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12. ABSTRACT

As outlined in the T8080-160062 Feasibility Study of Event Data Recorders for Commercial Buses contract, Mecanica Scientific researched a list of technical and scientific reports/papers that focused on the following:

- Accuracy, reliability and limitations of heavy vehicle event data recorders (HVEDRs)
- Studies on the impact of EDR and HVEDR on highway safety
- Studies on the impact of EDR and HVEDR on commercial fleet operations
- Standards and recommended practices for HVEDR
- Regulatory activities specific to HVEDR and bus/motorcoach/school bus vehicles

This report is the submission is a summary report of the facts based on the relevant literature reviewed, detailing the functionality of HVEDR devices and the reliability of data imaged from them. A list of technical and scientific reports/papers and validation studies on the accuracy, reliability and limitations of commercial vehicle EDR was compiled and submitted in Deliverable No. 2 to Transport Canada.

13. ACKNOWLEDGEMENTS
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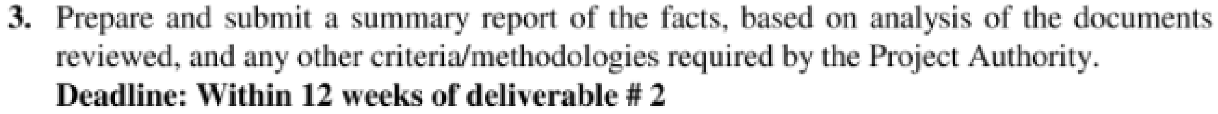
Summary Report of Facts



3. Prepare and submit a summary report of the facts, based on analysis of the documents reviewed, and any other criteria/methodologies required by the Project Authority.
Deadline: Within 12 weeks of deliverable # 2

Mecanica Scientific Services Corporation

TABLE OF CONTENTS

1.0 INTRODUCTION

Ever since the 1970s, some form of **event data recorder (EDR)** can be found in North American Free Trade Agreement (NAFTA) market passenger vehicles. Advancements in passive occupant restraint systems and their electronic controls in the 1990s set the foundation for further development and acceptance of EDR in NAFTA-market passenger vehicles in Canada, the United States and Mexico.

Parallel to the maturity of EDR in passenger vehicles, which consist of light-duty and some medium-duty vehicles, EDR-type functionality is increasingly found in medium- and heavy-duty vehicles.

As emissions requirements developed and became more stringent by 2002, starting with the United States Environmental Protection Agency (EPA) 2002 requirements for lower diesel nitrous oxide (NOX) emissions, medium- and heavy-duty truck engine manufacturers moved away from traditional mechanical or electro-mechanical engine controls to solid-state electronic engine controls to refine engine controls and meet EPA emissions requirements.

With these more advanced electronic engine controls came standardized on-vehicle serial communications protocols and later, high-speed Controller Area Network (CAN) standardized communications protocols, which defined the physical network (wiring), communications protocols, and messages. Such protocols would lay the foundation for EDR-type functions.

In June 2010, the Society of Automotive Engineers International (SAE) published a Recommended Practice, J2728: “Heavy Vehicle Event Data Recorder, Tier 1,” that defined an EDR function in a vehicle with a Gross Vehicle Weight Rating (GVWR) of 10,000 lbs. or more and equipped with a J1587 or J1939 communications data bus as a **heavy vehicle event data recorder (HVEDR)**.

The following report is a summary of the research and review of technical papers, studies, reports, and regulations pertaining to HVEDRs as they may be found in buses, motorcoaches or school buses.

This report focuses on the extensive research and publications found regarding HVEDR technology, including the data elements, data limitations and accuracy of HVEDR-sourced data. Studies pertaining to the potential impact EDR and HVEDR have on highway safety, their deployment in a commercial fleet, and the observed improvements in that commercial fleet’s accident rate and driver safety are also discussed.

It is important to note that the event data recorder (or heavy vehicle event data recorder) only records data for a short, finite period of time and must be triggered to record data. This is unlike a mechanical or digital tachograph that is defined as a *journey recorder,*[1] which records data continuously.

2.0 EXECUTIVE SUMMARY

As outlined in the *T8080-160062 Feasibility Study of Event Data Recorders for Commercial Buses* contract, Mecanica Scientific researched a list of technical and scientific reports/papers that focused on the following:

- Accuracy, reliability and limitations of heavy vehicle event data recorders (HVEDRs)
- Studies on the impact of EDR and HVEDR on highway safety
- Studies on the impact of EDR and HVEDR on commercial fleet operations
- Regulatory activities specific to HVEDR and bus/motorcoach/school bus vehicles

This report is the submission for Transport Canada, *T8080-160062 Feasibility Study of Event Data Recorders for Commercial Buses*, Deliverable No. 3, which is a summary report of the facts based on the relevant literature reviewed, detailing the functionality of HVEDR devices and the reliability of data imaged from them.

A list of technical and scientific reports/papers and validation studies on the accuracy, reliability and limitations of commercial vehicle EDR was compiled and submitted in spreadsheet format (Deliverable No. 1) to Transport Canada.

Mecanica submitted a second listing (Deliverable No. 2), which included additional references and available abstract summaries for each reference. This submittal included further supplemental references that were believed to support this summary report (Deliverable No. 3). While drafting this report, it was realized that additional references need to be included for completeness. Although an attempt was made to include technical studies from all nations, many countries offered few to no references pertinent to this study and therefore were not included.

2.1 History of Data Recorders

EDRs originated in the 1970s with the advent of a crude electro-mechanical data recorder for the first General Motors USA model vehicles that were equipped with the passive occupant restraint system, the Air Cushion Restraint System (ACRS) dual frontal airbag system.

Unlike the development of passenger-vehicle EDR, HVEDRs started as a result of more stringent U.S. EPA emissions requirements that mandated more advanced diesel emissions electronic controls.

Prior to advanced electronic engine controls with data-recording capabilities, it was common to find mechanical tachograph recorders in U.S. school bus operations and some truckload or less

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[1] "Journey recorder" as defined by the EC VERONICA Project, 2006.

than truckload freight operations. Tachographs have also been regulated and required safety devices in Europe and the United Kingdom for the last 32 years.

Numerous studies published in the United States, Europe and the United Kingdom have been reviewed and found to have reached the same general conclusions. EDR has the potential to make significant highway safety improvements on a macro level by revealing and providing new insight into accident studies not possible without EDR data, as well as making improvements in commercial fleet safety on a micro level when looking at specific fleets that implement EDR, train drivers on the EDR technology and actively use the EDR data to monitor and coach drivers consistently.

In-depth research was conducted and summarized here on any EDR-related regulatory activities in the NAFTA zone and the rest of Central and South America. The only EDR regulatory activity that could be located for these regions is the activity within Mexico, the United States and this feasibility study for Transport Canada.

On an international level, the only regulations somewhat related to EDR are the European Union and United Kingdom requirements for digital tachographs (or mechanical tachographs for older vehicles) used primarily for driver hours-of-service (HOS) records. However, these tachographs always record vehicle speed (and engine speed) over time and are therefore considered journey recorders.

An extensive review of the peer-reviewed technical papers and studies regarding the data sources, accuracy and reliability of original equipment manufacturer (OEM)-type EDR in commercial trucks and buses is also included.

3.0 SUMMARY OF FINDINGS

This research project into heavy vehicle event data recorders does overlap into passenger vehicles, namely the six classes defined in the United States as light-duty (Classes 1 and 2: GVWR of 10,000 lbs. or less) and medium-duty (Classes 3 through 6: GVWR of 10,000 lbs. to 26,000 lbs.) vehicles.

As of the writing of this report, a majority of NAFTA-market medium- and heavy-duty straight trucks, vocation-specific trucks (sanitation trucks, dump trucks, sweepers, fire apparatus, etc.), truck-tractors, buses, motorcoaches and school buses with model year 2000 and newer are equipped with some form of HVEDR. Typically, this is found in the vehicle's engine electronic control unit (ECU) or cab/chassis ECU. The current HVEDR functions that are built into the commercial vehicles' OEM ECUs have significant recording capabilities. These include the number of data elements recorded (eight channels or more, including vehicle speed, engine speed, service brake application, clutch brake application, parking brake application, engine brakes ON/OFF, cruise control status, etc.), the recording-time period duration (from 2 seconds to 90 seconds in duration) and the data resolution (from 1 Hz to 5 Hz resolution).

Figure 3.0-1 below is an example of an “acceleration triggered” event log from a late model Volvo truck-tractor.

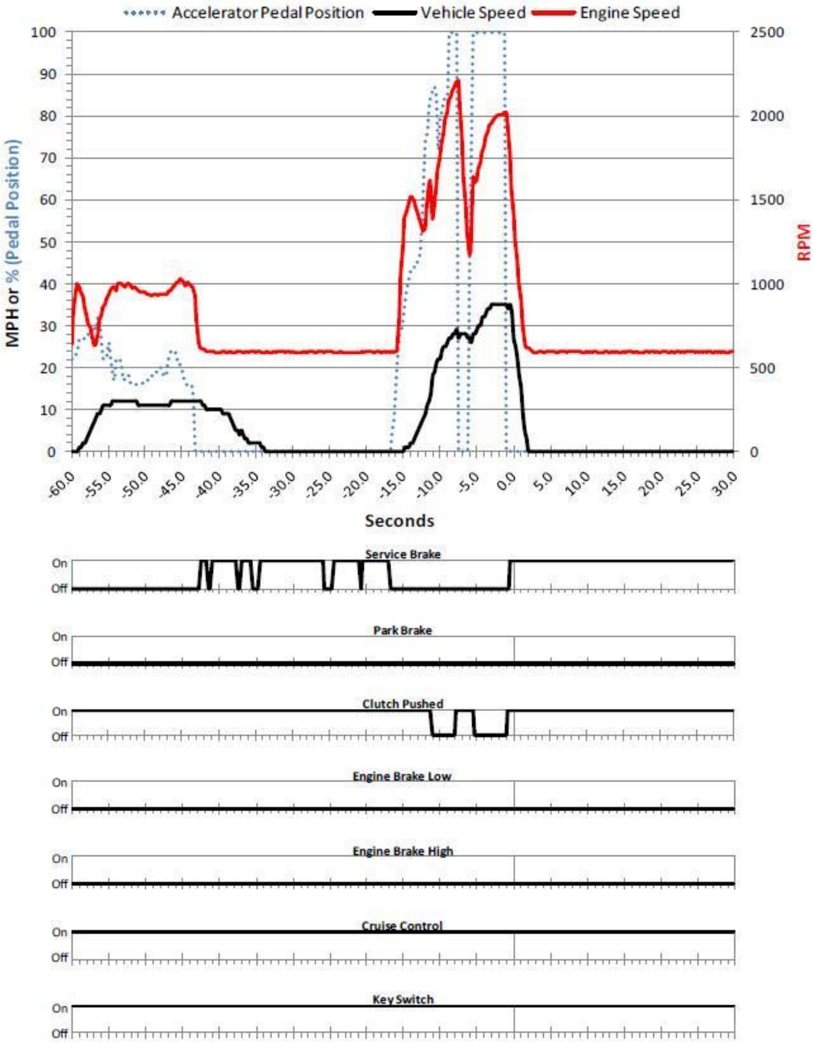

Figure 3.0-1. Sample late model HVEDR data

Whether it is a passenger-vehicle event data recorder, whose functionality is based on a passenger vehicle’s airbag control module (ACM), or a heavy vehicle event data recorder that is based on the commercial vehicle’s engine or chassis controller, the overall functionality and output are essentially the same:

- The EDR or HVEDR recording is activated by some predefined trigger, such as an airbag deployment command in a passenger vehicle or a change in the truck’s road speed as measured by the truck’s vehicle speed sensor (VSS), typically mounted on the rear of the main transmission.
- As a result of the trigger, the EDR or HVEDR is commanded to capture and store vehicle data, such as vehicle speed, engine speed, percent throttle, service brake application, clutch application, etc., for a period of 2 to 90 seconds surrounding that trigger.

It is important to note the differences between EDR and HVEDR, particularly the triggering method. Below is a brief outline discussing these triggers, as well as the difficulty in specifying a trigger for HVEDR:

Event Triggers

- For passenger-vehicle EDR, the use of the ACM accelerometer and deployment of various occupant restraint devices is a logical trigger for an EDR device to record data.
- Conversely, triggering an event can be a challenge for heavy commercial vehicles, such as trucks and buses. When a 45,000-lb. motorcoach is involved in an impact with a passenger vehicle, the peak acceleration, initial acceleration and the forces experienced by the motorcoach will be relatively small in magnitude compared to what the passenger-vehicle experiences. The actual values of peak acceleration, initial acceleration and the forces experienced by the motorcoach could be on the same order-of-magnitude or less than a typical or heavy braking event. Defining what triggers the HVEDR device to record data in crashes involving passenger vehicles or vulnerable road users such as pedestrians, bicyclists and motorcycles can therefore be challenging.

Foundational Data Networks and Data Elements

- Passenger-vehicle EDR was originally based on the older serial communication networks defined by SAE J1850. On newer vehicles, the passenger-vehicle EDR is based on high-speed CAN-based systems defined by SAE J2284 and ISO 15765. The older J1850 network is a diagnostic bus/protocol that is most commonly used by GM and Ford vehicles. The modern communication networks SAE J2284 and ISO 15765 are mandatory for all 2008 and newer vehicles sold in the United States. European On-Board Diagnostics (OBD) regulations allow for a 250 to 500 kbps CAN, while On-Board Diagnostics-II (OBD-II) only allows for a 500 kbps CAN. Both OBD and OBD-II have similar kbps bands because of the need for standardized communication links that would have a greater probability of being compatible on all makes and models. There are different variants for this network, but they differ only in identifier length[2] and bus speed.
    - The standardized physical connection port to access and image data from a light- or medium-duty vehicle is defined by SAE J1969 and is also federally regulated in the United States, Mexico and Canada by emissions laws. It is known as the OBD-II diagnostics link connector (DLC), which is shown below.

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[2] A software programming term for the length of an element identifier in octets. By means of the programmable CAN controller, the user can set the appropriate baud rate and identifier length of the communication interface.

Figure 3.0-2. OBD-II DLC

- HVEDR was originally based on the older serial communications network defined by SAE J1708 and J1587. As electronic controls advanced to meet more stringent emissions requirements, the industry has moved toward higher speed CAN and ISO networks as defined by SAE J1939 and ISO 15765: “2011 Road vehicles – Diagnostic communication over Controller Area Network (DoCAN).”
    - The standardized physical connection port to access and image data from a medium- or heavy-duty truck is defined by SAE J1939/13 and is known as a Deutsch® 6- or 9-pin DLC.
    - Some 2016 and newer heavy-duty vehicles have switched to using the passenger-vehicle OBD-II-style connector since the Deutsch 9-PIN DLC did not have enough pins to support J1939 and ISO 15765 communications protocols.

Refer to Figure 3.0-3, 3.0-4 and 3.0-5 below for examples of a J1939/13 9-pin connector, 6-pin connector and new OBD-II connector.

Figure 3.0-3. Late model 6/9-pin style DLC

Figure 3.0-4. Late model 9-pin DLC port

Figure 3.0-5. Late model Mack truck-tractor with OBD-II-style DLC

This report is a summary that discusses the vast set of research found and reviewed pertaining to EDRs and HVEDRs. The topics focus on the following:

- A brief overview of the history of EDR and HVEDR
- Highway and commercial fleet safety studies with the use of EDR and HVEDR

- The limitations and accuracy of data on HVEDR devices that have been found in a vast majority of NAFTA-market medium- and heavy-duty commercial truck and bus vehicles

The collection of regulatory documents, standards, recommended practices, recommendations, and technical and scientific reports/papers have been provided as part of Transport Canada *T8080-160062 Feasibility Study of Event Data Recorders for Commercial Buses*, Deliverables No. 1 and 2. Several key technical references were obtained and categorized in a Google Sheet. Within the document, references pertaining to topics that supported this summary report were included. Anticipating which topics needed to be addressed in this summary led to searching for other technical references that could potentially support this fact-finding report. The list was expanded and updated during technical document searches. The format and fields used in the collection process are specified in Table 3.0 below.

Table 3.0. Technical References Formatted Field Definitions

Field Names	**Field Description**
MSSC_Sort	Reference ID Number; the intent was to group sources based on relevance.
Document Type	This categorizes the type of document (e.g. Technical Paper, Recommended Practices, Standards, User Guides, Journals, etc.).
Category (Primary)	This field was used to categorize the primary topics covered for each reference in this spreadsheet.
Category (Secondary)	This field was used to categorize the secondary sub-topics covered for each reference in this spreadsheet.
Publisher	This indicates publishing entities (e.g. company, Societies, etc.)
Document No.	Included here is any document identification number that would be used to identify the document uniquely or to be used when requesting or purchasing the document from the publisher.
doi	The Digital Object Identifier (DOI) is used to identify objects that are uniquely indexed by the International Organization for Standardization (ISO). If available, it is included for certain references; otherwise, it is left blank.
Date Published	Each reference was opened, and its publishing date captured; otherwise, the year the reference was released is used.
Authors	The intent was to extract all authors' names and, if not available, the sponsoring entity is referenced; otherwise, this is left blank.
Title	This is the title of each document as stated within each electronic reference linked in the spreadsheet.
Abstract	The abstract, executive summary, introduction and conclusion, if available, are used to assist with a quick review of the linked reference content.
Publication Link	This is the URL link to aid in downloading or purchasing the available document.

3.1 The Origins of Data Recorders

The development of data-recorder technology has roots in the first American production frontal airbags introduced by General Motors in some 1973 products marketed as Buick, Cadillac, Chevrolet and Oldsmobile vehicles. Airbags in 1973 General Motors models were introduced to meet the then-new Federal Motor Vehicle Safety Standards (FMVSS) 208 regulations that called for passive restraint systems.

Heavy truck and bus data recorders developed much later in the late 1990s for different reasons and independently of passenger-vehicle data-recorder development, which was focused around passive-occupant restraint-system development. The development of data recorders for heavy trucks and buses was driven by the need for more advanced engine controls to meet increasingly stringent emissions requirements in North America. There was also interest in providing this on-board data recording to commercial fleets for driver coaching and mentoring.

3.1.1 Origins of EDRs

There has been a precedent for EDR functionality in North American passenger vehicles since the 1970s. Oldsmobile (General Motors), along with General Motors divisions Delco Electronics, Saginaw Steering Gear and Inland Manufacturing, developed and marketed the first North American production vehicle supplemental frontal airbag system. Marketed as the Air Cushion Restraint System (ACRS), it was designed to meet the new FMVSS 208 regulations that called for new passive restraint systems. The ACRS system was available in some 1973 through 1976 Buick, Cadillac, Chevrolet and Oldsmobile models.

