat soak

Tampering

The objective of this literature review was to survey current and future countermeasures of data security.

- There are commercially available EDR tampering services that claim to alter and erase data directly from the device.
- EDR data can be potentially tampered via the OBD-II port.
- Current security methods include:
    - Preventing unauthorized access.
    - Detecting unauthorized access.
    - Protecting crash data using encryption methods.

- No method can be foolproof, although some could prove to be more effective and or cost/effective than others. A combination of methods may be found to work synergistically.

EDR reprogramming

The outcome of EDR reprogramming is dependent upon the service chosen. For modules with a "locked" deployment-level event, it appeared that services that perform hardware modifications are more successful in resetting the ACM. There was, however, observable evidence of altering that is summarized below:

	SRSModule	Airbag Systems, Inc	MyAirbags
Housing alterations	• no evidence of altering	• top marked with "OK"	• top marked with "OK!" • sealing was loose and detached
Interior alterations	• foam padding partially peeled	• foam padding partially peeled	• foam padding detached
Report alterations	• deployment event present • some data made invalid or reset to zero	• no deployment event present	• no deployment event present

6. Task 5 — Assessment of Heavy Vehicle EDR Technologies

Introduction

A heavy-vehicle event data recorder provides a source of temporal vehicle data just prior to, during, and for a short period after, an event. In the 1990s manufacturers of heavy-vehicle engines expanded the capabilities of ECUs and engine control modules to include the ability to record and store small amounts of parametric vehicle data. The potential benefit of this advanced capability on the commercial vehicle industry has been noted by several authors (Kreeb, & Nicosia, 2005); Sapper et al., 2009) by helping law enforcement, fleet managers, and vehicle engineers reconstruct events of a vehicle crash and understand the details surrounding that vehicle crash. Today, EDR technologies have been incorporated into a wide range of commercial vehicle safety systems such as crash mitigation systems, air bag control systems, and behavioral monitoring systems. However, the adoption of EDR technologies has not been uniform across all classes of heavy vehicles or their associated vehicle systems. This project seeks to understand the industry's perception of HVEDR technologies and the implementation challenges posed by these technologies in heavy vehicles.

Objective

The objective of Task 5 is to evaluate the feasibility of installing HVEDRs or related technologies on the fleet of heavy vehicles having GVWRs greater than 4,536 kg (10,000 pounds). To meet this objective, the research team gathered information about the current HV fleet, current and planned HVEDR models, and potential updates to HVEDR technologies. This information was gathered through a survey of the HVEDR literature and outreach to the HVEDR industry, engine manufacturers, OEMs, and third-party analysts, through questionnaires and semi-structured interviews.

Approach

Literature Review

The literature review included relevant research and information that will serve as the foundation for the general HVEDR assessment as well as questionnaire and interview protocol development. The primary sources of information included SAE publications including SAE J2728, the Transportation Research Board'sTransportation Research Information Services database, and websites of heavy-vehicle engine manufacturers.

HVEDR Industry Outreach

<u>Participant subject pool</u>

The subject pool for this study consisted primarily of key HV stakeholders employed by or associated with the HV industry, the vehicle and engine manufacturers. Third-party data analysts were also included in the outreach. Stakeholders were recruited for their specific knowledge and expertise regarding HVEDRs. A summary of the industry outreach can be found in Table 56. Participant names and their associated companies are withheld to maintain confidentiality.

Table 56. HVEDR industry outreach summary

	Number of Companies Contacted	Questionnaires Sent	Questionnaires Returned	Interviews Completed	Total Participants
Vehicle Manufacturers	3	3	3	3	3
Engine Manufacturers	4	2	1	1	1
Third-party Data Analysts	2	2	1	2	2
Totals	**9**	**7**	**5**	**6**	**6**

Participant recruitment

The research team planned to recruit participants from several different HV industry related companies (vehicle and engine manufacturers) and third-party data analysts. Potential participants from these companies were identified using the research team's industry contacts and from searches on publicly available websites. Word of mouth recruitment was also used to identify potential participants.

Identified stakeholders from each company were contacted via e-mail and asked to participate (Appendix H). Potential participants were told in the e-mail about the purpose of the study and the time commitment involved. Follow-up calls were made, when necessary, to reach potential participants who did not reply to the e-mail.

As seen in Table 56, identified stakeholders from nine different companies were contacted. Of the nine, seven showed interest in participating and appropriate managers and engineers in the companies were sent questionnaires.

Participant protection

Several steps were taken to protect participant privacy. Once a stakeholder confirmed participation in the study, an e-mail was sent with the questionnaire that summarized the purpose of the study and the time commitment required (Appendix I). The e-mail provided informed consent information, explaining that participation was voluntary and personal identities would remain confidential. The e-mail stated that return of the questionnaire meant that the participant was providing voluntary consent to participate in the study.

Once a participant returned the questionnaire (Appendix J), the participant was asked to take part in a 1-hour phone interview. One exception did occur to this standard process. As was shown in Table 56, one third-party data analyst took part in an interview without first completing a questionnaire.

Whether or not a questionnaire had been completed prior to all phone interviews, participants were e-mailed informed consent forms to review and were asked to contact researchers with any questions or concerns prior to the interview. The ICF (Appendix K) described the purpose of the study, study procedures, general risks of the study, confidentiality procedures, and participants' rights and responsibilities. At the start of the phone interview, participants were reminded through a verbal consent process (Appendix L) of the key sections of the ICF (time required, confidentiality, etc.) and asked to voice any concerns or questions to a researcher. Once any questions and concerns were addressed, researchers asked participants to provide their verbal consent to participate in the interview.

During data reduction and analysis, participant privacy was protected. Participant names were not collected on questionnaires. Also, all audio files were transcribed without the use of participants' names so that no comments could be connected to specific participants. The questionnaire results, audio files, and transcripts are kept on password-protected computers that are only accessible to researchers and data reductionists working on the project.

<u>Data collection</u>

As part of the industry outreach process, the research team used questionnaires and interviews to gather opinions and data from stakeholders about current and planned HVEDR technologies. The purpose of these methods was to inform a feasibility assessment on the installation of HVEDRs or related technologies on HVs. The research team also wanted to gather participant opinions regarding the implementation issues associated with HVEDRs.