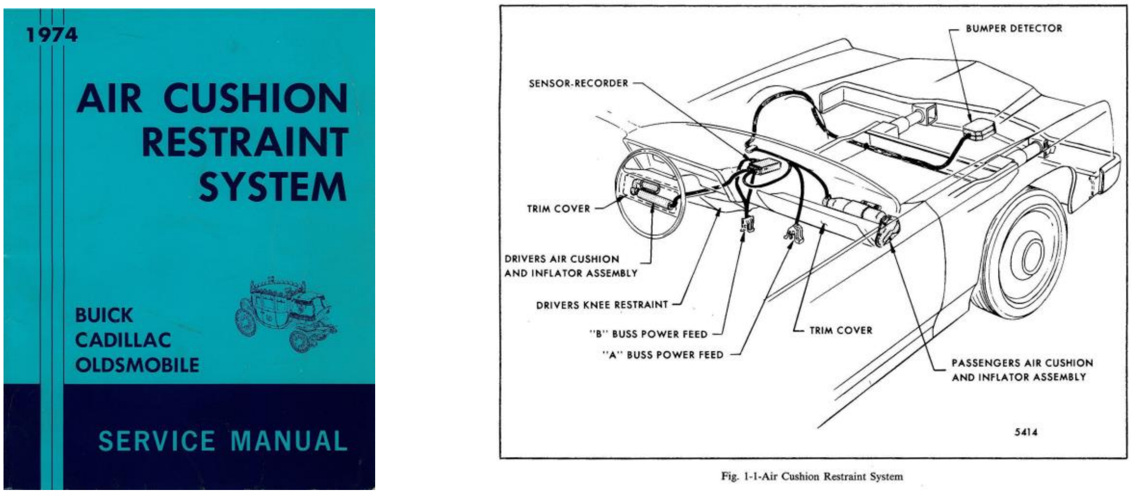

Fig. 1-1-Air Cushion Restraint System

Figure 3.1.1. General Motors ACRS

These early passive restraint systems had crude (by today's standards) electro-mechanical controls with some degree of system performance data-recording capabilities, which was the beginning of EDR functionality as it is known today.[3]

The first publicly available and accessible EDR was found in certain model-year 1994 General Motors NAFTA-market products from Buick, Cadillac, Chevrolet and Pontiac. The Vetronix Corporation created the first device capable of accessing and imaging this data, called the Crash Data Retrieval (CDR) Tool. Today, the CDR Tool is owned by Bosch Automotive Service Solutions, Inc.[4] With the advent of EDR and the CDR Tool, this “black box” data, as it is commonly

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[3] Louckes, T., Slifka, R., Powell, T., and Dunford, S., "General Motors Driver Air Cushion Restraint System," SAE Technical Paper 730605,1973.

[4] https://www.boschdiagnostics.com/cdr/

known as, has achieved steady growth in NAFTA-market vehicles.

The original function of the General Motors EDR was to evaluate and study the performance of their occupant protection systems internally, not to provide data on their customers or to third parties. However, it would not remain this way. The National Highway Traffic Safety Administration (NHTSA) conducted a highway safety research project with General Motors' assistance. Once National Accident Sampling System (NASS) investigators were exposed to the available data from General Motors, interest in this data and technology grew rapidly. The idea of applying this data to assist highway safety research evolved.

NHTSA's interest in event data recorders was a result of its experience with General Motors and their assistance in NHTSA's crash investigation program, in which early EDRs were accessed by NHTSA's crash investigators to better understand real-world crashes. From this first access to General Motors EDR, NHTSA's interest and use of EDR grew to include the access and analysis of EDR data in a number of NHTSA's crash investigation programs, including the Special Crash Investigation (SCI) program, the NASS Crashworthiness Data System (NASS-CDS), the Crash Injury Research and Engineering Network (CIREN), and the Crash Investigation Sampling System (CISS).

In the late 1990s, NHTSA focused on safety research to address the number of deaths caused by airbag deployments. One of the research activities included NHTSA contracting the U.S. National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL) to conduct a study and report on any technologies in aerospace and/or space industries that may have applications for highway safety, specifically in improving occupant restraint devices and technology. A 1997 JPL study concluded that the airbag technology was acceptable, and other than some recommendations for sensor suppliers, there was nothing that JPL could find to improve occupant protection devices. However, the JPL report questioned the lack of a recording device to collect data from the hundreds of thousands of accidents, especially the tens of thousands of fatal accidents that occur each year. The JPL study suggested that EDR data collected and studied over a period of time could be used to identify areas to improve highway safety that could then be pinpointed to driver, vehicle or environmental (roadway) issues.

Also in 1997, the National Transportation Safety Board (NTSB) issued a Safety Recommendation[5] to NHTSA requesting that NHTSA investigate the possibility of obtaining real-world crash data from EDRs. Specifically, the Recommendation prompted NHTSA to "[d]evelop and implement, in conjunction with the domestic and international automobile manufacturers, a plan to gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented crash sensing and recording devices."

As a result of the JPL and NTSB recommendations for highway vehicle EDR, NHTSA organized a Highway Vehicle Event Data Recorder Working Group that convened for the first time in 1997 and eventually published a two-volume report on highway vehicle EDR.

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[5] National Transportation Safety Board, Safety Recommendation H-97-10 through -18, July 1, 1997.

The first NHTSA R&D EDR Working Group volume focused on passenger vehicles, and a second volume focused on trucks, motorcoaches and school buses.

Meanwhile, General Motors worked closely with Vetronix Corporation (Santa Barbara, California), who was the supplier of the first generation General Motors OBD tool, the TECH-1. The Vetronix TECH-1 was one of the original tools for reading early EDR-type data.

In March 2000, Vetronix Corporation released and began selling the Vetronix CDR Tool, which could be used to image and save EDR data from select 1994 and newer General Motors vehicles. Soon after the release of the CDR Tool, vehicle coverage expanded to include select models of Ford and Lincoln-Mercury products. Chrysler, LLC was the next passenger-vehicle manufacturer who released their accessibility to EDR data by using this CDR Tool.

In August 2003, the Vetronix Corporation was acquired by Robert Bosch GmbH, as was its CDR Tool. As of model year 2016, the Bosch CDR Tool has coverage of 87% of the vehicles sold in the NAFTA market.[6]

In addition to the light-duty vehicle manufacturers who have partnered with Bosch to make their EDR data accessible by the Bosch CDR Tool, several manufacturers have opted to provide data access via their own proprietary diagnostics tool. These manufacturers include Subaru USA, Hyundai Motors USA, Kia Motors USA, Mitsubishi Motors USA and Tesla, Inc.

3.1.2 Origins of HVEDRs

Parallel to the maturity of passenger-vehicle EDR, the development of HVEDR technology has grown. This growth is largely driven by emissions requirements that have become more stringent, starting with the U.S. EPA 2002 requirements for lower diesel nitrous oxide (NOX) emissions. To meet EPA emissions requirements and refine engine controls, medium- and heavy-duty truck engine manufacturers moved away from traditional mechanical or electro-mechanical engine controls to solid-state, electronic engine controls.

Determining which passenger vehicles have EDR functionality is generally based on the model year, make and model of the vehicle. Truck and bus HVEDR functionality is determined not by the model year and make of the truck, but by the year, make and model engine installed in the truck.

Unlike light- and most medium-duty vehicles, when purchasing a truck-tractor or a motorcoach, a number of engine options are available. The late 1990s Freightliner FL-120 truck-tractor (shown in Figure 3.1.2-1 below), for example, may be equipped with either a Caterpillar, Cummins or Detroit Diesel engine, all of which have HVEDR functionality in their engine ECUs.

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[6] Source: Ruth, R., "Crash Data Retrieval Update Sept. 2016," 2016.

Figure 3.1.2-1. 1990s-era Freightliner FL-120 truck-tractor

It is important to note that like passenger-vehicle EDR, HVEDR is a programming algorithm run on a pre-existing ECU that has a processor (or processors) and internal memory. The EDR or the HVEDR are not additional or added, stand-alone data recorders with their own network of sensors. EDR and HVEDR are both algorithms added to pre-existing ECUs and leverage already-existing and standardized communication networks, sensors and closed-loop ECUs that have processors and memory for data storage.

Note that the ECU is defined by SAE J2728 as “an electronic subsystem that manages the functions of a vehicle system of components. ECUs are often called electronic control modules, or ECMs, or simply modules.” ECUs can communicate over the serial J1587, CAN J1939 or ISO 15765: 2011 DoCAN communications protocols.

The HVEDR function that is typically found as an add-on algorithm within OEM ECUs can also be found in OEM optional equipment. This equipment includes devices like optional trip computers that can be installed in the instrument panel, such as the Cummins RoadRelay 4 trip computer shown in Figure 3.1.2-2 below.

Figure 3.1.2-2. Cummins RoadRelay 4 trip computer

In the 1990s, the majority of NAFTA-market truck and bus-type vehicles utilized the older and slower SAE J1587 (messages broadcast defined)/J1708 (serial network defined), as shown in Figure 3.1.2-3 below.

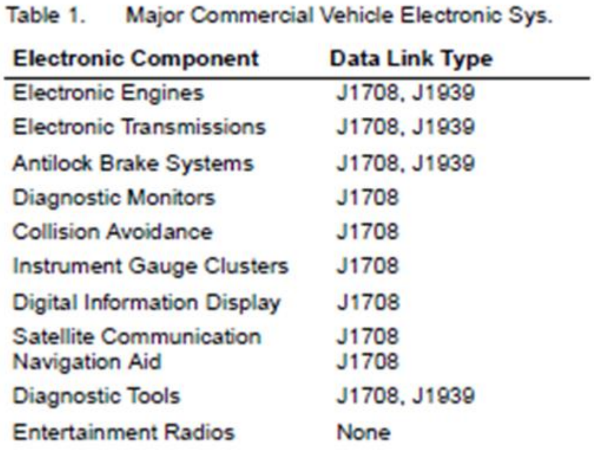

Table 1. Major Commercial Vehicle Electronic Sys.

Electronic Component	Data Link Type
Electronic Engines	J1708, J1939
Electronic Transmissions	J1708, J1939
Antilock Brake Systems	J1708, J1939
Diagnostic Monitors	J1708
Collision Avoidance	J1708
Instrument Gauge Clusters	J1708
Digital Information Display	J1708
Satellite Communication	J1708
Navigation Aid	J1708
Diagnostic Tools	J1708, J1939
Entertainment Radios	None

Figure 3.1.2-3. Summary of 1998 model year data link usage[7]

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[7] Source: Dannenberg, R., “Multiplexing Consumer Electronic Products in Truck Applications,” SAE Technical Paper 982757, 1998.

As EPA emissions requirements grew, the demands and requirements for performance from the serial communications protocols J1587/J1708 exceeded their capabilities. This ultimately resulted in the retirement of these protocols, which were replaced with the faster CAN high-speed communications protocol defined by SAE J1939 and ISO 15765: “2011 Road Vehicles – Diagnostic communication over Controller Area Network (DoCAN).” The number of sensors, digital inputs and data needed to meet the more stringent emissions requirements appeared to follow Moore’s Law[8] as shown in Figure 3.1.2-4 below.

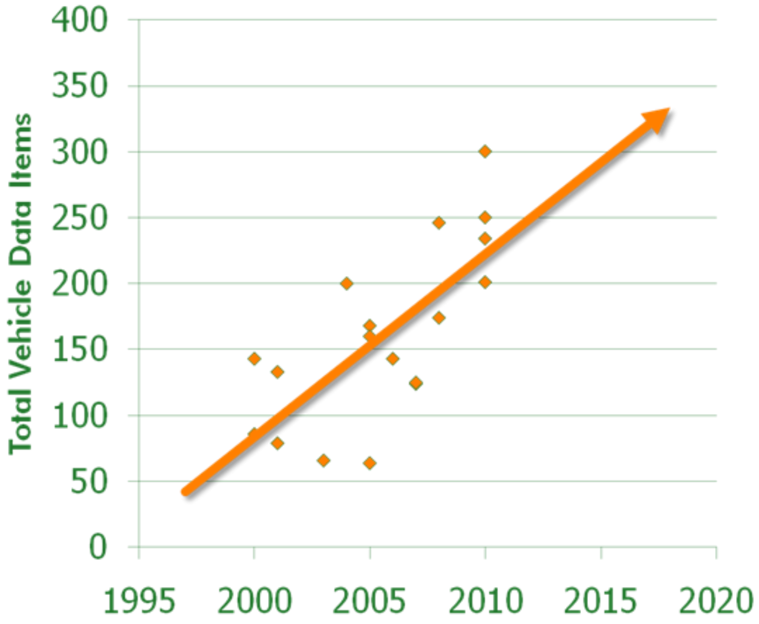

Figure 3.1.2-4. Total vehicle data elements count over time[9]

In the early 2000s, NAFTA-market commercial truck and bus vehicles were typically equipped with two to three ECUs, whose functions included managing the engine, chassis and the anti-lock brake system (ABS).

The original purpose of the data-recording functionality was for fleet management, driver coaching and warranty claims—not vehicle crashworthiness analysis or accident reconstruction. Some major engine OEMs who have HVEDR-type functionality in their ECUs include language stating that data is not intended for accident reconstruction, such as the Cummins disclaimer shown in Figure 3.1.2-5 below.

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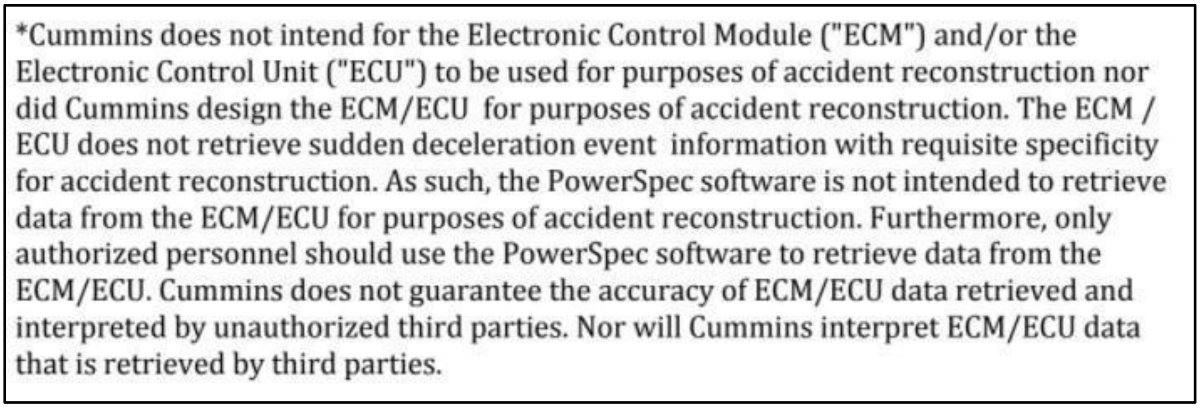
[8] Dr. Gordon Moore, 1965.

[9] Source: Austin, T., Cheek, T., Plant, D., Steiner, J., and Lackey, L., “SAE C1022: Accessing and Interpreting Heavy Vehicle Event Data Recorders,” Module 1, 2016.



*Cummins does not intend for the Electronic Control Module ("ECM") and/or the Electronic Control Unit ("ECU") to be used for purposes of accident reconstruction nor did Cummins design the ECM/ECU for purposes of accident reconstruction. The ECM / ECU does not retrieve sudden deceleration event information with requisite specificity for accident reconstruction. As such, the PowerSpec software is not intended to retrieve data from the ECM/ECU for purposes of accident reconstruction. Furthermore, only authorized personnel should use the PowerSpec software to retrieve data from the ECM/ECU. Cummins does not guarantee the accuracy of ECM/ECU data retrieved and interpreted by unauthorized third parties. Nor will Cummins interpret ECM/ECU data that is retrieved by third parties.

Figure 3.1.2-5. Cummins Sudden Deceleration data records disclaimer

There has been extensive independent testing of HVEDR functions found in Cummins engine ECUs, as well as other NAFTA-market engine ECUs from Caterpillar, Detroit Diesel/Mercedes-Benz, Mack, Navistar, PACCAR and Volvo. These series of tests conducted by various engineering and law enforcement agencies have been published as peer-reviewed technical papers by SAE and are discussed in detail later in this report.

3.1.3 Tachographs

Prior to today's electronic controls and HVEDR functionality, another form of data logger had been in use since the 1970s in North America, as well as in Japan, the United Kingdom and Europe. These data loggers were mechanical tachographs, as shown in Figure 3.1.3-1 below.

Figure 3.1.3-1. Mechanical tachograph with paper chart displayed

Tachographs are still in wide use in the United Kingdom and the European Union as they are regulated and required devices in larger “goods and passenger-carrying vehicles” for logging commercial driver HOS, or what is referred to in the U.K. as “driver’s periods of work and rest.” Examples of electronic tachographs for such vehicles are shown in Figures 3.1.3-2, 3.1.3-3 and 3.1.3-4 below.

Figure 3.1.3-2. Kienzle/VDO electronic tachograph

Figure 3.1.3-3. U.K.-market truck-tractor

Figure 3.1.3-4. U.K. electronic tachograph

In 1981, the installation and use of tachographs in the U.K. was made mandatory. As of 2006, relevant commercial vehicles are required to be equipped with a digital tachograph instead of a mechanical tachograph.

There are extensive publications on the forensic analysis of older mechanical tachograph scribed charts that continuously log vehicle speed (and some models that also record engine speed).

Training of the U.K. police force was required for law enforcement officers to be able to validate the data scribed on a mechanical tachograph chart and to conduct a time, speed and distance analysis of the tachograph chart. The result was that the tachograph chart and analysis were accepted as reliable evidence in a court of law. This is discussed in R. F. Lambourn’s 1985 paper, “The Analysis of Tachograph Charts for Road Accident Investigation,” and his excerpt on “Tachographs*”* from *Encyclopedia of Forensic Sciences*, published in 2000. Figures 3.1.3-5 and

3.1.3-6 below are excerpted from Lambourn's "Tachographs" in *Encyclopedia of Forensic Sciences.*[10]

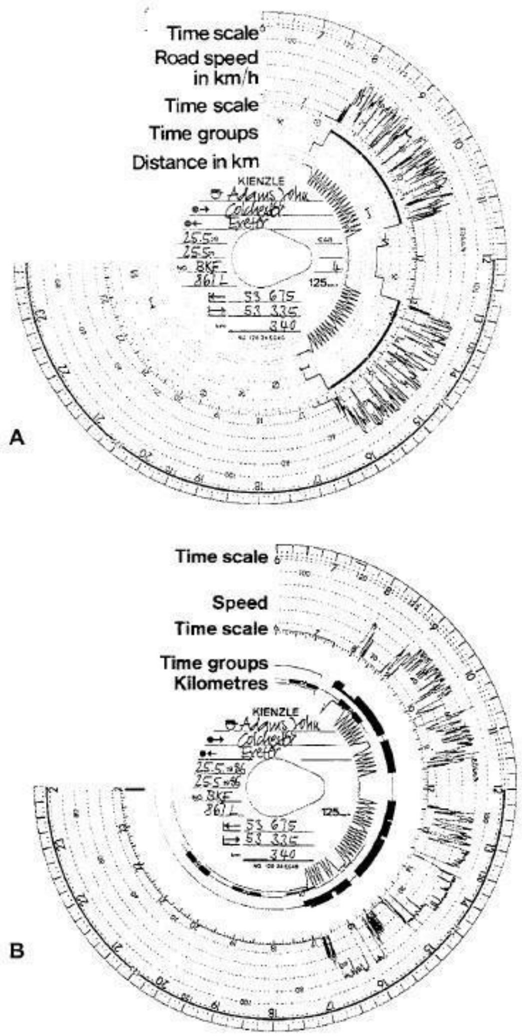


Figure 1 Tachograph chart showing recordings with **(A)** 'manual' time group recordings and **(B)** 'automatic' time group recordings. (*VDO Kienzle (UK) Ltd*)

Figure 3.1.3-5. Excerpt from Lambourn's "Tachographs"

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[10] Source: Lambourn, R.F., "Tachographs," *Encyclopedia of Forensic Sciences,* 2000.