Questionnaires

Participants were e-mailed brief questionnaires to fill out and e-mail back to researchers by a specific date. As necessary, reminder e-mails and follow-up phone calls were made to motivate completion of the questionnaire. Requested time commitment for the questionnaire was estimated at 20 minutes. Out of the seven questionnaires distributed, five were completed and returned. Five interviews were conducted with participants who filled out the questionnaires. Because of work demands, one person found it more convenient to complete the interview only. Table 56 provides a breakdown of how many participants from each stakeholder group completed the questionnaire.

The primary focus of the questionnaire was the specific engine models, associated ECUs, and the dates by which these specific engine and ECU models with HVEDR capabilities were implemented. In addition, the OEMs were asked to provide statistics regarding the prevalence of these engine models and ECUs as an indication of the overall level of HVEDR-related technology in the HV fleet. The remainder of the questionnaire sought to solicit OEM plans for future ECU development related to HVEDR technologies, the types of data elements collected (and plans for collection), and the data preservation needs for data retrieval and physical protection of data during crash incidents. Finally, the questionnaire included questions specific to data retrieval tools, communication protocols (and access ports), and OEM perceptions of data element needs. All data collected via the questionnaire was aggregated and reported as appropriate.

Interviews

The purpose of the questionnaire was to familiarize stakeholders with the interview discussion topics prior to the phone call and served as the basis of the discussion during the interview. The interview process used the information gathered in the questionnaire to inquire about specific issues requiring additional clarification and/or information. Researchers referred to the questionnaires throughout the interviews, encouraging participants to clarify and expand upon responses. This format allowed the researchers to be efficient in gathering information within the limited interview time. The interviews followed a general line of questioning but varied slightly depending on the stakeholder group (vehicle versus engine manufacturers) being interviewed (Appendix M). The duration of the interviews varied, but all were kept to under an hour with the average interview time being approximately 36 minutes.

The interviews focused primarily on data elements, data types, data storage, and communication techniques. Furthermore, the existing literature suggests that very little information is publicly available regarding the nature and architecture of existing ECUs/ECMs in production HVs. These interviews were designed to elicit information to fill in the gaps associated with the complex and varied system of HV engine model and ECU model combinations. Results of the interview process in combination with the questionnaires provided a more complete picture of the current and short-term planned ECUs relating to accident reconstruction and investigation, HVEDR technologies, crash sensors, and specific associated data (with data descriptions). Last, vehicle OEMs were asked to evaluate the current state of their systems to ascertain the value of current data inputs and the need for additional data capture for accident reconstruction and investigation purposes.

Data analysis

Questionnaires

The questionnaires served primarily to familiarize stakeholders with interview discussion topics prior to phone interviews and to guide interview discussions. Questionnaires were also used as a way to collect information needed by the research team that would have been cumbersome and timely for participants to relay over the phone (e.g., listing engine models and storage capacity, capabilities, and number of access ports for each HVEDR). No quantitative data analysis was conducted with the questionnaire results, though information was pulled from the questionnaires for reporting purposes. Instead, researchers reviewed the questionnaire and interview data for common themes from the HVEDR industry. Those themes are provided in this report.

Interviews

Six interviews were completed as part of the industry outreach process. All were audio-recorded and transcribed for data reduction purposes. The transcription process involved initial transcription and quality control of audio files by one member of the research team followed by a review of the transcript by a member of the research team who was involved in the interviews. The six interviews resulted in more than 3.5 hours of discussion about HVEDRs.

Once the transcripts were completed, a member of the research team reviewed the transcripts for input on key research areas including HVEDR prevalence, design, effectiveness, and standardization. The results of the industry outreach (i.e., questionnaires and interviews) were used to inform the research team's feasibility assessment regarding the installation of HVEDRs or related technologies on large HVs.

Assessment of the Current and Planned Updates of the HVEDR

For vehicle crash investigation and reconstruction, event-driven data regarding the operator inputs and vehicle dynamics is imperative. However, there is a need to understand industry perceptions of HVEDRs, the potential value of HVEDRs, and the current implementation of HVEDRs or HVEDR-like systems in HVs. This chapter describes the findings of an investigation into the current state of HVEDRs and includes findings from the questionnaires distributed to, and interviews with, engine manufacturers, vehicle OEMs and third-party EDR analysts.

Commercial vehicle industry

The key CV stakeholders include engine manufacturers, vehicle manufacturers, and third-party EDR analysts. These people and organizations have firsthand experience and knowledge of HVEDR technologies, their performance requirements, and implementation issues.

CV engine manufacturers

The research team targeted major engine suppliers to the CV market. As the developers of HVEDRs, these companies understand functional requirements and implementation issues. The key topics discussed with CV engine suppliers included the state of development of HVEDRs within the CV market and future use of these systems.

CV manufacturers

There are four major CV manufacturers that sell vehicles to the U.S. market. These companies possess unique knowledge of the vehicle integration issues (e.g., communication protocols with the vehicle SAE J1939 CAN) that are associated with EDR systems. The key topics discussed with each CV manufacturer included the multiple EDR systems in the vehicle electronic architecture and vehicle integration issues.

Third-party data analysts

Numerous companies specialize in accessing and interpreting EDR data for clients. These companies are not involved with the design or manufacture of HVEDRs but provide a needed service to the manufacturers, law enforcement personnel, and legal counsel involved with HV crash analysis. Although this group was not a target of the initial recruiting for this project, interviews with the CV industry revealed the importance of including these individuals in understanding the use of EDR data.

Results

HVEDR Literature

Over the past decade, there have been numerous publications that provide guidance on the implementation of HVEDR technology. The groups represented in this literature scan include the American Trucking Associations' Technology and Maintenance Council, NHTSA, the National Cooperative Highway Research Program, the Federal Motor Carrier Safety Administration, IEEE, and the SAE. These references will be discussed chronologically to provide the reader an understanding of the available knowledge at the time each publication was authored.

<u>Recommended practice 1214 (T) – Guidelines for event data collection, storage, and retrieval (American Trucking Associations Technology and Maintenance Council, 2001)</u>

The TMC published an RP to define the collection of event-related data onboard CVs. The RP outlines eight data elements, the storage methodology, and the retrieval approach for event data recording on CVs. The RP lists several data parameters based upon message ID and parameter ID specifications in the SAE J1587 RP. It also defines the sample rate as a minimum of 1 Hz and a recording interval as a minimum of 30 s before and 15 s after an event trigger (defined by an unspecified deceleration threshold that falls between 0 and 16 kph/s [10 mph/s; 0.5 G]). The RP also recommends that the heavy-truck data be stored in an ECU as opposed to the light-vehicle approach of storing EDR data in the ACM.

<u>NHTSA truck and bus event data recorder working group report (NHTSA EDR Working Group, 2002)</u>

Following the work of the 1998 NHTSA-formed EDR Working Group, NHTSA sponsored the Truck and Bus EDR Working Group to explore HVEDRs. The primary purpose of the working group was to determine the data elements, survivability, and event definitions specific to trucks, school buses, and motor coaches. The group's findings were published in May 2002.

<u>IEEE standard 1616, motor vehicle event data recorders (MVEDRs) (Institute of Electrical and Electronics Engineers, 2004)</u>

In September 2004, the IEEE released the first universal standard for MVEDRs that specifies the minimum performance criteria for these onboard recorders and is applicable to all types and classes of roadway vehicles. This standard identified 86 data elements (including format, structure, and properties) in addition to providing guidance on survivability requirements. Over the past several years, this standard has grown into a group of related standards (e.g., IEEE 1616a-2010: Standard for MVEDRs Amendment 1: Motor Vehicle Event Data Recorder Connector Lockout Apparatus) that address the ongoing needs of EDRs.

Use of event data recorder (EDR) technology for highway crash data analysis, NCHRP project 17-24 (Gabler, Gabauer, Newell, & O'Neill, 2004).

The objectives of this project were to recommend a minimum set of EDR data elements for roadside safety analysis and recommend procedures for the retrieval, storage, and use of EDR data from vehicle crashes. This project included the following tasks:

- Reviewed both U.S. and international EDR literature and met with a data collection agency to assess current EDR data collection techniques.
- Identified and prioritized existing (e.g., Model Minimum Uniform Crash Criteria [MMUCC]) and potential EDR data elements based on roadside safety analysis needs.
- Investigated current methods for initial retrieval and storage of – as well as subsequent use of – EDR crash data for roadside safety analysis, and identified key issues, problems, and costs associated with these methods.
- Recommended procedures for improved retrieval, storage, and use of EDR crash data, and determined possible obstacles to implementation of the recommended procedures. The recommendations considered, at a minimum, resource requirements, cost effectiveness, legal acceptability, and public acceptance.

Development of requirements and functional specifications for event data recorders, FHWA intelligent vehicle initiative (IVI) program 134 final report (Pierowicz, Fuglewicz, & Wilson, 2004)

Based on the findings of the NHTSA EDR Working Groups and other pertinent EDR research, the report provides specific EDR requirements for the reconstruction of crashes involving heavy trucks (greater than 10,000 lbs. gross vehicle weight). The report also provides specifications for EDR hardware, software, and databases. This report was published in December 2004 by the Federal Highway Administration.

Commercial motor vehicle technology diagnostics and performance enhancement program, FMCSA-PSV-06-001 (Kreeb & Nicosia, 2005)

The objective of the project was to explore the potential for the development of cost-effective vehicle data recorder (VDR) solutions tailored to varied applications or market segments. This objective was accomplished through a combination of technical research and analyses, including business-related cost-benefit assessment. This project identified five potential VDR configurations. Based on a cost-benefit analysis of these configurations, the report states that, "in general, both VDR and EDR devices will benefit the CV industry and society as a whole, but these benefits will likely be spread across three primary stakeholder groups: (1) benefits to fleets, (2) benefits to OEMs, and (3) benefits to the public sector." The primary benefits to fleets will be improved operational efficiency and reduced operational costs. OEMs will likely realize reduced liability costs and improved vehicle designs. The public-sector stakeholders will likely gain benefits through: improved vehicle safety; fewer crashes, injuries, and fatalities; and improved safety inspection capabilities.

SAE J2728 heavy vehicle event data recorder standard – Tier 1

The SAE J2728 RP describes "a common set of performance requirements for recording, storing, and retrieving data surrounding well-defined events that can occur during the operation of a heavy-vehicle." The scope of this document includes medium-duty (Class 3-7) and heavy-duty (Class 8) trucks. This document provides a list of 39 standard data elements that need to be recorded to be considered a SAE J2728-compliant HVEDR Tier 1 device. Additional data elements and sources are provided to be captured from the vehicle network, if available. This RP was published by SAE in June 2010. While all of the above literature informed the findings of this project, the most recent publication, SAE J2728 (2010), was the primary source referenced throughout this report.

Assessment of the Heavy Vehicle Fleet

For the purposes of this report, HVs are on-highway motor vehicles weighing more than 10,000 lbs. (4,535 kg). This heavy-vehicle fleet can further be divided into vehicles weighing between 10,001 lbs. and 26,000 lbs. (4,536 kg – 11,793 kg; Class 3 through Class 6), and vehicles weighing more than 26,000 lbs. (11,793 kg; Class 7 and Class 8). In the most recently published data shown in Table 57, the Bureau of Transportation Statistics reports that there were approximately 5.4 million HVs operating in the United States in 2002. Of those, 2.82 million HVs were Class 3 through Class 6 and 2.59 million HVs were classified as Class 7 and Class 8.

With approximately 5.4 million HVs operating in the United States, there is a need to understand the effect of HVEDRs on all stakeholders, including drivers, fleets, maintenance personnel, investigators, and other personnel of the commercial trucking industry. The number of HVs by itself does not provide a complete picture of the potential for usefulness and value of HVEDRs. However, the single reason HVEDRs are used is to reconstruct at least some of the events leading to a vehicle crash. Therefore, the value or benefit of the HVEDR in HVs is, to some extent, dependent on the number of HV crashes that occur.

Table 58 provides an overview of the number of crashes, fatalities, and occupant injuries associated with the HV crashes from 1992 through 2008.