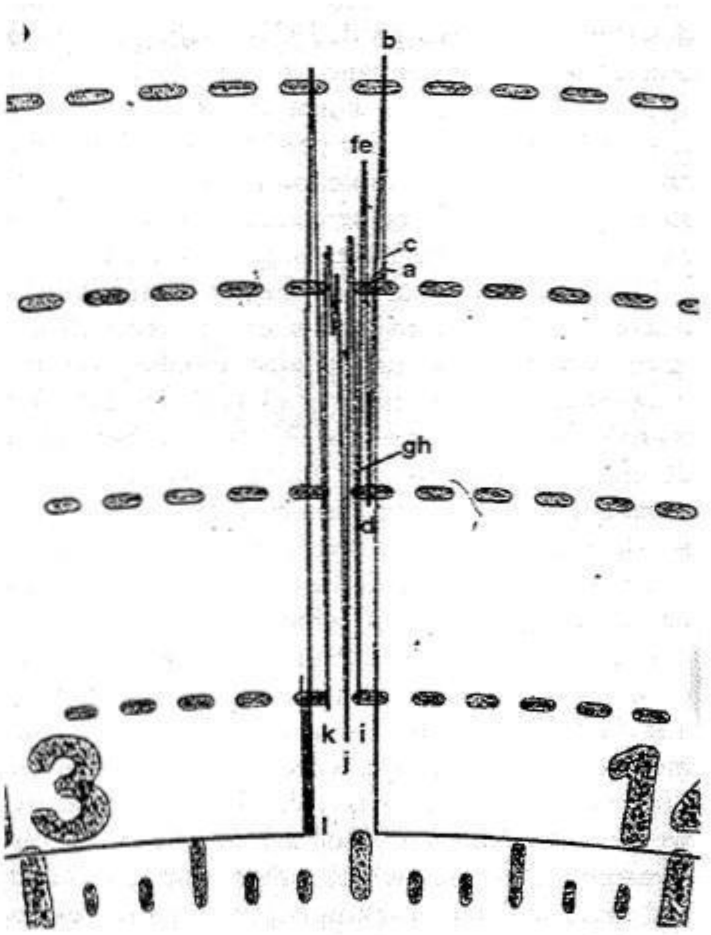

Figure 6 A real tachograph speed trace with analysis points.

Figure 3.1.3-6. Excerpt from Lambourn's "Tachographs"

In both "Analysis of Tachograph Charts for Road Accident Investigation" and "Tachographs," Lambourn discussed the importance of verifying and documenting the calibration of the mechanical or electronic tachograph. Verification and documentation are done by using either a certified tachograph workshop or by using the "20-metre track method," which is a calibration verification method approved by the British Department of Transport for use by calibration agencies in remote areas when a certified calibration shop is not accessible.

Once the tachograph's calibration and scribed data are verified, a visual analysis using a specialized tachograph chart microscope can be utilized to integrate (visually) the vehicle speed time history data with corrections, if any are required. Any required corrections would be identified in the calibration verification process.

Once the vehicle speed time history data is integrated to determine distance travelled, the route can be determined and plotted with the help of printed roadway maps and a scaled map wheel.

The skill and practice of analyzing the tachograph charts with specialized tachograph microscopes is of much interest and requires specialized skill. This forensic analysis art form will likely become a lost art in a short period of time.

Today's validation of vehicle-speed calibration is somewhat similar to the validation of a tachograph calibration. However, the analysis and mapping of data is not as labor-intensive or specialized. Data analysis and any corrections for calibration errors or wheel slip can be adjusted for by using Microsoft Excel® and setting up correction calculations to apply to an HVEDR data set, a topic that will be discussed in more detail further into this report.

3.2 EDR/HVEDR Recommendations & Highway Safety

Since the 1997 NASA/JPL report, significant EDR-related activity was undertaken by US government agencies like NHTSA, the NHTSA SCI program and NTSB, all of whom researched and published various positive recommendations for EDR, such as the following:

- July 1997, NTSB Safety Recommendation H-97-10 through -18
  Recommended electronic recording of crash data.
- April 1998, Jet Propulsion Laboratory, California Institute of Technology; *Advanced Air Bag Technology Assessment, Final Report*
  Included a recommendation to "study the feasibility of installing and obtaining crash data for safety analysis from crash recorders on vehicles."
- November 1999, NTSB Safety Recommendation H-99-45 through -54
  H-99-45: *"*Require on-board recorders for school bus and motorcoach operation*s."*
  *H-99-53: "*Require that all school buses and motorcoaches manufactured after January 1, 2003 be equipped with on-board recording systems.*"*
  *H-99-54: "*Develop and implement, in cooperation with other Government agencies and industry, standards for on-board recording of bus crash data.*"*
- August 2001, NHTSA R&D EDR Working Group, *Event Data Recorders: Summary of Findings, Final Report,* No. NHTSA-1999-5218-9
  EDR Working Group formed and hosted in early 1997 by NHTSA in response to the NASA/JPL-issued recommendations for EDR.
- May 2002, NHTSA R&D EDR Working Group, *Event Data Recorders: Summary of Findings, Final Report, Volume II Supplemental Findings for Trucks, Motorcoaches, and School Buses,* No. DOT HS 809 432
  Supplemented the NHTSA EDR Working Group 2001 *Final Report* by researching truck and bus EDR and proposing recommendations for data elements, survivability and event descriptions.
- June 2004, NHTSA, "Event Data Recorders," Notice of Proposed Rulemaking (NPRM) (69 FR 32932)
  Specified a minimum set of data elements for voluntarily installed EDRs to record and initiated 49 CFR Part 563.
- August 2006, NHTSA, "Event Data Recorders," Final Rule (71 FR 50998)
  Published the Part 563 final rule specifying requirements for light vehicle EDR data "accuracy, collection, storage, survivability, and retrievability."

- August 2007, NHTSA, “NHTSA’s Approach to Motorcoach Safety,” Memorandum to Docket No. 2007-28793

  Discussed within the context of NTSB Safety Recommendations H-99-53 and -54 how specifications for crash characteristics and other measurements would differ for motorcoaches and indicated a standard (the contemporaneously in-progress SAE J2728) was under co-development with the SAE Truck and Bus Committee, after which NHTSA was to consider appropriate HVEDR installation requirements in motorcoaches.
- September 2009, National Center for Transit Research, Center for Urban Transportation Research, University of South Florida, *Evaluation of Electronic Data Recorders for Incident Investigation, Driver Performance, and Vehicle Maintenance*, Project No. BD549-50

  Studied what appears to have been only aftermarket, add-on GPS-based fleet tracking systems or video data recorders but was hampered by numerous technical problems.
- October 2009, NHTSA, “Vehicle Safety Rulemaking and Research Priority Plan 2009-2011,” Docket No. NHTSA-2009-0108

  Included a priority to develop performance requirements for "heavy vehicle EDRs” with the next agency decision deadline set for 2010.
- November 2009, U.S. Department of Transportation (DOT), *Motorcoach Safety Action Plan*, Publication No. DOT HS 811 177

  Listed plans to augment the data currently collected on motorcoach drivers and operators by having the Federal Motor Carrier Safety Administration (FMCSA) explore other passenger carrier data sources. Also refers to NHTSA’s work with the SAE Truck and Bus Committee regarding the development of SAE Recommended Practice J2728 “Heavy Vehicle Event Data Recorder (HVEDR) - Base Standard”.
- March 2011, NHTSA, “Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan 2011-2013,” Docket No. NHTSA-2009-0108

  Included a priority for developing “heavy-vehicle EDRs” performance requirements and whether the agency would initiate rulemaking on EDR requirements for newly manufactured heavy vehicles by 2011.
- August 2012, NHTSA, “Event Data Recorders,” Final Rule (77 FR 47552)

  Amended the final Part 563 rule after receipt of petitions regarding light-vehicle EDR specifications.
- December 2012, NHTSA, “Federal Motor Vehicle Safety Standards; Event Data Recorders,” NPRM (77 FR 74144)

  Advanced FMVSS 405 “Event Data Recorders” and proposed FMVSS 405 Part 571 to require compliance with EDR crash test performance and survivability requirements.
- October 2014, NHTSA, “Request for Comment on Automotive Electronic Control Systems Safety and Security” (79 FR 60574)

Acknowledged the National Academy of Sciences (NAS) 2012 Transportation Research Board (TRB) Special Report No. 308 recommendations that NHTSA ensure commonplace EDR implementation in new vehicles.

- May 2015, NHTSA, “Guidelines for the Safe Deployment and Operation of Automated Vehicle [AV] Safety Technologies,” extension of comment period for proposed guidelines (81 FR 31296)

  Outlined the need to consider data-recording capabilities and which triggers are appropriate for determining correct operation, operational status and possible malfunctions in AV systems.
- September 2016, NHTSA and FMCSA, “Federal Motor Vehicle Safety Standards; Federal Motor Carrier Safety Regulations; Parts and Accessories Necessary for Safe Operation; Speed Limiting Devices,” NPRM (81 FR 61942)

  Proposed regulation applicable to commercial motor vehicles (CMVs) of GVWR greater than 26,000 and called for equipping the vehicles with a speed limiter and devices that read records of speed-setting changes to limit vehicle speed.

Several concurrent international research activities regarding EDR also resulted in the following positive findings and recommendations:

- September 1997, Andersson, et al., “The Volvo Digital Accident Research Recorder (DARR) Converting Accident DARR Pulses into Different Impact Severity*,”* 1997 International Conference on the Biomechanics of Impact in Hannover, Germany

  Volvo data-recorder analysis of 250 accidents that offered new insights into crash analysis because of the Volvo data recorder.
- November 2006, European Commission, Directorate-General for Energy & Transport, Vehicle *Event Recording based on Intelligent Crash Assessment (VERONICA),* Agreement No. TREN-04-ST-S07.39597

  Related to “exploring the possibilities of implementing Vehicle Event Data Recorders (EDRs) for enhanced understanding of collisions but also recognizing the potential benefits for prevention, road safety and legal fairness*.*”
- June 2009, European Commission, Directorate-General for Energy & Transport, *Vehicle Event Recording based on Intelligent Crash Assessment, VERONICA-II*, Agreement No. TREN-07-ST-S07.70764

  Studied European EDRs and concluded EDR’s purpose is to reduce the number of fatalities, provide opportunities for in-depth research using actual crash data from EDR and improve vulnerable road-user safety, among other EDR benefits.
- December 2014, Hynd and McCarthy, Transport Research Laboratory (United Kingdom), “DG MOVE” Project, *Study on the Benefits Resulting from the Installation of Event Data Recorders, Final Report*, Published Project Report No. PPR707

  Groundwork study for European Commission's decision on fitment of EDR for improved highway safety that concluded EDR’s potential for accident reduction as well as cost efficiency of implementing EDR in passenger vehicles.
- December 2015, Transportation Safety Board of Canada (TSB), *Crossing Collision - VIA Rail Canada Inc. Passenger Train No. 51, OC Transpo Double-Decker Bus No. 8017, Mile*

3.30, Smiths Falls Subdivision, Ottawa, Ontario, 18 September 2013, Railway Investigation Report No. R13T0192

> Included TSB Recommendation R15-03, which proposed that Canada's "Department of Transport require commercial passenger buses to be equipped with dedicated, crashworthy, event data recorders."

Of the literature found and reviewed pertaining to EDR or HVEDR, nearly all research in the United States, the United Kingdom and Europe has independently come to similar conclusions: EDR has vast potential to improve highway safety, reduce highway fatalities, improve vehicle safety, reduce commercial fleet accident rates and help improve commercial fleet safety.

One study that could not validate the benefits of EDR was the study *Evaluation of Electronic Data Recorders for Incident Investigation, Driver Performance, and Vehicle Maintenance* (Project No. BD549-50) published in September 2009 by the National Center for Transit Research at the Center for Urban Transportation Research, University of South Florida. The Florida research team encountered numerous technical difficulties. Poor technical support from the vendors of the aftermarket, add-on GPS-based fleet tracking systems and video data-recording systems prevented them from properly evaluating these systems. It does not appear that the Florida research team was aware of or just did not include OEM ECU-based HVEDR functionality in their study.

Legal issues over data ownership, access and privacy were a recurring theme in the EDR research published in North America, the United Kingdom and Europe and are of fair concern. It is important to understand the constitutional differences and expectations of privacy in North America compared to the United Kingdom and the European Union.

Several of the previously outlined papers concluded with recommendations for EDR, cited the positive ways in which EDR can potentially improve highway safety and referenced several key fleet and highway safety studies conducted in the United States, Iceland, the United Kingdom and Europe.

Overall, multiple highway safety studies specific to EDRs have concluded that EDR will have significant positive impacts on highway safety in the following ways:

- By including real-world EDR data within a national accident sampling database, highway accident, fatality and injury statistics can be further analyzed and possibly recognize previously unidentifiable accident causes rooted in driver, highway design, vehicle or other issues.
- Vehicle manufacturers can utilize real-world EDR data to improve the performance of vehicles generally and occupant restraint systems specifically.
- Vehicle manufacturers and regulatory agencies can utilize this data to leverage and make more powerful early-warning systems for the discovery, verification and response to possible vehicle defect issues and possible recall efforts.

- For commercial fleets, when professional drivers are made aware of the presence of EDR, it has been found that there is a temporary decrease in accident rates for that commercial fleet. When EDR data is actively used to monitor and coach drivers of a given commercial fleet, that commercial fleet can maintain decreased accident rates.

There are some additional advanced applications of EDR data that are promising and should be considered for the current and future technologies:

- Incorporation of EDR into the national emergency response system and automatic crash notification (ACN) systems can help dispatch the appropriate level of first responders and provide crash severity data to those first responders so they can prepare and properly triage the accident.
- None of the current publications reviewed discussed EDR’s potential role in evaluating and improving fast-developing future technologies, such as the intelligent transportation system (ITS), including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications; advanced driver assistance systems (ADAS), such as automatic emergency braking (AEB), forward collision warning (FCW) and lane departure warning (LDW) systems, as well as fully autonomous driver systems.

A more in-depth examination of some of these EDR recommendations follows in the subsequent sections.

3.2.1 JPL, Advanced Air Bag Technology Assessment, Final Report

NASA/JPL, via a Memorandum of Understanding (MOU), evaluated airbag performance, established the technological potential for improved (smart) airbag systems and identified key expertise and technology within the agency (NASA) that could potentially and significantly contribute to the improved effectiveness of airbags.

The JPL *Advanced Air Bag Technology Assessment* report, published in 1998, identified and recommended areas of improvement for airbag systems. A survey of NASA technologies, sensors, vendors, etc., was also conducted within the aerospace and space divisions systems. Specific technologies were identified that could be applied to advance airbags, including capacitive-type sensors that may be used for proximity sensing and stereoscopic vision systems that could also be used for stereoscopic proximity sensing or pre-crash sensing. It was proposed that more aggressive development of belt spool-out sensors and proximity sensors could provide information for improved occupant position determination and therefore improved safety responses—such as automatic suppression of inflation, two-stage inflators and advanced safety belts—by model year 2001.

The most relevant conclusion of the NASA/JPL research team was discussed in section 8.1.2 of the JPL airbag report that recommends to:

> *(7) **Study the feasibility of installing and obtaining crash data for safety analyses from crash recorders on vehicles.** Crash recorders exist already on some vehicles with electronic air bag sensors, but the data recorded is determined by the OEMs. These recorders could be the basis for an evolving data recording capability that could be expanded to serve other purposes, such as in emergency rescues, where their information could be combined with occupant smart keys to provide critical crash and personal data to paramedics. The questions of data ownership and data protection would have to be resolved, however. Where data ownership concerns arise, consultation with experts in the aviation community regarding the use of aircraft flight recorder data is recommended.*

The above conclusion excerpted from the JPL report triggered NHTSA's Motor Vehicle Safety Research Advisory Committee (MVSRAC) to organize and host the Event Data Recorder Working Group, whose work is discussed further (Section 3.2.4) in this report.

3.2.2 NTSB Recommendations for EDR/HVEDR

Since 1997, NTSB has issued numerous recommendations for EDRs, hosted or participated in six public forums and issued eight formal reports that focused on the need for recording technologies. Numerous accident briefs with recommendations have been published in addition to testimony given to the U.S. Congress.

It is important to note that the U.S. National Transportation Safety Board, although a federal government agency, is not a regulatory agency. NTSB does not set or enforce regulations. Rather, NTSB is tasked with conducting independent investigation of major catastrophes and making recommendations for safety improvements.

After NTSB was able to determine the root causes of a triple-fatality motorcoach accident that occurred outside of Canon City, Colorado in December 1999 (see 3.2.2.3), the agency published an additional recommendation in December 2002 for the industry to collaborate to establish on-board vehicle recorder standards.

Similar to this U.S. agency is Canada's Transportation Safety Board. It is TSB who prompted Transport Canada to fund the T8080-160062 research conducted by Mecanica Scientific Services Corporation (MSSC).

3.2.2.1 NTSB Safety Recommendations H-97-10 through -18

The focus of NTSB's Safety Recommendations H-97-10 through -18, issued July 1, 1997, was to refine the one-size-fits-all approach to airbag design. It was found that airbag-induced injuries were high among children and the elderly. The document recommended several steps be taken to study the issue by implementing standards for testing and data collection from real-world accidents. Among the recommendations was a desire to develop guidelines for the collection of standardized data elements from real-world collisions (H-97-15) and develop a plan to "gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented crash sensing and recording devices" (H-97-18).

3.2.2.2 NTSB Safety Recommendations H-99-45 through -54

On November 2, 1999, NTSB issued a recommendation concerning school bus and motorcoach safety. NTSB Safety Recommendations H-99-45 through -54 pointed to several studies that prompted several safety recommendations. At the time, on-board recorders had been in use by school bus fleets in over 100 U.S. jurisdictions.

The recommendation regarding on-board recorders pointed to a study by Laidlaw, Inc., that took place in Bridgeport, Connecticut from December 1, 1996 through May 30, 1997. Nearly half of the fleet's 150 buses were equipped with an on-board recorder. It was found that 72% of the accidents happened on buses not equipped with EDR. The results prompted changes to Laidlaw's training program. In this and other similar studies, the on-board recorder did not record data such as crash pulse but was able to determine speed.

Specifically, NTSB issued Recommendations H-99-53 and H-99-54 to NHTSA to require EDRs in motorcoaches and school buses:

> *All motorcoaches and busses manufactured after January 1, 2003 be equipped with on-board recording systems that will record a minimum of 18 parameters including acceleration, braking, speed, etc. Additional parameters regarding seat belts and airbags should also be considered. Other things to consider are the sampling rate, data preservation in the event of an accident or power loss and the location of the on-board recording system. Additionally, in cooperation with government agencies, develop and implement standards for bus crash data using on-board recording devices. Minimal parameters to be recorded should be data sampling rates, duration of recording, interface configurations, data storage format, incorporation of fleet management tools, fluid immersion survivability, impact shock survivability, crush and penetration survivability, fire survivability, independent power supply, and ability to accommodate future requirements and technological advances*.

3.2.2.3 NTSB Safety Recommendation H-02-35

On December 21, 1999, a single-vehicle accident occurred when a 1999 Setra 59-passenger motorcoach was traveling eastbound on State Highway 50 down a 7-mile grade just west of Canon City, Colorado. The weather was 20°F, with a light snow falling and snow and ice on the roadway. As the motorcoach descended the grade at approximately 63 mph, the motorcoach began to fishtail.[11] For approximately the next 36 seconds, the driver was in and out of control of the motorcoach as he attempted to negotiate the various curves on the downgrade. The accident event was captured by the Detroit Diesel DDEC IV engine ECU.

The accident resulted in three fatalities, 36 serious injuries and 24 minor injuries.

Because of the data obtained from the Detroit Diesel DDEC IV ECU, NTSB investigators were able to determine and conclude that one of the main contributing factors to this accident was the improper use of the engine retarder. With snow and ice on the roadway, the driver's attempt to downshift the Allison automatic transmission and put the transmission in neutral took away any of the natural engine braking to help maintain control and speed as the motorcoach descended the grade.