Table 57. Heavy vehicle count by weight and class

Class	Truck Weight				Number of Trucks*		
					1992	1997	2002
Class 3	10,001	to	14,000	LB	694.3	818.9	1,142.1
Class 4	14,001	to	16,000	LB	282.4	315.9	395.9
Class 5	16,001	to	19,500	LB	282.3	300.8	376.1
Class 6	19,501	to	26,000	LB	732.0	729.3	910.3
Class 7	26,001	to	33,000	LB	387.3	427.7	436.8
Class 8	33,001	to	40,000	LB	232.6	256.7	228.8
Class 8	40,001	to	50,000	LB	338.6	399.9	318.4
Class 8	50,001	to	60,000	LB	226.7	311.4	326.6
Class 8	60,001	to	80,000	LB	781.1	1,069.8	1,178.7
Class 8	80,001	to	100,000	LB	33.3	46.3	68.9
Class 8	100,001	to	130,000	LB	12.3	17.9	26.4
Class 8	Greater than 130,001			LB	4.6	5.9	6.3
Class 8	All Trucks				1,629.2	2,107.9	2,154.1
Total	**All Classes**				**4,007.5**	**4,700.5**	**5,415.3**

**In thousands.*
Source: Bureau of Transportation Statistics, 2010.

Table 58. Heavy vehicle accident characteristics

Year	Crashes	Fatalities	Injuries
1992	376,035	585	33,778
1993	397,328	605	32,102
1994	460,644	670	30,208
1995	377,472	648	30,344
1996	393,755	621	32,760
1997	437,917	723	30,913
1998	411,955	742	28,767
1999	474,920	759	32,892
2000	456,995	754	30,832
2001	429,823	708	29,424
2002	434,587	689	26,242
2003	456,721	726	26,893
2004	415,902	766	27,287
2005	440,951	804	27,000
2006	384,766	805	23,000
2007	413,833	805	23,000
2008	379,066	877	23,000

Source: Bureau of Transportation Statistics, 2011.

Over the 17-year period covered in Table 58, the median number of crashes is 420,157 per year. This equates to more than 1,150 crashes daily. Additionally, the median numbers of fatalities and injuries per year are 732 and 28,732, respectively. This equates to nearly two fatalities per day and nearly 80 injuries per day. Of course, these data include all Class 3 through Class 8 vehicles and do not provide an indication as to whether one or more vehicle classes anchor the data more so than others.

Data for fatal crashes involving a heavy vehicle by class for 2008 and 2009 are tabulated in Table 59 and Table 60. Available data for heavy trucks were not split out by vocation. As these data contain only crashes where a fatality occurred, the total numbers do not reflect the volume provided in Table 58 above. Percentages refer to the overall number of motor vehicle crashes that year.

Table 59. 2008 Fatal crash statistics for heavy vehicles by class

Class	Truck Weight	Crashes[2008]	
		Number	Percent*
Class 3, 4, & 5	10,001 to 19,500 LB	195	0.4
Class 6	19,501 to 26,000 LB	197	0.4
Class 7	26,001 to 33,000 LB	718	1.4
Class 8	Over 33,000 LB	2,798	5.5
Total		**3,908**	**7.7**

**Percent of total vehicle crashes in 2008.*
Source: Traffic Safety Facts 2008, NHTSA (2009).

The majority of truck crashes resulting in at least one fatality in 2008 involved Class 8 trucks (those weighing more than 33,000 lbs. or 4,535 kg). In fact, Class 8 trucks (tractor trailers, etc.) represented 72 percent of fatal crashes in large trucks in 2008.

Table 60. 2009 Fatal crash statistics for heavy vehicles by class

Class	Truck Weight	Crashes[2009]	
		Number	Percent*
Class 3, 4, & 5	10,001 to 19,500 LB	198	0.4
Class 6	19,501 to 26,000 LB	189	0.4
Class 7	26,001 to 33,000 LB	541	1.2
Class 8	Over 33,000 LB	2,161	4.8
Total		**3,089**	**6.8**

**Percent of total vehicle crashes in 2009.*
Source: Traffic Safety Facts 2009, NHTSA (2010).

Again in 2009, the greatest percentage of truck crashes (70%) with at least one fatality involved Class 8 trucks. Although the percentage of Class 8 crashes remains relatively static, there was an overall decrease in fatal truck crashes of 21 percent. With regard to the motor vehicle accident counts, truck crashes decreased nearly one percent from 7.7 percent to 6.8 percent.

HVs, those weighing in excess of 10,000 lbs. (4,535 kg), typically use diesel engines manufactured by Caterpillar, Cummins, Detroit Diesel, Mercedes Benz, Mack, Navistar, and Volvo. For more than a decade these engines have been manufactured using ECMs or ECUs to control dynamic processes of the engine. The ECU/ECM communicates with the engine and then with other ECUs/ECMs through a series of sensors and a standard protocol known as the CAN bus. This protocol allows various ECUs/ECMs to communicate with one another throughout the vehicle with standardized data elements. The overall communication control lies with the ECUs/ECMs. In addition to this communication network protocol, there are a series of higher-layer protocols used to track and transmit specific data from engine sensors to the ECU/ECM. These include, but are not limited to, SAE J1587, the SAE J1708 standard, the SAE J1939 standard, and the ISO 15765 standard (CAN/CAN bus). The SAE J1939 essentially replaces the SAE J1587 and SAE J1708 standards. Since 2000, the SAE J1939 standard includes a CAN. Because of emissions regulations, the SAE J1939 standard has been widely adopted by diesel engine manufacturers as it allows better control of the engine, resulting in a more efficient system.

Many heavy-vehicle engine manufacturers include memory modules in the ECUs/ECMs to provide the ability to save data (NHTSA EDR Working Group, 2002).If the data captured is related to a crash event and can be retrieved at later time for analysis, the ECU/ECM are commonly referred to as EDRs. Table 61 maps the engine types, OEMs, data retrieval software, data element types, and time thresholds for ECUs/ECMs acting as EDRs. The recently published (June 7, 2010) SAE J2728 is a RP for EDRs used on HVs (*i.e.*, greater than 10,000 lbs. [4,535 kg]). While it does provide recommendations for OEM original, modified, and aftermarket systems, it does not standardize the methodology or processes of data collection and communication.

The majority of the engine manufacturers typically employ a sudden negative acceleration threshold to trigger the event, and record at least 15 s beyond the event. However, there are variances with pre-event and post-event recording times and, in some cases (i.e., Mercedes and Detroit Diesel engines), power loss to the system (ECM/ECU) can delete the internal memory.

An HVEDR can record the status of these sensors for post-event analysis, if necessary. This method is currently part of the National Fire Protection Agency 1901-2009 Standard for Automotive Fire Apparatus. In addition to OEM ECUs/ECMs, there are several aftermarket HVEDR-type technologies available. Six of these have been identified and evaluated for comparison, amongst each other and for future comparison to OEM versions. Table 62 provides a comparison chart of the six aftermarket systems, associated data elements, and method for data recording (continuous, event-driven, or optional).

Table 61. Engine manufacturers and associated data capture information

Engine Manufacturer	Engine or ECM Model	Year Introduced	Configuration Data	Quick Stop Data	Sudden Decel. Threshold	Last Stop Data	Diagnostic Record	Pre-Event Record Time	Post-Event Record Time
Caterpillar	ADEM II	1994	Yes	ECM must have software revision after 11/1995	Factory Set	No	Yes	44 Seconds	15 Seconds
Caterpillar	ADEM III	1999	Yes	Yes	Factory Set	No	Yes	44 Seconds	15 Seconds
Caterpillar	ADEM IV	2005 (C-15), 2007 (other models)	Yes	Yes	Factory Set	No	Yes	44 Seconds	15 Seconds
Cummins	Celect	1993	Yes	No	N/A	No	Freeze Frame	59 Seconds	15 Seconds
Cummins	Celect Plus	1996	Yes	No	N/A	No	Freeze Frame	59 Seconds	15 Seconds
Cummins	ISB, ISC, ISL	1998	Yes	Sudden Decel Data 2007	9 mph/sec	No	Freeze Frame	59 Seconds	15 Seconds
Cummins	ISM, ISX	1998	Yes	Sudden Decel Data 2002 (with Late 2004 software revision)	9 mph/sec	No	Freeze Frame	59 Seconds	15 Seconds
Detroit Diesel	DDEC III	1993	Yes	No	7 mph/sec	No	No	104 Seconds	15 Seconds
Detroit Diesel	DDEC IV	1998	Yes	Yes	7 mph/sec	Yes	Yes	104 Seconds	15 Seconds
Detroit Diesel	DDEC V	2004	Yes	Yes	7 mph/sec	Yes	Yes	104 Seconds	15 Seconds
Detroit Diesel	DDEC VI	2007	Yes	Yes	7 mph/sec	Yes	No	104 Seconds	15 Seconds
Detroit Diesel	DDEC 10	2010	Yes	Yes	7 mph/sec	Yes	Yes	104 Seconds	15 Seconds
International	Maxxforce 11-15	2010	Yes	With software revision 3.8.1 or higher		With software revision 3.8.1 or higher	Freeze Frame		
Mack	V-Mac III	1998	Yes	Yes		With ECM Step 12 software revision	Freeze Frame		
Mack	V-Mac IV	2006	Yes	Yes		Yes	Freeze Frame		
Mercedes	PLD w/ VCU	2000	Yes	With ECM Step 12 software revision	7 mph/sec	With ECM software revision 12.09 or higher	With ECM Step 12 software revision	104 Seconds	15 Seconds
Mercedes	DDEC VI	2007	Yes	Yes		Yes	No	104 Seconds	15 Seconds
Paccar	PX-6, PX-8	2007	Yes	Yes		No	Freeze Frame		
Paccar	MX	2010	Yes	No	N/A	No	Yes		
Volvo	Heavy Duty Engines	2002	Yes	For EPA 2007 Engines with updated software		For EPA 2007 Engines with updated software	Freeze Frame		
Volvo	Heavy Duty Engines	2010	Yes	Yes		Yes	Freeze Frame		
Bendix	EC60 ABS Controller	2005	Yes	No	N/A	No	Freeze Frame		

Source: Austin & Messerschmidt, 2010.

Table 62. Aftermarket HVEDR technologies

Data Elements:	Tachnolink	24/7 Security	AngelTrax	Zepco	Drive Cam	Idrive
Speed	E	E	E	E	X	X
Odometer	E			O		
RPM	E			O		
Hard Braking	E	E		E		X
Acceleration	E	E		O		X
Idling Exceptions	E	E		E		
Impact		E		O		X
User Defined		E		O		
Location	X			O	X	X
Brakes	O	X	E			
Lights	O	X	E			
Signals	O		E			
Flashers	O					
Driver's Seat belt	O					
Engine Temperature	O					
Front Door	O					
All Doors			E			
Oil Pressure	O					
Low Air Pressure	O					
Low Voltage	O					
Video		X	X	X	X	E
Audio		X	X	X	X	E
Date/Time	X	X	X	X		
Hardware:						
Accelerometer	✓	✓	✓		✓	✓
Camera		✓	✓	✓	✓	✓
Driver Alert Button	✓					
GPS	✓	✓		✓	✓	✓

E: Event driven data recording

O: Optional Data Elements, some restrictions apply to number of total data elements recorded

X: System contains the capability, unspecified if event driven or continuous

Source: Sapper et al., 2009.

Assessment of the Current and Planned Updates of the HVEDR

Types of events that trigger recording

Based on questionnaire and interview results from industry representatives, the most prevalent data elements used for triggering recordings in HVEDRs (or EDR-like ECU systems) are: air bag events, ABS events, accelerations, vehicle speed, and sudden stops (hard braking). According to SAE J2728, there are three types of event triggers.

- Acceleration Trigger – This trigger is generated when the rate of change of vehicle speed is greater than the programmable threshold, which can range between 8.0 kph/s (5.0 mph/s) and 22.5 kph/s (14.0 mph/s) for more than 5.0 s. SAE J2728 recommends a default threshold setting of 11.3 kph/s (7.0 mph/s).
- Last Stop Trigger – This trigger occurs when the vehicle speed drops below 3.0 kph/s (1.9 mph/s) for 15 s or more. To prevent data loss because of the movement of the vehicle after the event of interest, the Last Stop Trigger cannot be reactivated until the vehicle reaches a speed of 24.0 kph/s (14.9 mph/s) or more for a minimum of 6.0 s.
- Safety Restraint System Trigger – This trigger is generated from the activation of the vehicle's air bag or other passive passenger restraint system.

SAE J2728 recommends that the HVEDR should retain at least two acceleration trigger recordings, at least one SRS trigger recording, and a minimum of two last-stop trigger recordings.

Data elements

Once an event trigger occurs, the HVEDR records a set of data elements to be analyzed to characterize the event. An analysis of actual ECU images provided a count of data elements for each manufacturer and is summarized in Table 63. A full listing of the data elements can be found in the appendices; Navistar, PACCAR, Cummins, and Detroit Diesel/Mercedes. A listing of HVEDR data elements for Volvo and Mack is not provided because of the proprietary nature of these HVEDRs.

Table 63. HVEDR data element counts

Manufacturer	Number of Data Elements
Navistar	467
PACCAR	78
Cummins	298
Detroit Diesel/Mercedes	114
Mack	284
Volvo	240
Caterpillar	Not reported

Of the data elements captured, the data set of each manufacturer can be broken down into the following categories: calibration information, diagnostic data, event data, maintenance data, and trip-related data. Each manufacturer image was reviewed, and the data elements categorized. Several manufacturers indicated that their data sets are based on the SAE J2728 HVEDR RP. Therefore, the available data sets were compared to that of the SAE J2728 RP to determine the industry's adoption rate (i.e., the number of collected data elements matching elements specified in the standard). The results of this analysis are presented in Table 64.