The president of the tour bus company that employed the driver indicated to NTSB that the driver was familiar with the route; however, the driver had not driven that new Setra bus with the seven-position transmission retarder, especially in icy conditions. The driver received little to no training on the transmission retarder device.

Without an HVEDR, it would not have been possible to determine at what points during the event the driver used the retarder or put the automatic transmission in neutral. HVEDR allowed for the determination of these contributing factors and took investigators back to a driver and driver-training problem that could then be corrected.

Because of the nature and complexity of commercial truck and bus driving and the need for commercial drivers to know proper grade descension—starting down the grade in the proper gear, as well as knowing when and when not to use other driver assistance or vehicle control devices like engine brakes (Jake Brakes), and driveline retarders (transmission retarders, Telma retarders, etc.)—HVEDR devices are mandatory technologies when investigating accidents to determine whether these controls are properly used or not.

The 2002 NTSB's Recommendation H-02-35 was published as follows:

> *To the Institute of Electrical and Electronics Engineers and the Society of Automotive Engineers: Work together, as part of your initiative to establish on-board vehicle recorder standards, to develop standards for brake and transmission electronic control units that require those units to store a full history of electronic fault codes that are time-stamped using a recognized clock synchronized with other on-board event data recording devices.*

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[11] A vehicle dynamic event in which the rear axle(s) of the vehicle slides out to one side or the other.

3.2.3 Recording Automotive Crash Event Data

One of the most seminal passenger-vehicle EDR papers, “Recording Automotive Crash Event Data,” was published in 1999 by Chidester (NHTSA), Hinch (NHTSA), Mercer (General Motors) and Schultz (General Motors), with significant contributions by Floyd (General Motors).

This paper provided a brief historical background into data recording in General Motors products as early as 1974 and included a concise overview of the relatively new Sensing and Diagnostics Module (SDM), generally referred to as the airbag control module (ACM). The General Motors SDM contains the EDR function for General Motors products.

Classes of event data were discussed in this paper and are organized in Table 3.2.3-1 below.

Table 3.2.3-1. Proposed Uses of Event Data[12]

Use	**Event Data Types**
Improve Vehicle Design/Highway Infrastructure	Vehicle systems airbag sensing system deployment criteria Highway systems roadside safety feature design standards
Provide a Basis for Regulatory & Consumer Information Initiatives	offset frontal impact severity average/extreme vehicle deceleration pulses
Provide Objective Data for Crash Reconstruction	Alleged defects & litigation unintended vehicle acceleration crash & airbag deployment sequence non-airbag deployments
Develop an Objective Driver Behavior Database	pre-crash driver braking/steering belt use vehicle speed

As shown, several example uses of event data were proposed; these included means of improving airbag sensing systems, improving roadway design, developing meaningful motor vehicle regulations and how NHTSA SCI research has improved, all with EDR.

The following Haddon Matrix Tables (3.2.3-2 and 3.2.3-3) illustrate the benefits of having enhanced EDR capabilities to improve understanding of crashworthiness-related activities as explored in a subsequent paper by Chidester, Hinch and Roston in 2001.

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[12] Source: Chidester, A., Hinch, J., Mercer, T. C., and Schultz, K.S, “Recording Automotive Crash Event Data,” 1999.

Table 3.2.3-2. Haddon Matrix without Event Data-Recording Capability[13]

	Human	Vehicle	Environment
Pre-Crash		Skid Marks	
Crash		Calculated & ΔV	
Post-Crash	Injury	Collision Damage	Environment After Collision

Table 3.2.3-3. Haddon Matrix with Enhanced Event Data-Recording Capability[14]

	Human	Vehicle	Environment
Pre-Crash	Belt Use Steering Braking	Speed ABS Other Controls	Conditions during Crash
Crash	Airbag Data Pre-Tensioners	Crash Pulse Measured & ΔV Yaw Airbag Activation Time	Location
Post-Crash	ACN (Automatic Collision Notification)	ACN	ACN

The authors' conclusions are excerpted as follows:

> *Conclusions*
>
> - *On-board vehicle recorders have the potential to greatly improve highway safety by providing regulators, vehicle manufacturers, and other researchers with objective data on vehicle crashes and pre-crash scenarios.*
> - *Well-coordinated efforts by all parties sharing highway safety responsibility will be needed to achieve the results envisioned when the NTSB issued its recommendation for cooperative efforts to utilize crash recording technology.*
> - *The Motor Vehicle Safety Research Advisory Committee's Event Data Recorder Working Group will establish guidelines for future on-board data recording capability including prioritization of the data required to improve highway and traffic safety and recommendations on the need for all manufacturers to install such equipment.*

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[13] Source: Chidester, A., Hinch, J., and Roston T. A., "Real World Experience with Event Data Recorders," 2001.

[14] Ibid.

- *The NHTSA is taking the necessary steps to collect and store data from onboard vehicle recording devices in its Motor Vehicle Research databases.*

3.2.4 NHTSA Event Data Recorders Working Group

In direct response to the 1998 NASA/JPL recommendation for NHTSA to "study the feasibility of installing and obtaining crash data for safety analysis from crash recorders on vehicles," and NTSB's subsequent recommendation to pursue vehicle crash information gathering using EDR, NHTSA's MVSRAC organized and hosted the NHTSA EDR Working Group (WG), who published the two reports discussed in this and the following section.

The NHTSA EDR WG included members of the MVSRAC, as well as the MVSRAC Crashworthiness Subcommittee for nominating several participants.

There were over 20 members representing vehicle manufacturers, EDR manufacturers and transportation providers, such as DaimlerChrysler (now FCA, LLC), DriveCam, Ford Motor Company, General Motors, Navistar, Toyota, United Motorcoach, Vetronix, Volkswagen and VDO.

Approximately 12 members represented universities, researchers, and other interested parties, such as the Association for the Advancement of Automotive Medicine, Florida Atlantic University, Georgia Tech, Insurance Institute for Highway Safety, National Academy of Sciences/Transportation Research Board, State Farm Insurance and the University of Virginia.

Approximately 15 members represented federal, state and local governments and agencies, including the Federal Highway Administration, NHTSA, NTSB and Transport Canada.

The NHTSA EDR Working Group membership defined and proposed their objective "to facilitate the collection and utilization of collision avoidance and crashworthiness data from onboard Event Data Recorders." A list of supporting core objectives included the following:

1. Status of EDR Technology - Describe current EDR technology, including OEM and aftermarket systems.
2. Data Elements - Discuss data elements listed as desirable by a diverse user set.
3. Data Retrieval - Discuss how data is retrieved from the vehicle or EDR system.
4. Data Collection and Storage - Discuss how data is collected by the users and stored for use by others.
5. Permanent Record - Delegate who is responsible for maintaining the permanent record of EDR data.
6. Privacy and Legal Issues - Discuss privacy issues as perceived by various users.
7. Customers and Uses of EDR Data - Discuss who the customers of EDR data are and their potential uses of crash data.
8. Demonstration of EDR Technology - Demonstrate current EDR data usages.

The WG held several meetings from October 1998 through December 2000 and published their final report in August 2001.

The report is a thorough source of historical data and then-current activities in the United States pertaining to EDRs for passenger vehicles and commercial vehicles, as well as European EDR activities. The report also touched upon data-recorder activities in other modes of transportation, such as aviation, rail and marine.

EDR legal issues, such as privacy and data ownership, were also discussed. Some participating vehicle manufacturers and U.S. government agencies generally agreed that vehicle EDR data would be owned by the vehicle owner. Other individuals made recommendations for secure "data vault" solutions, possibly for issues of privacy.

It has been determined by several U.S. court decisions that the privacy expected of a (properly licensed) driver on a public road is greatly diminished as each driver's actions (or inactions) can have grave consequences for other road users.

One of the key findings of the WG that aligns with findings from other EDR research is:

> *Event Data Recorders have the ability to profoundly impact highway safety. While simple or complex in design and scope, EDRs collect vehicle and occupant based crash information. EDRs can assist in real-world data collection, better define safety problems, and aid law enforcement's understanding of crash specifics, ultimately improving safety.*

Work continued by the NHTSA EDR Working Group after the August 2001 publication. The Group organized a separate Working Group to focus on EDR issues and topics pertinent to commercial trucks and buses and published Volume II of the NHTSA EDR Working Group *Final Report*.

3.2.5 NHTSA EDR Working Group, Final Report, Volume II

After the NHTSA EDR WG published their first report in August 2001, the Group continued work that focused on commercial truck and bus EDR and other related issues.

Many of the original members of the original NHTSA EDR Working Group continued work as the Truck and Bus Event Data Recorder (T&B EDR) Working Group. The membership reached out and interviewed NTSB experts, EDR manufacturers and other experts on truck and bus EDR.

Because Volume II was released so closely after the original NHTSA EDR Working Group *Final Report*, the WG considered this as an updated supplemental report to the original and published it as "Supplemental Findings for Trucks, Motorcoaches, and School Buses" (DOT HS 809 432). The T&B EDR Working Group considered data elements, survivability and event description as the core objectives for this supplemental report.

For data elements, the T&B EDR Working Group identified two priorities of data elements. Priority 1 data elements were considered the basic data elements for EDR in truck and bus, akin to a required-minimum list for a basic truck and bus EDR. Priority 2 data elements included more advanced data elements such as airbag deployment data, exterior lighting status, steering wheel angle, windshield wiper status, and driver assistance systems status such as cruise control, traction control and ABS status.

At the time, most of the Priority 2 data elements such as exterior lighting status, windshield wiper status and driver assistance systems status would have been difficult to achieve. However, since equipment like parking lights, headlights and turn signals are now also addressed data on the present-day J1939 CAN bus, these systems can now be captured by an HVEDR function on increasingly more NAFTA-market commercial truck and bus vehicles today.

The T&B EDR Working Group consulted with the Smiths Group and referenced the FMCSA and NHTSA's joint in-progress *Large Truck Crash Causation Study* (LTCCS)[15] on the topic of EDR survivability. The WG discussed EDR survivability factors, such as physical location, impact shock, temperature, immersion, penetration, crush, fire and independent power supply.

From Mecanica's experience in examining, accessing, retrieving and imaging data from thousands of NAFTA-market truck-tractors, straight trucks and motorcoaches, the survivability requirements outlined in the NHTSA T&B EDR WG supplemental report (*Final Report*, Volume II) appear overly aggressive and should be revisited.[16]

Another important analysis in the NHTSA T&B EDR WG supplemental report is the review of a case study from the NTSB and their use of data recorded by a motorcoach's Detroit Diesel Series 60 turbo-diesel engine ECU, namely a DDEC IV ECU. This NTSB investigation was of a motorcoach crash that occurred on December 21, 1999 in Canon City, Colorado (discussed in section 3.2.2.3 of this report). Without an HVEDR, it would not have been possible to determine at what points during this event the driver used the retarder or put the automatic transmission in neutral. HVEDR identified a driver and driver training problem that could then be corrected.

Finally, the T&B EDR WG reexamined the definition of an *event.* The Working Group generally agreed that the definition of an event should include a crash. However, some members recommended that different types of events should be defined in addition to a crash event, including "hard brake" events and aggressive driving events such as aggressive lane changes and acceleration events.

Events outside of crashes, such as hard brake events and aggressive driving events, should be included in HVEDR technology to help coach commercial drivers and achieve lower accident rates, as numerous U.S. and international research studies have found.

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[15] FMCSA and NHTSA, *Large Truck Crash Causation Study*, study period 2001-2003.

[16] This is discussed in Deliverable No. 6, "Commercial Bus HVEDR Feasibility Report."

3.2.6 Safety in Numbers Conference

The 2002 Safety Data Initiative Conference entitled *2002 Safety in Numbers* was hosted by the Georgetown University Conference Center in Washington, D.C. The focus of the conference was to discuss projects for improving the quality of safety data so that planners and decision-makers can make more informed safety decisions to reduce the number of transportation-related deaths and injuries.

Several projects were identified, including the re-engineering of U.S. Department of Transportation (DOT) programs, developing common criteria for injuries and death, developing common denominators for safety measures and advancing the timelines of safety data.

One of the projects (Project 5, "Developing Common Data on Accident Circumstances") addressed the problem of different transportation modes using incohesive terminology to describe crash-related circumstances and how to refine common accident descriptors, including a more detailed characterization of human factors and crash survival factors.

This project proposed ways to leverage and incorporate EDR data into police reports and Fatality Analysis Reporting System (FARS) and NASS data in a manner that would be easy for researchers to use.

3.2.7 Use of EDR Technology for Highway Crash Data Analysis

Dr. Clay Gabler and several of his graduate students at Virginia Tech's Wake Forest University School of Biomedical Engineering & Sciences conducted and published several key research studies on EDR. Prior to joining the faculty at Virginia Tech, Gabler and his colleagues at Rowan University worked in conjunction with Professor Michael E. O'Neill of George Mason University on the *Use of Event Data Recorder (EDR) Technology for Highway Crash Data Analysis*. This research was prepared for the National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board of the National Academy of Sciences.

This research identified and addressed the following problem statement:

> *There is a critical need to obtain accurate and reliable "real-world" crash data to improve vehicle and highway safety. The use of Event Data Recorder (EDR) information has the ability to profoundly affect roadside safety. EDRs are capable of capturing vehicle dynamics data, such as vehicle speed; lateral and longitudinal acceleration-time histories; principal direction of force on the vehicle; the status of braking, steering, seat belt usage, and air bag deployment; and other valuable crash information. This represents a new source of objective data for the highway and vehicle safety community because it will provide a "real world" connection between controlled test results and actual field performance of vehicles and highway design features. EDRs have the potential to capture a large number of crash-related and other data elements for a wide range of users with different data needs. The data elements related to improving vehicle safety and driver*

> *performance are being used, but little has been done to apply the data elements to roadside safety analysis. Research can identify data elements relevant to roadside safety and improve methods to retrieve, store, and access these data.*

Published in 2004, this study provided an in-depth examination of then-current roadside safety data needs and a detailed review of existing roadside safety databases, such as FARS, NASS/CDS, NASS/GES and several others. Accident database needs versus EDR data elements were also analyzed; the study discussed then-current and future data elements for passenger car EDR with an optic of what data is important for the analysis of the different roadside safety databases.

The study's in-depth reporting on the *Legal Issues Surrounding the Implementation and use of Event Data Recorders* discussed legal problems stemming from the U.S. federal government's mandate of EDR and what authorities would permit NHTSA or state departments of transportation to access and include EDR-source data in their own state databases. Accessing a private vehicle's EDR and requiring the vehicle owner's consent are legal complications that arise when acquiring data; the EDR device and data being a part of a law enforcement's search of a private vehicle are of special concern for the United States considering the Fourth and Fourteenth Amendments. The study examined EDRs in the context of the Fifth Amendment as well.

Finally, the researchers examined the American public's perceived acceptability of EDR via consumer surveys and focus groups. The public's perceived acceptability was gauged in two phases. The first phase was conducted by a questionnaire specifically drafted for the study and mailed to 10,000 licensed U.S. drivers. The second phase consisted of a focus group providing even more detailed feedback.

The two-phase study of American public acceptance produced significant findings, including:

- A majority of respondents were unaware of EDR and its use.
- Most expressed that EDR would be beneficial in accident investigations, lower insurance rates for safe drivers and encourage monitored drivers to behave more safely.
- Respondents indicated a preference for EDR use to be optional and for vehicle owners to maintain control of the data.

Regarding the overall findings for EDR's potential to improve statistical data analysis and quality, the researchers concluded:

- *In 2004, an estimated 40 million passenger vehicles were equipped with EDRs. By carefully collecting and analyzing the details provided by the growing number of EDR-equipped vehicles, state transportation agencies, federal agencies, and the highway safety research community have an unprecedented opportunity to understand the interaction of the vehicle-roadside-driver system as experienced in thousands of U.S. highway accidents each year.*

- *The initial benefit for state transportation agencies will be the use of EDR data from individual traffic accident investigations as a powerful new form of evidence in legal proceedings, e.g. to defend against lawsuits or to recover costs of repairing collision damage to the highway infrastructure. With a more methodical system of EDR data collection, state and federal transportation agencies can expand this benefit to significantly improve the efficiency of database collection for accident statistic databases.* ***For example, in state accident databases designed to meet the Model Minimum Uniform Crash Criteria (MMUCC) format, one-third (24 of 75) of the recommended data elements could be provided by EDRs.*** *The ready availability of EDR data in an accident statistics database will enable highway safety researchers to address a number of elusive research questions which directly affect state transportation agencies, e.g. the relevancy of the NCHRP 350 roadside safety feature crash test guidelines.*
- *"State and federal transportation agencies can expect to incur both startup and operational costs associated with EDR data collection. Startup costs will include both the purchase of EDR data retrieval units and training for the accident investigators or law enforcement personnel who will be performing the actual EDR downloads. In addition, EDR data collection will add somewhat to the time required for accident investigation.* ***These costs however are expected to be a barrier to EDR data collection only in the near term. As EDR data becomes more widely used in the courts and as EDRs become more widespread in the passenger vehicle fleet, there will be growing legal incentives for the states to collect EDR data.***

In addition to the cost- and time-efficiency EDR allows for investigations, this research identified key benefits that EDR can bring to roadside accident databases that align with several other studies' findings of the same. A significant conclusion is that EDR is very similar in many ways to the instrumentation used in laboratory crash tests.

Particular to heavy truck and bus accident databases, this research identified database data elements that can be attributed to the Trucks Involved in Fatal Accidents (TIFA) and the Motor Carrier Management Information System (MCMIS) Crash File databases. The TIFA database consists of accidents specifically involving medium- and heavy-duty vehicles with GVWR of 10,000 lbs. or more and, since 1980, has been maintained by the University of Michigan Transportation Research Institute (UMTRI). The MCMIS database is operated and maintained by FMCSA and contains data from state police reports for crashes involving drivers and vehicles of motor carriers. Regarding data elements for improving highway safety research databases and analysis, Gabler et al. concluded that EDRs can make significant improvements to the very quality of data for these databases. Regarding TIFA, for example, the database at the time of the study consisted of 250 data elements, 15 of which Gabler et al. suggested could be provided by the then-current EDR technology and 37 of which could be provided by future EDR technology.

The study also identified and recommended improvements to EDR, such as prioritization of the data elements, an increase in the pre-crash and post-crash recording durations to 5 seconds for each phase (pre-impact and post-impact) as well as increasing the crash phase recording of the crash pulse data to a minimum of 300 milliseconds. Additional recommendations included increasing the number of individual events that can be recorded from two events to three. Finally, expanding the definition of an *event* to include events from new systems, such as Lane Departure Warning systems and Roadway Departure Warning systems, was recommended.

Gabler et al. highlighted issues of accessing and downloading (imaging) EDR data from passenger vehicles and identified some key needs to maintain data integrity in the transfer of EDR data from the accident-involved vehicle and into the database. Some key elements in the transfer of data from vehicles to databases include the need for a standardized EDR data retrieval method; the need for an automated method to export EDR data to a database-compatible format such as XML; the need for reliable, universal hardware to connect to vehicles; standardization of data formats; and most importantly, the need for training.

This research made an important distinction between "Production EDR Systems" (or what the Mecanica research team refers to as OEM EDR) and "Aftermarket EDR." Production EDR is a function or algorithm included in an ECU that is equipped in the vehicle by the manufacturer and is a key controller to the everyday operation of the vehicle, not an add-on device. An Aftermarket EDR is a device that is added to the vehicle by the vehicle owner or fleet operator.

3.2.8 NHTSA/Volpe Center Analysis of EDR Data for Vehicle Safety Improvement

In 2008, the U.S. DOT Volpe Center performed an engineering analysis on a set of EDR data supplied by NHTSA with the main objective of determining whether data should be used by vehicle safety researchers to aid in the development and evaluation of vehicle safety concepts. Even though EDR provides limited recording capabilities, it is believed that it can provide objective real-world crash information for vehicle safety research purposes. NHTSA requested this analysis in support of their organizational mission of saving lives, preventing injuries, and reducing health care and other economic costs associated with motor vehicle crashes. Table 3.2.8 below summarizes the conclusion of the analysis performed by Volpe Center regarding EDR data for vehicle safety improvement.

Table 3.2.8 Analysis of EDR Data for Vehicle Improvement Summary[17]

Data Item	Issues	Current Status	Benefits/Concerns
• EDR Data Acquisition • EDR Data Set Characterization	• There is data reported by EDRs that are not available in crash databases	• Further research focusing on significant EDR vehicle and occupant protection system performance data elements, which might provide insight into system performance and aid in injury mitigation research, is recommended.	• Potentially benefits crash reporting • Increases reporting frequency of several data elements in crash databases. • Might add more insight into the understanding of the pre-crash situation.
• CDS EDR Data Analysis • SCI EDR Data Analysis • CIREN EDR Data Analysis	• Showed a potential under-representation of attempted avoidance maneuvers involving braking in the crash databases.	• Longitude Delta V parameter, EDR data was available in many files in which no crash files was available;	• Substituting unknown delta V values in crash files with known EDR data would increase reporting frequency by 23%
• Crash Reconstruction and Safety Research	• Limited in number of recorded parameters and storage capabilities • A wide range of EDR module-specific limitations exist • A clear understanding of what (and when) the EDR is measuring needs to be gained before any analysis. • EDR data should always be used in conjunction with other data sources, including a complete reconstruction.	• Current EDR technology objectively reporting real-world crash data provides very useful information for Safety Researchers. • The introduction of rollover stability technology and associated sensors, many more near-future EDR module types, will have the capability to store information on these parameters. • Awareness of EDR limitations is needed for correct interpretation and use of data.	• Present-day EDR information can be used to support crash reconstruction research; has potential of augmenting data in crash databases related to non-traditional system performance. • Further analysis of the EDR lateral delta V and acceleration pulse when more data becomes available. • Ultimately, present-day EDR data can be a powerful investigative and research tool by complementing existing crash evidence and estimates.

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[17] Source: daSilva, M. P., *Analysis of Event Data Recorder Data for Vehicle Safety Improvement*, NHTSA Report No. DOT-VNTSC-NHTSA-08-01, Oct. 2008

3.2.9 National Center for Transit Research, Center for Urban Transportation Research

The one study reviewed that could not validate the benefits of EDR was the *Evaluation of Electronic Data Recorders for Incident Investigation, Driver Performance, and Vehicle Maintenance* (Project No. BD549-50) published in September 2009 by the National Center for Transit Research, Center for Urban Transportation Research, University of South Florida.

The Florida research team encountered numerous technical complications with poor technical support from the vendors of the aftermarket, add-on GPS-based fleet tracking systems and video data-recording systems that prevented them from properly evaluating these systems. Furthermore, it does not appear that the Florida research team was aware of or just did not include OEM ECU based HVEDR functionality in their study.

3.2.10 U.S. Dept. of Transportation, Motorcoach Safety Action Plan

In 2009, the U.S. DOT published the *Motorcoach Safety Action Plan,* which identified opportunities for enhancing motorcoach safety. The Plan presented the Department’s analysis of safety data and assessment of causes and contributing factors for motorcoach crashes, fatalities and injuries.

The Department's analysis of data showed that driver fatigue, vehicle rollover, occupant ejection, and operator maintenance issues contribute to the majority of motorcoach crashes, fatalities and injuries.

Seven priority action items were outlined to improve motorcoach safety. The first action item was a call to “[i]nitiate rulemaking to require electronic on-board recording devices on all motorcoaches to better monitor drivers’ duty hours and manage fatigue.”

In addition to requiring what are now called electronic logging devices (ELDs), the Department outlined action items for NHTSA and FMCSA to improve data collection and analysis and called for these organizations to “[m]ake agency decision on installation and performance characteristics of heavy vehicle event data recorders (HVEDRs) on motorcoaches - Q2 2010 (NHTSA).” The report highlighted the collaborative work between NHTSA and the SAE Truck & Bus Committee’s J2728 “Heavy Vehicle Event Data Recorder (HVEDR) Recommended Practice, Tier 1.” The report provided a deadline outlining the first quarter of 2010 as the (SAE J2728 Committee’s) estimated release date for the J2728 document; by the second quarter of 2010, NHTSA was to make a decision on “installation and performance characteristics of HVEDRs on motorcoaches.”

In 2010, Mecanica Scientific’s John C. Steiner served as the Chairman of the SAE J2728 Committee. The J2728 Committee published SAE J2728 “Heavy Vehicle Event Data Recorder, Tier 1” in June 2010 three months behind schedule at the end of Q2 2010. No further action or information was heard of from NHTSA on HVEDR activities for motorcoaches.

3.2.11 UDS Accident Data Recorder - A Contribution to Road Safety

The Kienzle Automotive *UDS Accident Data Recorder - A Contribution to Road Safety* study published by VDO in 1998 discussed the positive outcome of equipping fleet vehicles with accident data recorders. The report found that the use of accident recorders reduced accidents; provided clarification through objective data and detailed qualification that could improve certainty in legal, actuarial and investigative matters; and reduced accident-induced costs.

It was found that several E.U. fleets including police vehicles, buses, security vehicles and taxis fitted with Unfalldatenspeicher (UDS), or “accident data recorder,” showed a reduction in accidents anywhere from 15% (buses) to 66% (taxis). In addition, the use of UDS and its system extension, Emergency Management, could improve safety by sending alarm signals when an accident occurs, providing the accident location using GPS and establishing communication with emergency services resulting in reduced response times. Regarding buses specifically, a pilot test sponsored by the German Ministry of Transport using buses from the Association of Württemberg-Baden Bus Companies (WBO) examined 123 buses fitted with UDS and discovered that “accidents were reduced by 15 to 20%” depending on the company.

The paper also explored positive results of accident reduction for other vehicles, such as patrol cars and company cars, though the premise underlying accident reduction via UDS for all considered vehicle types was rooted in how UDS could monitor driver behavior. The authors argued that, at least in Germany, “about 90% of the recorded accidents are caused by human failure of the involved parties, [and] only about 10% by technical defects or the condition of the roads.” When developing safety recommendations, therefore, “suitable measures for a positive effect on the behavior of the road users have to be taken.” The authors proposed that UDS could advance highway safety by analyzing, understanding and improving the behavior of road users.

3.2.12 SAMOVAR and Traffic Accident Reduction through Monitoring Driver Behavior with Data Recorders

In 1995, a field trial phase was implemented for out of the SAMOVAR: The DRIVE Project V2007, developed from the Safety Assessment Monitoring On-Vehicle with Automatic Recording (SAMOVAR) framework from the Commission of the European Communities 1992-1995 Drive II research program. The Association of Dutch Insurers and some members made an additional trial phase possible.

The study was carried out through the voluntary coordination and, in some cases, individual expense of an international consortium consisting of the United Kingdom’s University of London, the Motor Industry Research Laboratory (MIRA), the Transport Research Laboratory (TRL), and Royal Mail; Greece’s IMPETUS Consultants bureau; and The Netherlands’ SWOV Institute for Road Safety Research. Fleet participants were Dutch and Belgian.

A comprehensive report of the study was published for the SWOV Institute for Road Safety Research by Wouters and Bos in 1997, followed by a succinct summary published in *Accident Analysis and Prevention* in 2000.

At the time of writing, prior indications for such research included evidence from a German study in which installing "accident reconstruction recorders" into a fleet of vehicles allegedly resulted in 30% reduction in accidents.[18] An unnamed British insurance company was claimed to have offered fleets a 15% reduction in premiums if "trip recorders" were installed in their vehicles.[19] Finally, data from the United Kingdom's Royal Mail fleet showed accident reduction of 17% with the use of 500 data recorders.[20] A research gap remained, however, formally stating what accident reduction effects were possible, which factors brought about such effects, or if positive effects would be produced in all circumstances of installing data recorders to influence driver behavior and safety.

The project required considerable logistical and information-sharing cooperation of fleet owners, telematic monitoring-device manufacturers, insurance companies, and regional and national authorities. Given the voluntary participation and expense of some fleet owners, the study sample consisted of 840 vehicles that varied widely in character and use. The study also depended on the off-the-shelf supply of commercial data recorders from various manufacturers available at the time.

Of the 840 participating vehicles, 270 were fitted with telematics monitoring devices, the majority of which were accident data recorders (ADRs) and others more generally considered trip recorders or "journey data recorders" (JDRs). The researchers proposed the different information collected by each type of device indicated that ADRs could be used to provide feedback to drivers on an occasional basis whereas JDRs could be used to provide feedback to drivers on a regular basis, regarding speeding behavior (mean speed, rapid decelerations or accelerations) for instance. Because the study's focus was neither the exact data nor the way feedback was given, both types of recorders were deemed suitable for the experiment.

The researchers acknowledged in their design that the heterogeneity of vehicles in the fleet complicated controlling for similar accident risks encountered during the trial. As such, treatment and control groups were matched by relevance in vehicle type, the nature of the transport business using the vehicle, and the traffic conditions in which the vehicle operated. Thus, Cluster A consisted of heavy trucks, Cluster B of medium and heavy trucks, Cluster C of coaches, Cluster D of taxis and vans, Cluster E of company cars, Cluster F of coaches, and Cluster G of taxis. The range and duplication of vehicle types among clusters was a result of which fleets were available from the participants and where the trial occurred. For example, Cluster C was comprised of experimental and control groups of motorcoach fleets provided by two different touring companies

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[18] Wouters, P.I.J., and Bos, J.M.J, *The Impact of Driver Monitoring with Vehicle Data Recorders on Accident Occurrence; Methodology and Results of a Field Trial in Belgium and The Netherlands*, SWOV Institute for Road Safety Research Report No. R-97-8, 1997

[19] Ibid.

[20] Ibid.

in the Netherlands while Cluster F consisted of an experimental and control group of coach fleets from one Belgian international travel and touring company. For feasibility purposes, measure of exposure to accident risk was based on months of vehicle use rather than mileage for all Clusters.

The quasi-experimental field trial began in 1994 and consisted of seven groups fitted with recorders and drivers made aware they would be monitored and confronted with data and accountability for their driving behavior; these were matched by 12 control or quasi-control (not all matching criteria was applicable) groups without the intervention. One year of each fleets' accident history was provided for the trial's pre-test phase before the intervention of data recorder installation was implemented in the post-test phase. Accident data was recorded for at least one year in the post-test phase, resulting in a total study of at least 24 months of accident data. During the observation period, the fleets were involved in 1,836 accidents.

The study was conducted on the premise that humans are known to modify behavior when aware they are being observed; therefore, the researchers set out to examine whether such "behavior influence" could be implemented with drivers and thus improve highway safety. The researchers proposed that telematic monitoring devices, namely ADRs as well as JDRs, would be effective in influencing driver behavior only if the drivers were aware they were being monitored and could be confronted with accountability for their driving by management.

Assessing the effect of a telematics monitoring feedback mechanism on driver behavior, the researchers found that the intervention effected an overall accident rate reduction of 20% in experimental groups when adjusted for safety developments in non-experimental groups. This was concluded within a 90% level of confidence. Estimates of adjusted risk rates varied across clusters, from a nonsignificant 13% increase in accidents in measure strain of Cluster A (heavy trucks) to a 42% reduction in Cluster C (coaches) and 72% reduction in Cluster F (coaches). Clusters A (heavy trucks) and B (medium and heavy trucks) had additional accident history data for time periods that did not coincide with the observational study time periods of other clusters.

For methodological reliability, the researchers calculated a result based only on the full-time overlap of pre-test and post-test data for applicable clusters' experimental and control groups and estimated a significant 31% reduction in accidents. Alternatively, if the post-test study period of Cluster A was shortened for the non-overlapping 14 months, the researchers concluded an overall accident reduction of a nonsignificant 12% when including data from this cluster of all heavy trucks. The seasonal variability of traffic hazards made the factor of coinciding observational study periods essential to reliable assessment of exposure risk across clusters.

The study's main subject was driver response to data recorder feedback, which was found to reduce accident rates by 20% in particular fleets and, in one cluster, to attenuate accident severity and damage. A margin of ±15% was partly dependent on the fleet's pre-test accident history. The results could only be given within wide confidence intervals with the divergence stemming from small sample size. It was thus recommended that such a project be implemented on a larger scale, with attention paid to the content of feedback given to drivers when confronted and how feedback implementation (via incentive schemes or the basis of recurrence, for example) influenced the large variation in accident reduction effects. The difference in fleet owner's attitudes of safety were also proposed as a factor contributing to the variation in accident rates among fleets of similar vehicle types.

Wouters and Bos advised that the study's discovered reduction in accident rates could not provide a comprehensive assessment of all potential accident reduction given the actual accident rates of various fleet types and risks encountered by different sectors of transport. Finally, they recommended that the effect of the feedback mechanism may be sustained by providing drivers feedback on a more regular basis, rendering JDR preferable for regular and consistent behavior monitoring.

3.2.13 European Commission, Directorate-General for Energy & Transport: VERONICA

During 2005 and 2006, the Vehicle Event Recording on Intelligent Crash Assessment (VERONICA) team formed three working groups that generated several sub-reports referred to as the *VERONICA I Final Report* and reviewed in the following sections. The VERONICA project explored the possibilities of implementing EDR in the European Union to better understand collisions and also to recognize the potential benefits for prevention, road safety and legal fairness.

In 2009, a second report released as the *VERONICA II Final Report* was generated when the planned actions to reduce the number of road fatalities by 2010 fell behind the previously established goal.

The subsequent sections highlight the VERONICA team's recommendations to achieve the potential benefits of implementing EDR in Europe.

3.2.13.1 VERONICA I

The VERONICA I Project's *Final Report* addressed the technical, administrative, legal, safety and environmental issues with the implementation of EDR in Europe. The objective for this project was to examine and evaluate available and necessary standards, solutions and requirements and recommend a legal framework, in particular to collect accident data into the European accident databases. The project clarified the definition of an "accident" as *"*an unwanted or unintended sudden event or a specific chain of such events which have a harmful consequence*."* The VERONICA team realized that there was a lack of real-world collision data and a need for sharing comprehensive European accident databases. The work of the VERONICA team on this project aligned with the European Commission (EC) safety approaches for improving accident data for enhanced research on active, passive and infrastructure safety as well as for accident mitigation.

The VERONICA I Project delivered a list of required collision parameters and a recommended list of sampling rates and recording frequencies. The project concluded that, depending on the elevated accident or damage risks, hazardous goods transports, coaches, buses and other commercial vehicles would benefit from EDR implementation because of decades of well-established legal experiences with tachographs.

There were several potential benefits that varied by fleet type, but it was noted that the overall accident reduction benefit was difficult to identify and therefore not quantifiable in this review. The VERONICA project therefore assessed benefits only in qualitative terms.

The VERONICA Project made several recommendations, including the following:

- Several recommendations addressed the acceleration measured in the longitude and lateral directions. With the higher minimum sampling rate of 250 Hz and the recommended improved acceleration measurements, crash investigators and researchers could calculate the desired delta-V estimates without relying on the usually unspecified EDR algorithms.
- Several recommendations were made for the Part 563 requirements, and it was noted that the proportion of new U.S. light-vehicles fleet that were equipped with a portion of the Part 563-compliant EDR had grown to over 90%. This indicated that Part 563 specification compliance was well underway.
- The authors proposed further discussion with vehicle manufacturers regarding the cost or limitations of changing the recording of recommended parameters from “optional” to required or “if recorded.”
- Increasing the minimum recording interval for delta-V and accelerations parameters from 0-250 ms to 0-300 ms or even higher in order to accommodate a wider range of collision types was suggested.
- Defining an open list of data items so that the activity of each system is “flagged” along with any new systems added to the EDR was also suggested. VERONICA recommended additional and more sensitive triggering requirements than the NHTSA triggering requirements.

Among the legal issues, the team paid special attention to data privacy concerns. It was pointed out that data recordings were not required to be continuous and therefore only a few seconds of recorded data before, during and after the accident were needed. Also, the so-called Art 29 Working Group members shared a common understanding that EDR implementation as a benefit for society is legally possible if, under the data privacy provisions, all collected details were handled carefully.

To realize the benefits of EDR implementation in Europe, the VERONICA Project proposed that a follow-up project be jointly conducted with other members from state authorities to define binding standards for generating, processing and handling accident data. The information contained in the VERONICA II report was gathered after wide-range consultation with practitioners, including collision investigators; enforcement authorities; academic, medical and legal institutions; public and private sector representatives; and relevant E.U. member state governmental organizations.

3.2.13.2 VERONICA II

The VERONICA II Project's *Final Report* addressed the concerns that the VERONICA I goals for reducing the number of fatalities by 2010 were falling behind schedule. A more in-depth data set was therefore required to enhance the information available for improving road safety in terms of road infrastructure, vehicle design and training.

The VERONICA II Project's *Final Report* focused on presenting EDR's most appropriate requirements. The authors also aimed to organize and consolidate all collected information that could assist with the introduction of EDR technologies in Europe and would accordingly result in a recommendation for a draft Directive. The included recommended requirements would amount to the most effective evidential chain to satisfy road safety research, collision investigation requirements and procedures.

The VERONICA II report provided the example of the European Road Safety Observatory (ERSO) that promoted safety research, but the VERONICA II team would not be able to fulfill their expectations as they lacked real-world data that could have been provided had they installed EDRs. Therefore, it was recommended that to expect enhanced in-depth research, EDR data should play a more important role in future European Commission actions.

In a joint effort with researchers, the VERONICA team recommended not to restrict manufacturers from recording other data with non-harmful consequences for safety and diagnostic purposes.

The Project team carried out the task of defining and categorizing a ranking of "triggers" (0 = "Never triggered," 10 = "Always triggered") based on their experience, followed by defining a "trigger" combination matrix and recommended technical consequences.

The VERONICA team did not always agree upon all recommendations. Ford Motor Company, for example, doubted the feasibility of recording low delta-v impacts; Ford only agreed to use existing EDR technologies and that the greatest benefits of such technology would be realized by a widespread deployment of EDR.

The VERONICA report pointed out that, since 1991, E.U. member states have been collecting individual road accident data details on a voluntary basis using their own national collection system, the CARE database (i.e. Community Road Accident Database), which hindered their potential and limited their data analysis and comparisons at the E.U.-level. For this reason, a recommendation for a Common Accident Data Set (CADaS) was presented to help standardize a minimum set of data allowing recipients to obtain comparable road accident data, eliminating the limits restricting CARE. This would allow the CADaS system to accept increasingly more national data to be aggregated within the CARE database.

Another recommendation addressed the need for an EDR emergency power supply to be made available to ensure safe and reliable EDR functionality, specifically allowing data acquisition prior to a crash, during a crash, and safe data storage and download after a crash. The challenge was to develop a fail-safe power supply solution that ensured safe EDR operation for all three cases and would be deemed valid by all vehicle manufacturers (i.e. low in cost and complexity, with as few interferences with existing wiring harness as possible). A further recommendation was made to have an operating procedure concerning data processing.

In order to realize the developments of these recommendations, several options and alternatives had to be addressed to balance each implementation. The proposed introduction date of this new regulation was set for October 29, 2009. This meant that the new regulation could be amended by the functionality and test specifications of event data recording and also by the vehicle categories to be equipped with EDR.