The participants suggested several additional data elements that should be considered in future HVEDRs. These additional data elements include: odometer, GPS coordinates, oil level, oil pressure, percent brake application, acceleration, and inclination. While several of these data elements (e.g., GPS, inclination) are dependent on increased functionality of EDRs, they may prove to be helpful in providing a more complete understanding of the events surrounding a crash event.

Table 64. HVEDR data comparison to SAE J2728 recommended practice

SAE J2728 Data Elements	Cummins/Paccar PX	Detroit Diesel	Navistar	Mack	Mercedes Benz	Paccar MX	Volvo	Caterpillar	Adoption Rate of RP
Alternative Vehicle ID	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Event Data Recording Complete	☐	☐	☐	☐	☐	☐	☐	☐	0.0%
Event Date	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Event Time	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
HVEDR Make	☐	☐	☐	☐	☐	☑	☐	☐	12.5%
HVEDR Model	☐	☐	☐	☐	☐	☑	☐	☐	12.5%
HVEDR Serial Number	☐	☐	☐	☐	☐	☐	☐	☐	0.0%
Pre-Event Buffer Size (samples)	☐	☑	☑	☐	☑	☐	☐	☐	37.5%
Post-Event Buffer Size (samples)	☐	☑	☑	☐	☑	☐	☐	☐	37.5%
Rear Axle Ratio	☑	☑	☑	☐	☑	☐	☐	☐	50.0%
Tire Size	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Total Event Records HVEDR Supports	☐	☐	☐	☐	☐	☐	☐	☐	0.0%
Trigger Thresholds	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Trigger Threshold Activated	☐	☐	☐	☐	☐	☐	☐	☐	0.0%
Trigger Threshold Count	☑	☑	☑	☐	☑	☐	☐	☐	50.0%
Vehicle Identification Number (VIN)	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Vehicle Configuration	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
ABS Retarder Status	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
ABS Brake Control Status-Tractor	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
ABS Warning Lamp Status-Tractor	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
ABS Brake Control Status-Trailer	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
ABS Warning Lamp Status-Trailer	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
Accelerator Pedal Position	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Brake Status-Parking	☐	☐	☑	☑	☐	☐	☑	☐	37.5%
Brake Status-Service	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Clutch Switch	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Cruise Control Active	☑	☑	☑	☑	☑	☐	☑	☑	75.0%
Cruise Control Set-Speed	☑	☐	☑	☐	☐	☐	☐	☐	25.0%
Cruise Control States	☑	☐	☑	☐	☐	☐	☐	☐	25.0%
Engine Hours	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Engine Retarder Percent Torque	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
Engine Retarder Status	☑	☐	☑	☑	☐	☐	☑	☑	62.5%
Engine Speed	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Event Buffer Number	☐	☐	☐	☐	☐	☐	☐	☐	0.0%
Transmission Gear	☑	☐	☑	☐	☐	☐	☐	☐	25.0%
Two Speed Axle Switch	☐	☐	☑	☐	☐	☐	☐	☐	12.5%
Total Vehicle Distance	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Vehicle Speed	☑	☑	☑	☑	☑	☑	☑	☑	100.0%
Wheel Based Vehicle Speed	☑	☑	☑	☑	☑	☑	☑	☑	100.0%

Duration and sample rate of pre-crash/event recording

SAE J2728 currently provides guidance about sampling rates for HVEDRs, requiring a minimum rate of 10 Hz and duration of no less than 15 s prior to an event and 15 s after an event for a total minimum recording of 30 s. As seen in Table 64, HV engine manufacturers are not capturing all the data suggested by this standard. For event-driven data captured on the ECU, each manufacturer determines the duration of data captured before (through a buffering-type method) and after an event. For the majority of cases, the duration of data recording is the same regardless of the event type. However, in the case of Mack and Volvo, there are some differences. As shown in Table 65, both Mack and Volvo record 90 s before hard braking (i.e., stop) events and 60 s before acceleration (or vehicle speed) events. Also shown in the tabulated breakdown is the fact that post-event recording times differ similarly for Mack and Volvo with no time recorded after a hard braking event and 30 s recorded after an acceleration event. Current data indicate that the frequency of data collection varies by manufacturer.

Table 65. HVEDR data record times

Engine Manufacturer	Engine or Engine Control Module (ECU/ECM) Model	Pre-Event Record Time	Post-Event Record Time
Caterpillar	ADEM II, ADEM III, ADEM IV	44 s	15 s
Cummins	Celect, Celect Plus, ISB, ISC, ISL, ISM, ISX	59 s	15 s
Detroit Diesel	DDEC III, IV, V, VI, 10	104 s	15 s
Navistar	Maxxforce 11-15	105 s	15 s
Mack	V-Mac III, V-Mac IV	90 s/60 s	0 s/30 s
Mercedes	PLD w/ VCU, DDEC VI	104 s	15 s
PACCAR	PX-6, PX-8, MX	Not reported	Not reported
Volvo	Heavy Duty Engines	90 s/60 s	0 s/30 s

HVEDR survivability requirements

The results of the questionnaires and follow-up interviews suggested that the HVEDR units should protect against: voltage loss, thermal extremes (e.g., massive vehicle fires), thermal cycling, humidity, and shock. Although suggestions were made about the survivability requirements, there was a consistent theme from the HVEDR industry that heavy trucks typically do not suffer extensive damage during crashes unless there is significant engine intrusion into the cab from striking an object of similar mass (i.e., collision with an HV) or an immovable object such as a bridge abutment or the ground. The industry outreach indicated that HVEDRs survive a great number of vehicle crashes and have the highest probability of survival if it is placed in the cab; more specifically, around the center of the dash. Several manufacturing representatives stated that they did not feel any special precautions from physical impacts were necessary based on the belief that there is little chance of HVEDR unit damage during most HV accidents. Even in cases where an extreme intrusion into the vehicle has physically damaged the housing of the HVEDR, analysts have been successful at retrieving the data from the electronic modules within the HVEDR. The more common concern from the industry was data loss incurred from massive vehicle fires in which the HVEDR componentry has melted, or data loss from power interruptions before data can be saved to non-volatile memory.

The SAE J2728 standard provides guidance on crash survivability. Specifically, the J2728 standard indicates mounting location, impact shock, extreme temperature, penetration/static crush, and power reserve issues, and it guides HVEDR placement and development decisions accordingly. Furthermore, the standard references another SAE standard, J1455, which discusses environmental exposures for typical HVEDR operations. The J2728 standard does not specifically define numeric measurement thresholds; rather, it discusses specific concerns that should be dealt with prior to implementation of the HVEDR.

Data storage capacity

Collected data from an ECU/ECM are currently stored in the unit of collection. According to industry representatives, the data storage is handled by memory in the control unit allocated for that purpose. The volume of data storage varies based on the intention of the system, essentially providing more data storage capacity for continuous data recording versus event-based data collection. A discussion about storage capacity with an industry representative suggested that the storage of HVEDR-related data would be approximately 1 Mb for every 2 hours of recorded parametric data. This assumes a certain set of criteria being recorded and does not include any video capture. An additional effort is currently underway to determine the memory requirements for a set of criteria based on this research to include the potential for collecting video data.

Manufacturer/operator strategies for capturing HVEDR data

The outreach indicated that the CV industry is not currently moving towards a stand-alone HVEDR in HVs. Instead, manufacturers appear to be headed towards using multiple distinct modules with HVEDR functionality. These EDR modules will be included in the engine control units, various safety systems, and other vehicle control modules. The current process for capturing most data in HVs is through the existing control units in each section of the vehicle. For instance, the engine control unit often captures data related to engine faults, while the antilock braking system unit captures event-driven data such as actuation or ABS fault codes. Where data are event-driven, the OEMs typically capture discrete data based on a time-buffering option such as 60 s prior until 15 s after an event. Where data are collected continuously (e.g., the ECU) it is often sampled from the CAN bus at a given frequency throughout operation.

Vehicle manufacturers indicated that customer interest in current HVEDR-type data collection is neutral. Customers stated a need for this type of system; however, actual sales did not support this reported interest for telematics systems offered by several manufacturers. Several interviews with OEMs provided information about telematics solutions that included HVEDR-type systems that are no longer offered or are being evaluated for removal because of waning customer demand. According to HV manufacturer interviews, the costs of HVEDRs are difficult to justify for many customers, thus limiting their current market penetration. Conversely, other aftermarket HVEDR-type technology such as driver monitoring systems and fleet telematics are projected to grow strongly in HV fleets (Kilcarr, 2010; Insurance Business, 2014). The market appears to be driven by perceived customer value. These aftermarket HVEDR-type devices provide data that can translate into savings on the fleet's bottom line through improved driving performance and reduced insurance costs.

Data-imaging strategies for reporting of HVEDR data

Data retrieval for HVs is manufacturer-dependent. Each manufacturer has developed a software tool to capture and decrypt (where necessary) the data stored in the ECUs. The majority of OEMs indicated on the questionnaires that their data retrieval tools were proprietary. Certain data retrieval tools were for tier-2 supplier units (e.g., ABS) requiring the investigator to use additional software to capture said data. For at least two cases, the data retrieval can only be conducted by OEM-approved, third-party firms using OEM-developed tools. For most cases, the fleet maintenance personnel can obtain the appropriate tools to retrieve collected data in their facilities.

Table 66. HVEDR data retrieval tools

EDR Provider	Data Retrieval Tool	Approximate Initial Costs*	Approximate Recurring Annual Costs*
Caterpillar	Caterpillar ET	$$	$$
Cummins	PowerSpec	$$	$$
Detroit Diesel**	DDEC Reports	$$	$$
Navistar	ServiceMaxx	$	$
Mack***	Proprietary/Restricted	$	$
Mercedes**	DDEC Reports	$$	$$
PACCAR	Runtime/PACCAR Electronic Service Analyst	$$$$$$$$$$$$	$
Volvo***	Proprietary/Restricted	$$	$

* Note: each "$" represents an approximate $500 increment in cost.
** Note: The same data retrieval tool can be used for Detroit Diesel and Mercedes.
*** Note: These reported hardware/software costs are ONLY for diagnostics and general vehicle usage reporting. The specific HVEDR function is called DataMax Incident Logs. A proprietary engineering level software tool is required to image (download) the Incident Logs from a late model Mack or Volvo truck. This engineering level software tool is NOT available for purchase and only two third-party analysts (Delta [v] Forensic Engineering and Keva Engineering) are authorized by Volvo Trucks North America/Mack Trucks, Inc. to have and use this proprietary software tool.

Based on conversations with vehicle OEMs, there is some indication that liability is a factor during system development decisions. Table 66 provides the engine manufacturers associated with the data retrieval tools and the associated start-up and maintenance costs. These costs were obtained during the interviews.

Standardization of retrieval tools and data elements

Based on industry feedback, standardization should focus on regulating the data bus format rather than providing a standard set of data elements. Most data elements collected by each system are similar. This suggests that the information captured is necessary for specific functions (e.g., crash reconstruction, crash investigation, and power plant/electronic system evaluation) and aligns across the industry. However, there is a perceived increase in cost associated with the unique development of retrieval tools and third-party units, and a lack of flexibility for unit adaptation using multiple data bus formats.

Plans for functionality of future HVEDR models

The interviews with both vehicle and engine manufacturer representatives provided a consistent message that there are few or no plans to incorporate automatic crash notification systems into HVs. Often, the industry representatives compared the functionality to the well-known On-Star system and stated that the customer demand is not available to support such a system. Of note, one manufacturer decided to develop a similar system with capabilities beyond automatic crash notification, including fuel-mileage data, integrated GPS/geographic information system data, and more. The manufacturer eventually discontinued development and sales of the system because of low customer demand. The manufacturer reported increased customer support and interest in the concept of a telematics system with HVEDR-like functionality. However, customer interest and support dropped when the system was implemented with a monthly service fee. The manufacturer believes that the commercial nature of HVs forces customers to restrict spending to only those products and services they believe they can recoup in revenue generated from the product or service. Most manufacturers interviewed indicated that either they had not evaluated customer interest in automatic crash notification or had evaluated it and found little interest in the service to justify moving forward with development.

Costs of installation and development of HVEDR data elements and models

Although HV industry indicated that current HVEDRs do not suffer extensive damage during most HV crashes, there is still the chance that data could be lost in the extreme crash scenarios such as striking an immovable object such as a bridge abutment or the ground. In these extreme cases, the HVs will experience severe forces and loads on the vehicle structures, including the HVEDR. Just as in other industries such as trains and aircraft, additional provisions for "hardening" the HVEDR may be needed to survive such extreme forces. However, this "hardening" of the HVEDR will increase the cost of HVEDRs, which may not be warrantied in HVs. As mentioned, the "HVEDR Survivability Requirements section," the current HVEDR designs have a high probability of surviving crashes if located within the cab near the center of the dash.