3.2.14 Transport Research Laboratory, DG MOVE EDR Report

This 2014 research project conducted and managed by the Transport Research Laboratory, Ltd. (TRL; Wokingham, Berks, United Kingdom) was organized in response to a European Parliament resolution for a study *on the Benefits for Road Safety Resulting from the Installation of Event Data Recorders*. This funded research project supported the European Commission's commitment to examining the benefit of installing EDR for the purpose of improving road safety in Europe, with a specific optic on “professional vehicles.”

EDR was defined by this project as:

> *A system for recording vehicle data during unintended events with harmful outcomes (i.e. damage or injury), with no continuous monitoring of driver behaviour or performance.*

The research team at TRL defined their project as the groundwork study for assisting the European Commission on the decision of whether the fitment of EDR in all vehicles or certain categories of vehicles could result in an improvement in highway safety, as well as any other consequences that would justify the cost associated with the adoption of E.U. regulations for EDR.

The TRL study focused on quantifying the costs and benefits for several categories of vehicles, including “heavy goods vehicles, light goods vehicles, buses and coaches, and passenger cars (for private and commercial use).”

The report identified similarities in United Kingdom categories of vehicles, including passenger vehicles (M1) and small commercial vehicles (N1), that could fall under the United States CFR Title 49 Part 563 rule; conversely, the equivalent U.K. large commercial vehicles (N2/N3) and buses and coaches (M2/M3) are not defined in the U.S.

The TRL research team identified the same recurring theme Mecanica has observed in the research literature published in the United States, Canada and Europe, which echoes a consensus that EDR installation in vehicles shows a reduction in accidents when the driver is aware of the EDR and its presence serves to modify driver behavior, allows data to be used by vehicle manufacturers to help improve vehicle safety and assists highway accident investigators in more thoroughly and efficiently analyzing accidents and determining root causes of accidents that might not have been otherwise determined without EDR.

Similar to the legal concerns raised by the NHTSA R&D EDR Working Group in 2001 and the Veronica I Project in 2006, the main complications of EDR installation identified by the TRL team were the legal issues surrounding privacy, data access and data ownership. The TRL study included an in-depth legal discussion on data ownership and data access for six European countries, including English, Austrian, French, German, Italian and Spanish laws. However, the legal basis and expectation of privacy in Europe (and the United Kingdom) are different than in the United States and Canada.

Regarding cost analysis, the TRL team recognized that more passenger vehicles are increasingly equipped with an EDR function built into the vehicle's OEM ACM, which makes the cost of adding EDR negligible. The analysis also discussed potential costs of retrofitting an aftermarket EDR, such as the Kienzle Automotive UDS.[21]

The recommendations put forth by the TRL research team were grounded in this cost-benefit analysis. The researchers concluded that, in consideration of OEM-type EDR included in the vehicle's OEM ECU utilizing the vehicle's own power, communications network and sensors in compliance with the U.S. CFR Title 49 Part 563 (or upcoming FMVSS 405) rule, this should be considered a minimum.

The TRL research team indicated hesitation in proposing similar EDR recommendations for passenger vehicles given the lack of research on the impact the presence of EDR has on *private* vehicle drivers and fleets when compared to the extensive North American, British and European studies demonstrating the effects of EDR on commercial fleet accident rates. If a study could determine EDR's effects on private vehicles (and drivers) and improvements in road safety, the TRL team concluded that it might then justify the cost of an add-on or aftermarket EDR device that exceeds the U.S. CFR Title 49 Part 563 (or upcoming FMVSS 405) rule.

It was proposed that if [HV]EDR is recommended for "Heavy Goods Vehicles (HGV)," then [HV]EDR should also be required for "Light Commercial Vehicles (LCV)." However, if the LCV contains a passenger-vehicle EDR that is compliant with U.S. CFR Title 49 Part 563, certain channels of data will have to have the option of "if fitted" for those data channels representing options or safety systems (such as side airbags) that may not be available on a LVC-category vehicle.

Regarding HGVs, the TRL research team recommended the development of standards for heavy-vehicle manufacturers requiring that they define data channels, recording duration, sample rate, and the physical storage location of the [HV]EDR data.

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[21] https://www.kienzle.de/index.php?108&tt_products=33

In particular, it was determined that the fitment of EDRs to large commercial vehicles (N2/N3) and buses and coaches (M2/M3) varies in terms of how the system is organized and the types of data recorded. In these studies, a range of reduction in accidents was shown when in-vehicle data recorders (which include EDRs) were installed; the EDR affected the driver's behavior, resulting in fewer operational (as opposed to technical defect) accidents. It was noted that the reduction in accidents was limited for commercial fleets with EDR as commercial fleet vehicles (N2/N3 and M2/M3) were already engaged in monitoring with EDR technologies to support the driver; it was therefore estimated that more than 30% of the fleets had already realized the benefits of fewer accidents.

Another finding was that behavioral change of drivers was strongly linked to information feedback provided by installed EDRs; this aligns with the positive results EDR feedback has on driver behavior and therefore accident reduction found by VDO's 1998 Kienzle Automotive UDS study, as well as the SAMOVAR Drive II Project in which TRL participated in 1992-1995.

Furthermore, with the installation of EDR, manufacturers can obtain more accurate information on accident causation, which would allow accident researchers to improve on accident countermeasures and therefore potentially reduce the number of accidents and injuries. From the view of cost benefits, several estimated projections of accident reductions were assumed to be the most probable outcome.

The TRL research team explicitly recommended that [HV]EDR data be stored separately from digital tachograph data. The TRL research team discussed the SAE J2728 "Heavy Vehicle Event Data Recorder Committee, Tier 1" document published in June 2010 and reviewed in Mecanica's report.

Table 3.2.14 - European EDR Installation Study Summary[22]

Buses/ Commercial Vehicles	**Legality**	**Implementation Status**	**Highlighted Benefits/Concerns**
Passenger Cars (M1)	● Recorded Data meets Mandatory specifications demanded by 49 CFR Part 563. ● More accurately determine liability. ● Reduces time and legal costs.	● EDR fitted to almost all new M1 vehicles in Europe. ● Equipped for some years.	● More parameters than the minimum requirements of 49 CFR Part 563 are recorded. ● Studies show reductions in accidents via effects on driver behavior. ● Improve future vehicle designs and safety systems. ● Provided reconstruction data helps assess effectiveness of countermeasures that help avoid accidents
Small Commercial Vehicles (N1)	● Ownership of EDR data was not defined; Clarification of ownership would be beneficial to the access and management of EDR data. ● Countries have degree of uncertainty for collected data; need to specify conventions once ownership is determined.	● EDR fitted to almost all new N1 vehicles in Europe. ● Equipped for some years.	● More parameters than the minimum requirements of 49 CFR Part 563 are recorded. ● Studies show reductions in accidents via effects on driver behavior. ● Improve future vehicle designs and safety systems. ● Provided reconstruction data helps assess effectiveness of countermeasures that help avoid accidents.
Large Commercial Vehicles (N2/N3)		● EDR fitment varies more for N2/N3 vehicles in organization and types of data recorded; ● Less standardized EDR design and capability for larger vehicles.	● Standardizing EDR may result in greater cost to manufacturers. ● State of the art currently exceeds minimum data frequency requirements in 49 CFR Part 563; greater frequency data offers better understanding of accident.
Buses and Coaches (M2/M3)		● EDR fitment varies more for M2/M3 vehicles in organization and types of data recorded.	

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[22] Source: Hynd, D., and McCarthy, M., *Study on the Benefits Resulting from the Installation of Event Data Recorders, Final Report*, TRL Published Project Report No. PPR707, 2014.

3.2.15 Transportation Safety Board of Canada, Railway Investigation Report R13T0192: Crossing Collision - VIA Rail Canada Inc. Passenger Train No. 51, OC Transpo Double-Decker Bus No. 8017

On September 18, 2013 at approximately 08:48 AM, a collision occurred between a westward VIA Rail Canada (VIA) commuter train and an OC Transpo double-decker bus.

The OC Transpo is the municipal transit authority for the City of Ottawa, Province of Ontario. The OC Transpo bus involved in this accident was an Alexander Dennis Enviro500 42-foot-long double-decker bus built in model year 2012. The AD Enviro500 was equipped and powered by a Cummins turbo-diesel engine with electronic controls with an HVEDR function.

VIA was operating the daily westward scheduled commuter train service VIA 51 from Montréal, Quebec, to Toronto, Ontario, via Ottawa. The VIA 51 train was comprised of one General Electric Genesis (Model EPa42) locomotive at the head of the train, pulling four Light, Rapid, Comfortable (LRC) passenger cars. The train weighed 312 tons and stretched 410 feet in length. The locomotive was equipped with a locomotive event recorder (LER).

A diagram of the accident site from TSB Report No. R13T0192 is shown below in Figure 3.2.15.

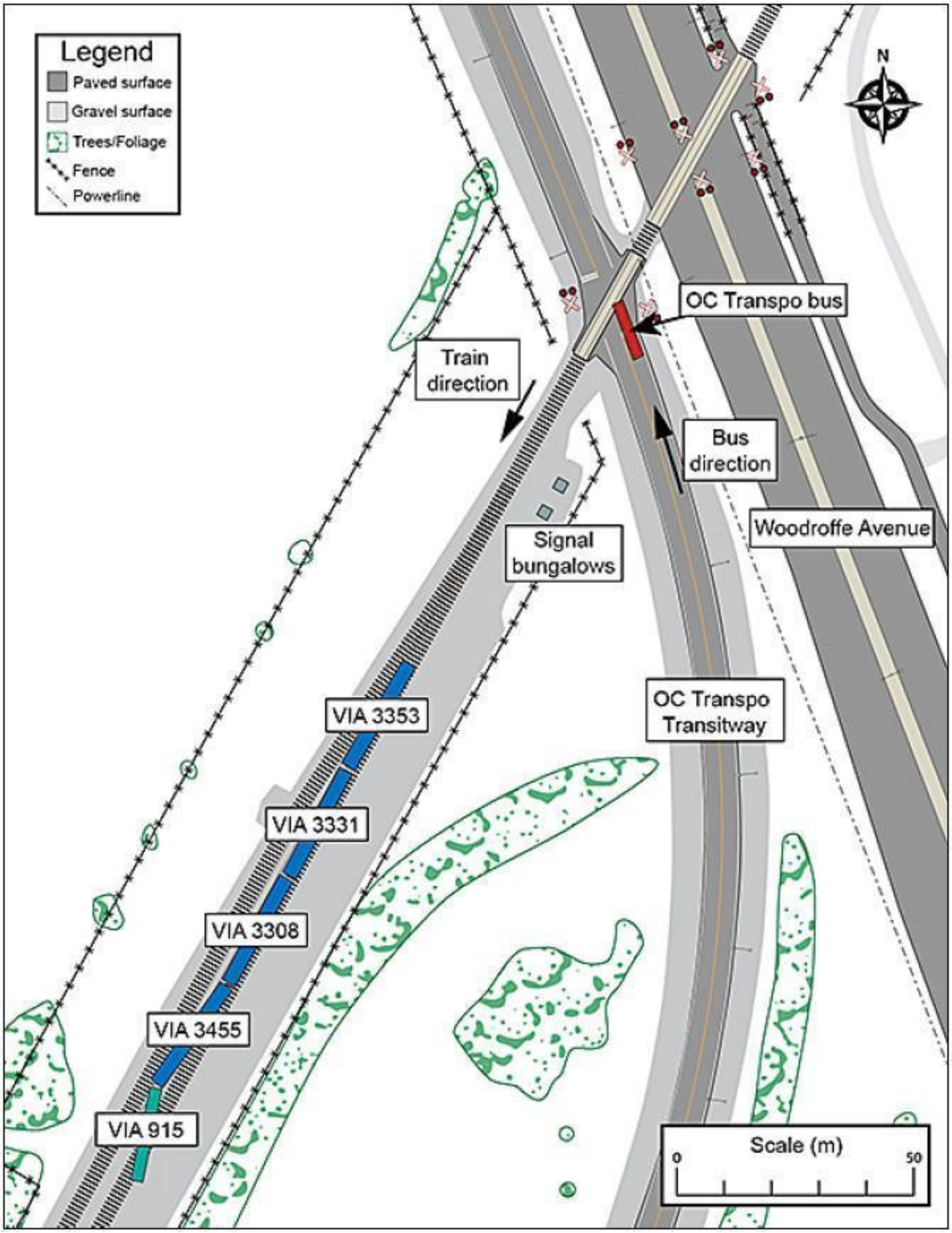

Figure 3.2.15. Accident site diagram[23]

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[23] Source: Figure 2, Transportation Safety Board of Canada, Railway Investigation Report No. R13T0192, *Crossing Collision - Via Rail Canada Inc. Passenger Train No. 51, OC Transpo Double-Decker Bus No. 8017*, 2015.

The collision resulted in six fatalities, nine serious injuries and approximately 25 minor injuries among the occupants of the double-decker bus. No VIA crewmembers or passengers were injured on the train. The final investigation report authored by TSB contained numerous safety recommendations, with one of those recommendations focused on bus EDR.

TSB investigators identified eight "electronic units" (electronic control units) on the AD double-decker bus, including the "ECM" (Cummins Engine "electronic control module") data recorder. As a result of this investigation, TSB published Recommendation R15-03, which suggested that

> *The Department of Transport require commercial passenger buses to be equipped with dedicated, crashworthy, event data recorders.*

Obstacles to the ensuing crash analysis provided some indication as to ideal data-recording specifications underlying TSB's recommendation for EDR. It was noted that, of the eight ECUs that provided recoverable non-volatile memory, the ECM was the only unit that retained useful data: the ECM was triggered to record only because the bus decelerated at a rate greater than the programmed sudden deceleration event rate of 9.0 mph/s. No data would have been stored on the ECM had the bus decelerated at a lower rate. TSB further noted that the data that was recovered still lacked sufficient detail for meaningful analysis, such as a meaningful time stamp, distance traveled, data regarding ABS and emergency brake operation, details about braking beyond its mere application, and brake line air pressure to determine the force applied when braking. It was concluded that a 1 Hz reporting rate was insufficient for detailed analysis.

This TSB Recommendation (R15-03) is the triggering event for Transport Canada to request this research for the *Feasibility Study of Event Data Recorders (EDRs) for Commercial Buses* (T8080-160062).

3.3 EDR & HVEDR Regulations - Americas

Research was conducted to determine what EDR/HVEDR-related legislative activities, if any, have or are currently taking place throughout the Americas, including North, Central and South American countries.

The only significant EDR/HVEDR-related legislative activity found in the Americas is that of the United States.

No EDR-related legislative activity currently takes place in Canada beyond this feasibility report conducted by Mecanica.

No EDR-related legislative activity currently takes place in Mexico beyond some partial requirements for the equipping of tachographs in "luxury bus" operations. However, Mexico has no regulatory requirements for how a tachograph chart is used for driver HOS or accident investigation. Mexican law requires only that a tachograph meet Economic Commission for Europe (ECE) requirements of tachograph installation in motorcoaches.

Finally, no EDR-related legislative activities were currently found to take place in any Central or South American countries.

3.3.1 United States

In 2004, NHTSA published a NPRM (69 FR 32932) for voluntarily installed EDRs to record a minimum set of specified data elements useful for crash investigations, analysis of safety equipment performance and CAN systems. Manufacturers were recommended to make information publicly available for enabling retrieval of EDR data by crash. The NPRM explicitly stated it did not mandate EDR and applied to voluntarily installed EDRs in vehicles with GVWR of 8,500 lbs. and an unloaded vehicle weight of <5,500 lbs. This NPRM set the foundation for Part 563.

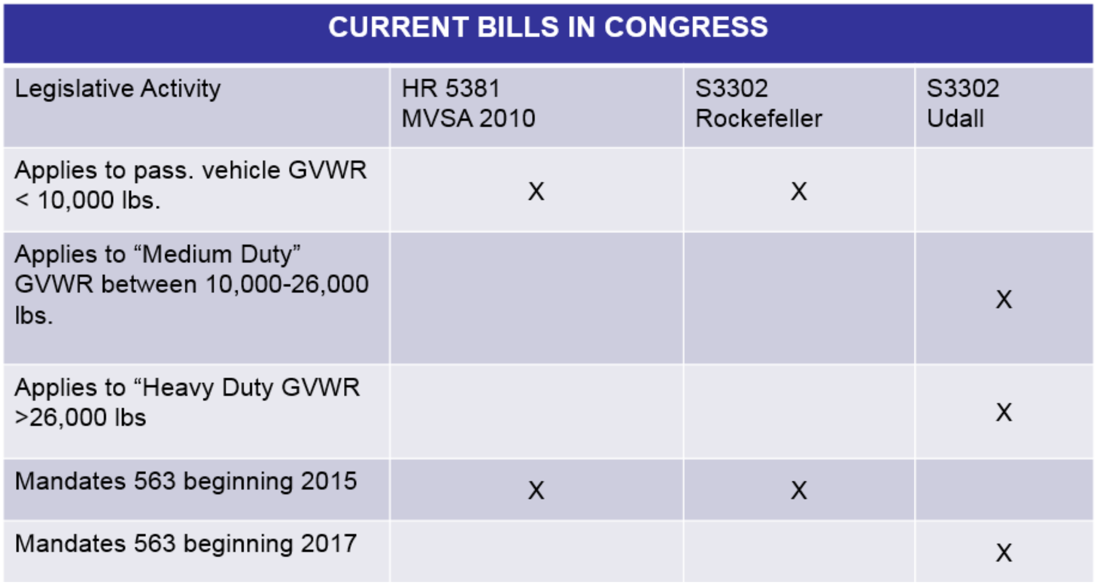
In 2006, NHTSA published the Part 563 rule in CFR Title 49 (71 FR 50998). The original Part 563 rule published in 2006 was revised and reissued in 2009. Part 563 outlined specifications for uniform, national requirements for equipping EDR. It also proffered requirements vehicle manufacturers were to use when developing commercially-available tools and methods for crash investigators and researchers to retrieve EDR data. Furthermore, the rule was voluntary and applicable to light-duty vehicles of GVWR 3,855 kg (8,500 lbs.) or less manufactured on or after September 1, 2012.

NHTSA published an “Approach to Motorcoach Safety” memorandum to Docket No. 2007-28793 in 2007. Within the context of NTSB Safety Recommendations H-99-53 and H-99-54, the memorandum discussed how specifications for crash characteristics and other measurements would differ for motorcoaches compared to the requirements for light passenger vehicles established in Part 563. NHTSA indicated they were collaborating with the SAE Truck & Bus Committee to co-develop a standard for recording crash parameters relevant to heavy trucks. NHTSA referred to then in-progress SAE J2728 standard developing functional requirements for HVEDRs and indicated NHTSA would consider an appropriate requirement for HVEDR installation in motorcoaches once J2728 development completed.

NHTSA published a revised “NHTSA Vehicle Safety Rulemaking and Research Priority Plan 2009-2011” in October 2009. The plan outlined a priority to develop performance requirements for "heavy vehicle EDRs” and planned for the next agency decision for 2010. A month later in November 2009, NHTSA’s *Motorcoach Safety Action Plan* (Publication No. DOT HS 811 177) augmented the requirements for data currently collected on motorcoach drivers and operators and proposed FMCSA explore other passenger carrier data sources.

In 2010, Toyota Motors Sales USA and Lexus, alongside NHTSA, responded to and investigated numerous unintended acceleration claims against Toyota’s Electronic Throttle Control (ETC) system from the public. NASA and the NAS also participated in the investigation of these consumer complaints, which resulted in Toyota’s recall of millions of vehicles. In its report of findings, NHTSA concluded it would consider initiating rulemakings into several safety technologies, including EDR.[24]

NHTSA published the “NHTSA Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan 2011-2013” in 2011. This plan outlined a priority for developing “heavy-vehicle EDRs” performance requirements and indicated that the agency would decide by 2011 whether to initiate rulemaking for EDR requirements for newly manufactured heavy vehicles.