HVEDR limitations

The most frequent limitation of the HVEDR system mentioned by the HV OEMs is the technology's inability to sense a crash pulse because of the weight disparity between the HV and the object struck, typically a light vehicle. Typically, the HV can outweigh a light vehicle by a factor of 32 (i.e., 80,000 lbs. versus 2,500 lbs.). For an acceleration trigger, the EDR system records any event for which the vehicle speed changes at a rate higher than the selectable threshold. In a collision involving a heavy truck and a light car, there is the possibility that the momentum of the heavier truck will mask the deceleration profile and the EDR will miss the collision event, unless the truck driver stops the EDR-equipped vehicle or there is a fault code from a vehicle component damaged in the collision (e.g., an oil pan becoming damaged could create a "low oil pressure" fault code). Conversely, if the acceleration trigger is adjusted lower to compensate for this weight disparity, then the EDR will record more false positives (or false alarms).

Incorporating HVEDR functionality into E-log technology

Like HVEDRs, E-log technology (formerly known as electronic onboard recorder [EOBR]) records a set of data elements; however, there are key differences. Unlike HVEDRs that record event-driven data, E-log technology records continuous data for an extended period of time. Also, E-log technology captures data about the driver and load such as the driver's name, motor carrier's name, and shipping documents. Based on responses received from the industry, there was a general agreement that HVEDR functionality could be incorporated in the E-log systems because both are essentially data recorders. As the E-log records, the data would be marked and parsed to memory when a notable event (e.g., a crash) occurs. The respondents cited the following benefits for incorporating the two separate technologies:

- Integrated systems have advantages for assembly, physical space requirements, and costs.
- Incorporating the, now discrete, EDR functionality into a continuously recording EOBR would allow analysts to review a larger window of the vehicle history and improve vehicle prognostics and diagnostics.

However, the HVEDR industry had a concern that the commercial trucking industry's perception of E-log technology isn't favorable at the moment, and this claimed negative industry perception of EOBRs could taint the industry's perception of EDR technology.

Specific HVEDR needs by vehicle class

SAE J2728 acknowledges the varied CV configurations, applications, and vocations and recommends that the default 11.3 kph/s (7.0 mph/s; 0.3 G) acceleration trigger be adjusted to within a range of 8.0 kph/s (5.0 mph/s; 0.2 G) to 22.5 kph/s (14.0 mph/s; 0.6 G) to account for these variations. One interviewee illustrated this principle in a comparison of two HV vocations. The first vocation is a Class 8 tractor-trailer combination unit that travels long distances without making many stops. The second vocation is a garbage truck that travels relatively short distances and makes frequent stops. The tractor-trailer combination unit (or motorcoach) could use a lower acceleration trigger threshold (e.g., 8.0 kph/s to 12 kph/s) to be more sensitive to rapid stops and better able to detect collisions with lighter objects while the garbage truck (or school bus) could use a higher threshold (e.g., 18 kph/s to 22.5 kph/s) to make it less sensitive to these stops, resulting in more relevant EDR data collection.

Conclusions

HVEDR technology has helped in understanding of events that lead to and occur during a HV crash (Kreeb & Nicosia, 2005; Sapper et al., 2009) Law enforcement uses the HVEDR information to improve how crashes are analyzed and conclusions are drawn about the matters that led to the crashes and assigning fault. Vehicle engineers use the HVEDR data to improve the vehicle's performance and crashworthiness during a crash. Examples include generating vehicle recalls to improve existing vehicles or create improved designs of future vehicles. Insurance companies use the HVEDR data to make informed claims decisions and reduce claim costs. Finally, fleets use the HVEDR data to pinpoint problems in driver behavior and poor decision making. The HVEDR data helps fleets tailor training for specific drivers to improve their performance or cull repeat offenders.

As is seen in everyday life, technology is developing at a rapid pace. These advancements will benefit future HVEDRs through faster data processing speeds and more capacious data storage. Faster processing speeds will allow HVEDRs to increase the data sampling rate and gain a higher resolution of the events leading up to and during a crash. The more capacious data storage will allow for longer periods of data collection. Both of these advancements will provide the CV industry and the crash reconstruction community with a more complete understanding of crash events.

Based on the findings of this report, the feasibility of HVEDRs in CVs does not lie in the concept of recording event-based data or in the technology's capabilities but in the implementation of the technology. There are several implementation challenges revealed by this report; namely, standardization of data elements recorded, standardization of data retrieval tools, and the unique HV characteristics such as mass and vocation differences. Of the 39 data elements recommended by the SAE J2728, only approximately 25 percent have been completely adopted by the CV industry. As seen in Table 63, the number of data elements captured by the different ECUs/ECMs ranges from 78 to more than 450. Each manufacturer has set up its individual HVEDRs to meet unique company needs. Still, another challenge is the lack of common data retrieval tools for the various HVEDRs. Unlike light-vehicle EDRs that can use the Bosch CDR system to download data from numerous supported passenger car, light trucks, and sport utility vehicle (SUV) manufacturers, HV manufacturers and vendors require unique tools and software to access their specific EDR technologies. These differences in collected and downloaded data elements and retrieval tools make it difficult for the entire transportation community (e.g., vehicle engineers, crash investigator, and law enforcement) to explore and explain crash causation across different vehicle makes. It appears that aftermarket EDR-like technologies such as driver monitors and telematics systems might be resolving the access issues that might result in a wider use of event-based data for the HV industry. Finally, HVs have unique characteristics that must be considered in the implementation of an HVEDR. The HV OEMs mentioned several aspects of HVs requiring consideration when deciding on appropriate threshold levels. These considerations include the mass differential between HV and other lighter vehicles and objects and the varied driving styles performed by HVs. The performance of the HVEDR may be negatively affected if engineers do not account for these distinctive HV considerations.

Despite these challenges, the feasibility of installing HVEDRs or related technologies on the HV fleet continues to be promising. As mentioned, HVEDRs are now a proven tool in examining crash events involving HVs. Based on the themes from this study, it is anticipated that HVEDR technologies will be more capable in the near-future (i.e., a longer data window with a higher resolution) and will be incorporated into a wide range of CV subsystems.

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