CURRENT BILLS IN CONGRESS

Legislative Activity	HR 5381 MVSA 2010	S3302 Rockefeller	S3302 Udall
Applies to pass. vehicle GVWR < 10,000 lbs.	X	X	
Applies to “Medium Duty” GVWR between 10,000-26,000 lbs.			X
Applies to “Heavy Duty GVWR >26,000 lbs			X
Mandates 563 beginning 2015	X	X	
Mandates 563 beginning 2017			X

Figure 3.3.1. EDR-related bills in Congress (2006-2010)[25]

In November 2012, a Preliminary Regulatory Evaluation (PRE) was released. The PRE analyzed potential impacts of a NHTSA-proposed FMVSS 405, “Event Data Recorders,” which would require all light vehicles to be equipped with EDRs that meet the standardized data elements, capture, format, retrieval and crash survivability requirements outlined in Part 563. The proposal made no modifications to Part 563’s requirements but required all manufacturers of applicable vehicles meet compliance by September 1, 2014.

NHTSA reported that the industry’s response to the New Car Assessment Program (NCAP) survey indicated 91.6% of model-year 2010 applicable vehicles were EDR-equipped. FMVSS 405 was proposed to close the EDR installation gap. It was indicated that this move would allow researchers to be able to evaluate complex vehicle electronic systems more comprehensively and identify critical issues in how such safety devices perform. Standardized data elements as well as capture and retrieval were suggested for improving data availability for advanced ACN systems and emergency traffic responses.

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[24] NHTSA, *Technical Assessment of Toyota Electronic Throttle Control (ETC) Systems*, 2011.

[25] Source: Austin, T., Cheek, T., Plant, D., Steiner, J., and Lackey, L., “SAE C1022,” Module 2.

This proposal, however, mandated EDR installation in frontal air bags of light vehicles whereas the 2006 Part 563 rule instituted passenger-vehicle EDR installation on a voluntary basis. The cost for equipping the 1.32 million light vehicles without EDR and thus raising EDR installation from 91.6 to 100% of light vehicles was estimated $26.4 million. The estimated costs accounted for hardware for recorded data storage, technology improvements, assembly and compliance costs, and paperwork; the cost per vehicle was estimated at $20 USD. The PRE reported that the majority of vehicles without EDR were luxury specialty vehicles, but these were exempt from the mandate due to their advanced electronic control and safety systems.

The 2012 PRE on FMVSS 405 did not discuss medium- and heavy-duty vehicles, likely due to already widespread in-vehicle recording for these classes as well as differing requirements.

On December 13, 2012, NHTSA published a NPRM “Federal Motor Vehicle Safety Standards; Event Data Recorders” (77 FR 74144), which advanced the previously proposed FMVSS 405: “Event Data Recorders.” As intended, FMVSS 405 expanded on the then-current Part 563 rule and mandated the installation of EDR as defined in the current rule. Additionally, the proposed FMVSS 405 Part 571 outlined and required compliance with EDR crash test performance and survivability requirements. The standard was applicable to light vehicles, including passenger cars, trucks and buses of GVWR 3,855 kg (8,500 lbs) or less and an unloaded vehicle weight of 2,495 kg (5,500 lbs) or less, manufactured on or after September 1, 2014, with “walk-in van-type trucks” exempt.

On January 30, 2013, representatives from small volume manufacturers (SVMs) including McLaren Group, Lotus Cars Ltd., Ferrari SpA and Aston Martin Lagonda Ltd. met with NHTSA to discuss the December 2012 NPRM mandating EDRs via FMVSS 405. These SVMs were concerned with the impact that EDR incorporation into existing development and testing programs would have on their development cycles, which are longer than those of larger manufacturers. The SVMs noted that their ECUs were not compliant with Part 563 and, in some cases, manufacturers reduced ECU functionality to be exempt from the purview of Part 563 given its extensive criteria. The SVMs presented cost and time estimates to argue for exclusion from phase-in EDR implementation by the proposed compliance date of September 1, 2014 and estimated a compliance date of September 1, 2017 could be expected.

On March 5, 2013, NHTSA representatives convened with Agero to discuss the December 2012 NPRM proposing mandatory EDR installation in all light vehicles. Agero, whose partners include insurance companies and vehicle manufacturers, communicated how EDR could potentially improve their services, which include collision notification and roadside assistance. On April 25 of the same year, representatives of Bosch also met with NHTSA to discuss the NPRM.

NHTSA issued a “Request for Comment on Automotive Electronic Control Systems Safety and Security” (79 FR 60574) in October 2014. This request acknowledged the NAS 2012 TRB Special Report No. 308, which identified five safety challenges in future electronic control systems and proposed recommendations for addressing those challenges. Among these recommendations, NAS proposed NHTSA ensure commonplace EDR implementation in new vehicles. It was suggested EDR could potentially identify when malfunctions occurred in automotive electronics critical to safety.

On January 6, 2015, the 114th United States Congress held its first session of the new year and introduced H.R. 22: “Fixing America’s Surface Transportation Act”, or the FAST Act. The FAST Act appropriated funds to DOT for infrastructure improvement projects. Within this 490-page Act under Subtitle C “Miscellaneous Provisions” was “Part I – Driver Privacy Act of 2015,” which addressed the ownership of data and outlined data privacy, with specific limitations on the retrieval of data from vehicle EDR. The Act ultimately provided for use of EDR data for ACN system purposes and traffic safety research.

The Driver Privacy Act of 2015, §24303, outlined the planning of a vehicle EDR study, directing the NHTSA Administrator in one year's time to report to Congress the amount of time before and after a crash that EDR should capture data to provide sufficient information to investigate crash causes. It further required the NHTSA Administrator promulgate EDR regulations no more than two years after this initial report.

NHTSA published a notice extending the comment period for “Guidelines for the Safe Deployment and Operation of Automated Vehicle Safety Technologies” (81 FR 31296) in May 2016. NHTSA outlined the topics addressed in public meetings regarding AV-specific guidelines, which included consideration of data-recording capabilities to monitor correct AV system operations as well as appropriate triggers for determining operational status and possible malfunctions in these systems. Data access and privacy concerns were also outlined regarding how the data would be accessed and by whom. Consideration of AV system capabilities for roadway hazard detection and crash mitigation were proposed in addition to methods and documentation that could be produced regarding functional safety and cybersecurity of these systems.

In 2016, NHTSA and FMCSA jointly published the “Parts and Accessories Necessary for Safe Operation; Speed Limiting Devices” NPRM (81 FR 61942). This NPRM required OEMs and CMV carriers install speed-limiting devices for heavy vehicles, identified as multipurpose passenger vehicles, trucks, buses and school buses with GVWR greater than 11,793.4 kg (26,000 lbs), manufactured on or after September 2020 with current consideration for retrofitting older vehicles. The intention was to limit vehicle top speed and provide accountability by incorporating a device that reads the vehicle’s current speed setting and two previous speed settings (records that include date and timestamps of setting changes) through the OBD connection. The costs of compliance were assessed to be minimal given already existing OEM ECU capabilities for limiting vehicle speed. The NPRM did not mention HVEDR but clearly addressed data-recording and monitoring capacities already present in heavy-vehicle OEM ECUs.

NHTSA published a 2017 NPRM, “Federal Motor Vehicle Safety Standards; V2V Communications” (82 FR 3854), for standardizing the message and format of V2V transmissions. The proposed FMVSS 150 required the sending and receiving of Basic Safety Messages regarding vehicle speed, heading, transmission state, stability control status, brake status and other data elements between vehicles in order to warn of hazards and prevent accidents. The NPRM applied only to light vehicles with V2V-communication capabilities.

As of the writing of this report, no current regulations requiring HVEDR are in place in the United States. NHTSA's last discussion of HVEDRs was published in the U.S. DOT *Motorcoach Safety Action Plan* (DOT HS 811 177) in November 2009 and was still outlined as a priority in the "NHTSA Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan 2011-2013" of 2011.

3.3.2 Mexico

In 1990, then-president of Mexico Carlos Salinas de Gortari founded the first-class differentiated service Enlaces Terrestres Nacionales (ETN), who used the first Brazilian Mercedes Benz motorcoaches (Model OM-371 RS and RSD) that included the tachograph as standard equipment. To justify the introduction of this new and largely unknown tachograph to Mexico, Salinas de Gortari pressed the Secretaria de Transportación y Comunicaciónes (Communications and Transportation Secretary) to produce a law regulating the public passenger transportation service.

As a result, the "REGLAMENTO para el servicio público de autotransporte federal de pasajeros" (REGULATION for public service of federal motor transport of passengers in Mexico) was produced and published in the *Diario Oficial de la Federación (DOF; Official Gazette of the Federation)* on May 30, 1990. Mecanica's Spanish-speaking researchers translated and summarized excerpts of the Mexican laws here. Tachographs are treated in the publication's Articles 25, 26 and 38 in the chapter on services.

> ***ARTICLE 25.*** *The first luxury service operates on trips of origin and destination between populations offering the passenger additional services for their comfort; must be provided in an integral bus up to 7 years old, with air conditioning system, reclining seats, sanitary, sound equipment,* **tachograph** *and other characteristics to be indicated by the Secretariat.*
>
> ***ARTICLE 26*** *The first-class service is the one that operates on trips of origin and destination that limits the number of passengers to the number of seats on the bus. It must be an integral bus that has* **tachograph***, air conditioning system, reclining seats, sanitary and other features that the Secretariat indicates.*

In the above cases, the tachograph is mentioned but without explanation for its use or benefits of use.

> ***ARTICLE 38.*** *Vehicles destined for the federal public service must have graphic speed controls. The Secretariat shall issue such provisions as it deems necessary to ensure that the vehicles comply with the authorized speed limits.*

Here, there was no further explanation or other regulations as to the purpose of the graphic speed controls (tachograph) or the manner in which graphic speed controls were to be used for enforcing speed laws.

3.4 International EDR & HVEDR Regulations

On an international level, the only regulations found that were somewhat related to EDR are the European Union and United Kingdom requirements for digital tachographs (or mechanical tachographs for older vehicles).

3.4.1 United Kingdom, European Union & Russia

A literature review of relevant regulations in the United Kingdom, European Union member states and Russia was conducted. The only mandated technology that somewhat resembles EDR or HVEDR is the mechanical or electronic tachograph, the primary purpose of which is to log driver HOS.

European tachograph regulations are defined by Commission Regulation No. 1360/2002, issued June 13, 2002.

In August 2003, the European Commission, under the Competitive and Sustainable Growth Programme of the Fifth Framework, published the *ECBOS - Enhanced Coach and Bus Occupant Safety Final Report*. This project was jointly researched by Technical University Graz (Austria), Cranfield Impact Centre (United Kingdom), Loughborough University (United Kingdom), Gesamtverband der Deutschen Versicherungswirtschaft (Germany), Politecnico di Torino (Italy), TNO Automotive (The Netherlands), and Universidad Politécnica de Madrid - INSIA (Spain).

This ECBOS research was motivated by approximately 20,000 European buses and coaches that were involved in crashes, resulting in 30,000 injuries and 150 deaths. The study’s findings led to various recommendations on bus crashworthiness, addressing compatibility of large truck and bus structures with lower and smaller passenger vehicles, occupant restraints, better crash protection for drivers, rollover mitigation and prevention of occupant ejections (or partial ejections). Also discussed were recommendations for a harmonized bus accident database and guidelines for use of numerical techniques.

Of all safety recommendations made in the 2003 ECBOS report, there was no mention of EDR or HVEDR technology.

The United Kingdom, European Union member states and Russia have no EDR or HVEDR regulations as of the writing of this report.

3.4.2 Japan

Following a January 2015 fatal bus crash in Nagano Prefecture, the Japanese government announced a requirement on March 7, 2016 that all charter buses be equipped with video data recorders.

As of the writing of this report, we have not been able to obtain a copy of the Japan regulations to review and discuss in the findings.

3.4.3 China

At the July 14, 2011 Sixth SHRP 2 Safety Research Symposium, Dr. Yan Wang presented a "National Road Safety Action Plan in China." In this presentation, Wang identified a 2008 cooperative agreement signed among China's Ministry of Science and Technology, Ministry of Transport and Ministry of Public Security. This agreement inaugurated a national highway safety action plan for preventing and decreasing accidents, mass injuries and fatalities and improving pre-warning, control and emergency rescue operations. Technology was cited as the means to achieve four main objectives in support of such goals, namely intervening in traffic participants' behavior, organizing transportation vehicle safety, managing and enforcing road traffic and safety and enhancing road infrastructure safety.

For the first objective of intervening in traffic participants' behavior, the use of technology was suggested to monitor, analyze and intervene in road user behavior; identify and pre-warn commercial vehicle drivers of abnormal roadway conditions; train, test, and manage such technology for drivers; and use the technology to communicate and educate on road safety. Secondly, technology was suggested for organizing vehicle safety and transportation by monitoring commercial vehicle operations and inspecting vehicle safety performances. Thirdly, technology was to be used in road traffic and safety management by enhancing emergency rescues, more rapidly dealing with serious traffic accidents, enhancing accident analysis and reconstruction, and identifying and controlling traffic violations. Finally, improving road infrastructure safety could be achieved through technology-enhanced safety assessments during road design and operation periods, monitoring operations and emergency management for large bridges and tunnels, diagnosing road infrastructures for repairs, and monitoring and warning traffic of adverse weather conditions.

A research phase from 2009 to 2011 funded by local and central governments sought to implement large-scale demonstration projects across a 5000-kilometer road network to establish a series of road-safety technology specifications into a sustainable action plan. Five provinces participated in commercial vehicle safety inspections and remote traffic safety education and training. An integrated traffic accident database belonging to police and highway agencies was developed, as were vehicle operation-monitoring technologies. The presentation proposed its objectives for the next phase of research. Major targets for the new safety infrastructure were expressways, rural and low-volume roads, and commercial vehicles, with a vision for implementing this infrastructure in the internet of things, Beidou Navigation System, and driver behavior interventions.

As of the writing of this report, the Mecanica research team has made several unsuccessful attempts to make contact and discuss EDR research or regulatory activities in China.

3.4.4 Middle East Region

In Israel, the Ministry of Transport (MOT) is a government entity whose stated objectives are to plan and develop the national transportation network, with emphasis on increased safety, security and efficiency; to integrate transport solutions; to ensure sustainable transport systems; and to utilize advanced technologies in the operation of transport facilities. In the 2006 document, “Intelligent Transportation Systems [ITS] in Israel,” MOT’s Chief Scientist Zeev Shadmi identified ITS initiatives of interest.

One initiative focused on fleet management systems. It identified on-board units such as GPS, CAN-bus and cellular modem systems equipped in dozens of fleets and thousands of vehicles. Additionally, an electronic driver’s assistant and the use of “IVDR” were highlighted for fleet safety management.

In-vehicle data recorder (IVDR) impact had been studied by Toledo and Lotan at the Technicon-Israel Institute. Their 2006 publication “In-Vehicle Data Recorder for Evaluation of Driving Behavior and Safety” detailed a prototype IVDR that would monitor vehicle motions and driver inputs to study driver behavior and vehicle collisions for improved safety. The study implemented IVDR not only to monitor driver behavior during crash-relevant events but to monitor normal, non-collision driving behavior as well. The researchers found a “significant positive impact” on driver safety during the initial exposure to IVDR feedback but discovered the influence on driver behavior diminished after five months. The researchers’ conclusions that IVDR can affect driver behavior and therefore highway safety if drivers are exposed to consistent feedback from data recorders aligned with contemporaneous findings from the SAMOVAR Drive II Project of 1992-1995.

Presenting the ITS initiative addressing electronic driver’s assistants and IVDR, Shadmi highlighted GPS, accelerometers (x, y), and cellular modem for their real-time measurements of speed and accelerations and ability to determine excessive maneuvers. Safety officer interventions were highlighted, and a large-scale field operational test involving two service suppliers and 900 vehicles belonging to five organizations was indicated.

At the time of the presentation, an ongoing eSafety research and development program hosted by the Ministry of Science and Technology was cited and said to focus on such developments involving Mobileye, Roadeye, and the “Aider” (eCall) E.U. FP5 project technologies, with a commercial market for the eCall service.

These initiatives were identified as contributing to an Israeli national ITS policy and framework architecture adapting the European ITS FRAME or U.S. DOT architectures. ITS standards were to be developed by the Israel Institute of Standards expert committee with a view towards cooperation with the European Union in ITS e-Safety.

An effort was made to research government initiatives to study collisions, driver safety and EDR type devices in Turkey, Saudi Arabia, Kuwait, Qatar and the United Arab Emirates. To date, no information was found on this topic.

3.4.5 Australia

Australia's National Transport Commission (NTC) is an independent research body legislatively chartered to counsel Australian intergovernmental transportation authorities on regulations and operational reforms across road, rail and intermodal transport. The 2014 publication *Delivering a Compliance Framework for Heavy Vehicle Telematics, Final Policy Paper* sought to establish a framework maximizing the commercial and safety benefits of in-vehicle telematics in accordance with safety and regulatory compliance.

The paper highlighted that Australian freight and bus industries had already been equipped with telematics devices to improve on-road safety and efficiency. In 2011, NTC made recommendations for developing an enforcement policy that would support industry uptake of telematics, followed by a 2012 proposal for ensuring ITS in each jurisdiction were compatible and a set of agreed compliance and enforcement principles was established. The proposal for a compliance framework began with a *Discussion Paper* released in 2013 with the stated vision:

> *Widespread use of in-vehicle telematics supported by responsive management and reporting systems has delivered better levels of regulatory compliance. This has led to increased accountability and self-regulation within industry and allowed more targeted enforcement of high-risk operators. Overall this has made a significant contribution to lowering crash rates among heavy vehicles, improving productivity and lowering their environmental impact.*

The framework's objectives were threefold. The first objective was to provide a resource for public authorities to assess risks and identify high-risk operators and for businesses to harness telematics to improve driver performance. The second objective aimed to establish a common dataset based on international standards that would achieve a "privacy-by-design mechanism" to ensure only pertinent telematics data needed for a regulatory task is accessed. A common dataset and data dictionary were drafted and included the recording of work and rest hours, vehicle and consignment location logging, and mass and speed monitoring, with the ability for alternative standards to be integrated into the common dataset.

The third objective established 10 Principles for the development of this common dataset, eight of which addressed responsibility and public accountability for use of such data by authorities. The remaining two addressed the dataset's purpose of interoperability and universality across commercial and compliance applications for the fundamental goal of improving safety.

The NTC's 2014 *Final Policy Paper* reaffirmed its 2013 *Discussion Paper* position, which concluded that a general framework was not the appropriate means for assessing regulatory impacts of mandatory telematics. Instead, NTC argued that a cost-benefit analysis must validate the need for mandatory telematics, for which they found insufficient evidence to recommend mandatory telematics generally. NTC concluded that although telematics monitoring speed and fatigue provided some operators with a means of ensuring driver safety, government does not typically intervene in commercial decision-making. Hence, the industry should explore commercial contracting arrangements to encourage greater uptake of telematics in the transport supply chain. NTC concluded that a more specific regulatory application would have to be identified to justify a regulation-mandated telematics policy although voluntary commercial uptake of telematics in line with the proposed framework was recommended.

3.5 Data Accuracy

Since model year 2000, a vast majority of commercial trucks and buses have been equipped with OEM HVEDR functions that have the capability of recording extensive data when triggered by aggressive braking ("hard brake") events or collision events with or without braking. Some of these HVEDR functions can also trigger data recordings for "last stop" events, simply defined as the vehicle coming to a complete stop. Regarding a last stop event, some HVEDR functions may or may not require a time period for the vehicle to be stopped, for the application of the parking brake or for turning the ignition off.

It is important to distinguish that a majority of HVEDR-type data in the United States is sourced from OEM-supplied HVEDR. OEM-supplied HVEDR functions utilize the vehicle's factory-equipped ECU, communications network and sensors; therefore, no additional equipment is purchased or installed in the vehicle.

The following discussion of data sources and their reliability and accuracy focuses on data sources for OEM-supplied HVEDR specifically.

Within the NAFTA market, there exist commercial fleet aftermarket tracking/dispatch devices and ELDs that record incident-specific records such as "harsh brake" events or "critical event" reports. These systems do not rely on their own sensors to record data elements such as vehicle speed, engine speed, percent throttle, brake, clutch and engine brake application. Rather, these systems tap into the vehicle's CAN bus (or J1587 serial bus for older vehicle models) and are configured to monitor these channels for data over the J1939 CAN bus (or J1587 serial bus).

For these aftermarket devices with HVEDR functionality, the recorded speed data may be sourced from the vehicle's own VSS over the vehicle's J1939 CAN or J1587 serial bus. Alternatively, the vehicle speed data may be calculated from the aftermarket HVEDR's GPS vehicle position data. Some systems also allow switching between local bus-sourced data when the GPS signal is weak back to GPS-calculated speed automatically.

The Mecanica Scientific research team has conducted extensive testing and evaluation of GPS-based telematics data to examine the accuracy and reliability of the GPS-calculated vehicle speed. GPS position and calculated vehicle speed reliability and accuracy are a dynamic function of the GPS signal strength and operating mode of the vehicle. Mecanica's findings on the accuracy and reliability of GPS position and calculated vehicle speed are discussed further in this section.

Three main questions should be asked regarding the accuracy of reported data from HVEDR:

1. Is the data from a particular vehicle?
2. Is the data from a particular event?
3. How accurate is the data?

The following sections address these questions and provide methods and solutions for determining HVEDR data accuracy.

3.5.1 Vehicle Data Sources

Several different data types are stored and recorded within the ECU of NAFTA-market heavy vehicles. A multitude of sensors and data sources work in tandem to capture this information and make it readily available for imaging. Chief among these sensors are the vehicle speed sensor, engine speed sensor, accelerator pedal position sensor, brake pedal position sensor and the clutch pedal position sensor. Below are brief descriptions and figures of each.[26]

The VSS is generally mounted on the tone ring located at the rear of the transmission, which must be in rotation to generate a signal for the VSS to send to the ECU. The VSS data is broadcasted as an AC voltage signal (sine wave) and represents a value of pulses/revolution, which is converted to kph (or mph) by the ECU.

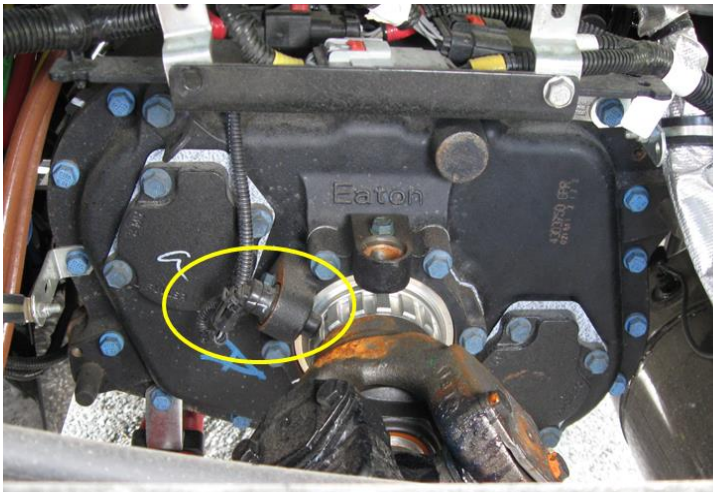

Figure 3.5.1-1. Vehicle speed sensor

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[26] Ibid., Module 1.

The engine speed sensor is mounted on the rear of the engine and functions much like the VSS by measuring the rotation of the engine's crankshaft at the flywheel to calculate the engine's rotational speed in revolutions per minute (rpm).

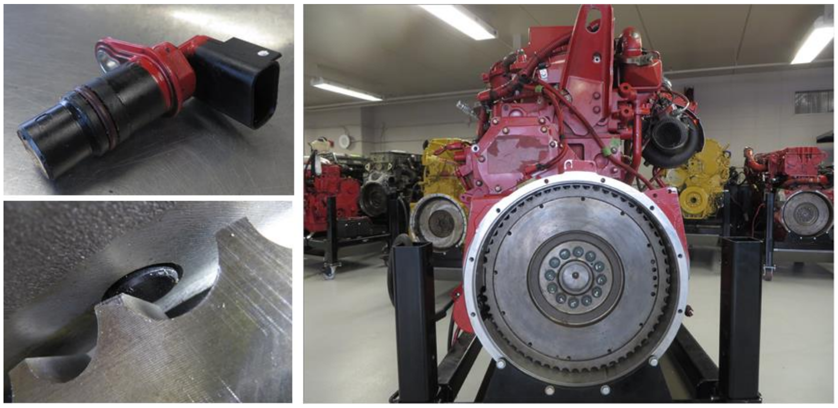

Figure 3.5.1-2. Engine speed sensor

The accelerator pedal position sensor is typically mounted on or near the accelerator pedal and outputs a voltage proportional to the percentage of pedal application.

Figure 3.5.1-3. Accelerator pedal position sensor

The clutch pedal position sensor is also mounted near the pedal itself, but it essentially functions as an ON/OFF switch to record pedal application.

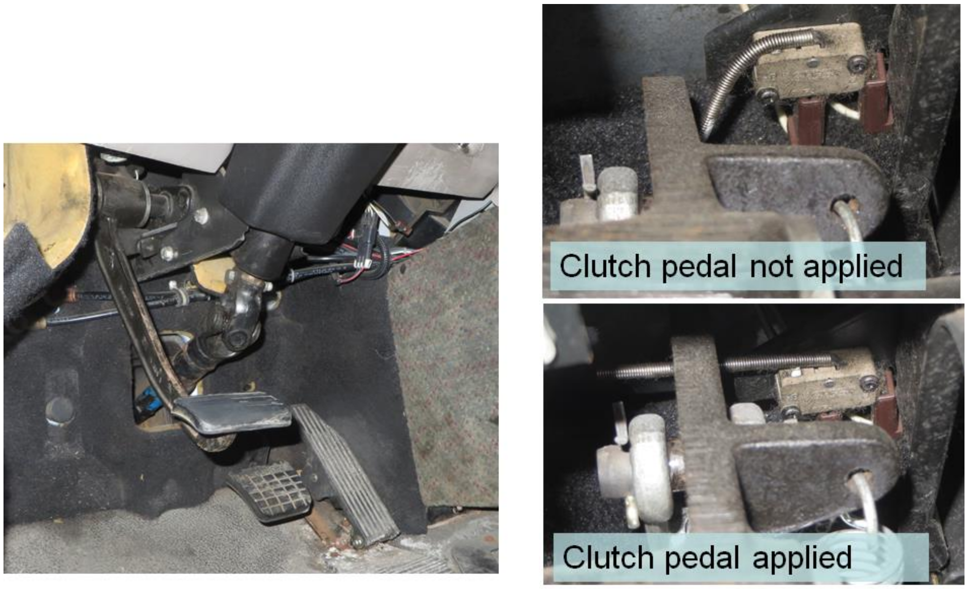

Figure 3.5.1-4. Clutch pedal position sensor

The brake pedal position sensor is installed in line with the air system of the vehicle, and it too functions as an ON/OFF switch.

In order to verify the accuracy of data imaged from HVEDR, the programmed parameters must be compared to the physical characteristics of the vehicle.[27] Physical inspections should document numerous data sources on the vehicle, including the placards located inside the vehicle, such as door placards (Figures 3.5.1-5 and 3.5.1-6), dash placards and “glove box” placards. These placards indicate the Vehicle Identification Number (VIN), build date and recommended tire size. The engine placard (Figure 3.5.1-7) indicates the engine model, unit/serial number and build date; the ECU placard (Figure 3.5.1-8) indicates its model, part number, serial number and engine serial number; the transmission placard (Figure 3.5.1-9) indicates the model and serial number; the drive axle differential placard (Figure 3.5.1-10) indicates the axle’s model, serial number, ratio and build date; and the drive axle/axles tire sidewall will indicate the tire size, load range and DOT number.

Data imaging provides the programmed parameters for the engine ECU, such as the VIN, which should match what was found on the vehicle. All parameters must be cross-checked against the data gathered from the physical inspection to ensure the programmed parameter values match those found on the vehicle.

If requested, many heavy vehicle dealers will provide the build sheet of the vehicle, which provides much of the data required to cross-check the ECU programmed values and those found during

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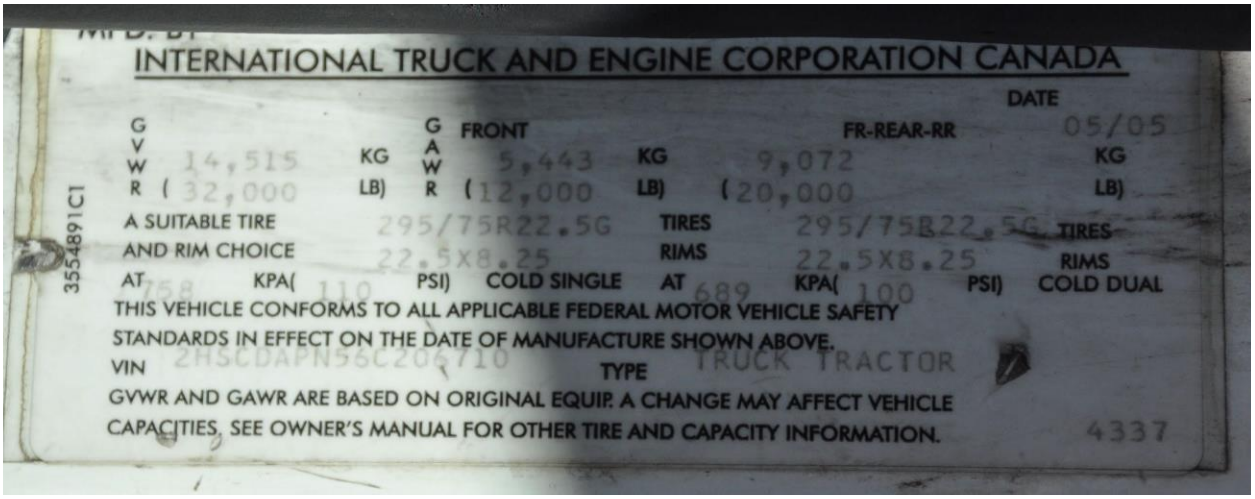
[27] Steiner, J., Cheek, T., and Hinkson, S., "Data Sources and Analysis of a Heavy Vehicle Event Data Recorder – V-MAC III," *SAE Int. J. Commer. Veh. 2*(1):49-57, 2009; see also Bayan, F. P., Cornetto, A. D., Dunn, A., Tanner, C. B., et al., “Comparison of Heavy Truck Engine Control Unit Hard Stop Data with Higher-Resolution On-Vehicle Data,” *SAE Int. J. Commer. Veh. 2*(1)*. 2*:29-38, Apr. 2008.

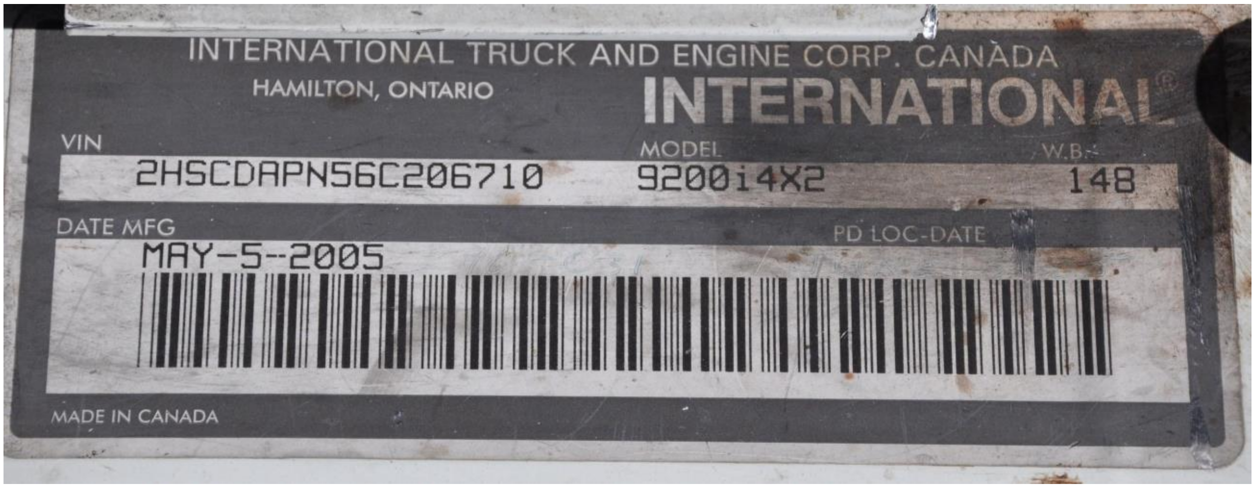
the physical inspection. The build sheet can also be used to determine whether modifications have been made to the vehicle since its initial sale.

The purpose of determining the programmed and actual tire size, transmission and rear end ratio is to correct the data when calculating actual road speed. The tire and transmission manufacturers have published data, available on the internet, specifying revolutions per mile and gear ratios depending on the type of transmission. These values can be used to cross-check the programmed ECU values to ensure data accuracy.



INTERNATIONAL TRUCK AND ENGINE CORPORATION CANADA
DATE 05/05
GVWR 14,515 KG (32,000 LB)
GAWR FRONT 5,443 KG (12,000 LB) FR-REAR-RR 9,072 KG (20,000 LB)
A SUITABLE TIRE AND RIM CHOICE 295/75R22.5G TIRES 22.5X8.25 RIMS AT 758 KPA(110 PSI) COLD SINGLE
295/75R22.5G TIRES 22.5X8.25 RIMS AT 689 KPA(100 PSI) COLD DUAL
THIS VEHICLE CONFORMS TO ALL APPLICABLE FEDERAL MOTOR VEHICLE SAFETY STANDARDS IN EFFECT ON THE DATE OF MANUFACTURE SHOWN ABOVE.
VIN 2HSCDAPN56C206710 TYPE TRUCK TRACTOR
GVWR AND GAWR ARE BASED ON ORIGINAL EQUIP. A CHANGE MAY AFFECT VEHICLE CAPACITIES. SEE OWNER'S MANUAL FOR OTHER TIRE AND CAPACITY INFORMATION.
4337
3554891C1

Figure 3.5.1-5. Door pillar placard - example 1



INTERNATIONAL TRUCK AND ENGINE CORP. CANADA
HAMILTON, ONTARIO
INTERNATIONAL®
VIN 2HSCDAPN56C206710
MODEL 9200i4X2
W.B. 148
DATE MFG MAY-5--2005
PD LOC-DATE
MADE IN CANADA

Figure 3.5.1-6. Door pillar placard - example 2

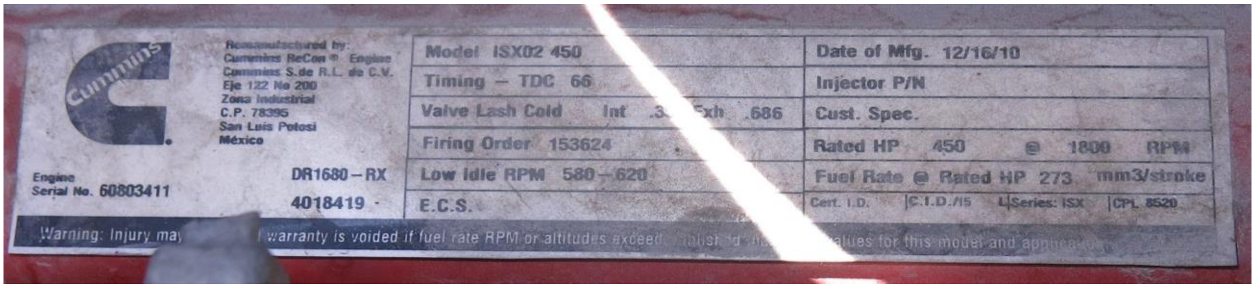


Figure 3.5.1-7. Engine placard

Figure 3.5.1-8. ECU placard

Figure 3.5.1-9. Transmission placard

Figure 3.5.1-10. Drive axle differential placard

This identification data for the vehicle's chassis and serial numbers for the engine, transmission and axle are also used to verify that a data set imaged (downloaded) from a particular vehicle can be verified by the VIN, the engine verified by the engine serial number and the particular ECU verified by the ECU serial number(s).

3.5.2 Vehicle Events

Most over-the-road heavy vehicles have the capability of recording incident-specific data such as hard brake or last stop events. A hard brake event is triggered as a result of a rapid deceleration of the vehicle that exceeds the programmed speed change threshold. A last stop event is triggered when the vehicle comes to a complete stop. These events are triggered and captured differently among various engine manufacturers, such as Detroit Diesel and Cummins. Many engine manufacturers also include the capability for recording diagnostic trouble code (DTC) snapshots, which are triggered when a particular DTC goes active. These events are often marked by timestamps that also feature engine distance.

The table below briefly summarizes the data each engine module is capable of recording. Note that each engine manufacturer uses their own nomenclature for the aforementioned incident-specific events, such as “quick stop” or “fast stop” for hard brake events, and “freeze frames” or “fault reporter” for DTC snapshots.[28] Event triggers also vary in recording frequency and triggering thresholds.

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[28] Austin, T., Cheek, T., Plant, D., Steiner, J., and Lackey, L., “SAE C1022,” Modules 4-10.

Table 3.5.2-1. Data-Recording Capabilities

Engine Manufacturer	**Data-Recording Capabilities**
Detroit Diesel	Two Hard Brake Events (1998 – present) One Last Stop Event (1998 – present) Three Diagnostic Records (1998 – 2007 & 2010 – present)
Cummins	Three Sudden Deceleration Events (2005 – present) Fault Code Snapshots (1998 – present)
Caterpillar	Quick Stop Events (2007 – present)* Diagnostic Snapshots (1995 – present) External Triggers (1995 – present)
Mack	One Acceleration Triggered Event (1998 – present) One Last Stop Event (2007 – present)** Fault Reporter (1998 – present) Prior to 2007 it was possible for Mack trucks to record two acceleration triggered events instead of one of each.
Volvo	One Acceleration Triggered Event (2011 – present) One Last Stop Event (2011 – present) Freeze Frames (2002 – present)
International/Navistar Maxxforce	Two Hard Brake Events (2010 – present) Two Last Stop Events (2010 – present) Freeze Frames (2010 – present)
PACCAR	Three Fast Stop Events (2008 – present) Freeze Frames (2008 – present)

As aforementioned, these incident-specific events are time-stamped as shown in Table 3.5.2-2, which summarizes how each engine manufacturer stamps their incident-specific events.[29]

Timestamps are either in the form of an actual date and time or a relative timestamp, such as an hour meter or odometer value at the time of the incident log recording.

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*Quick Stop Events possible since 1995 but not factory-enabled until 2007.

**Depends on VECU software version.

[29] Ibid.

Table 3.5.2-2. Timestamp Capabilities

Engine Manufacturer	**Incident-Specific Event Stamps**
Detroit Diesel	Date and Time Odometer
Cummins	Odometer ECM Run Time
Caterpillar	Date and Time Engine Hours
Mack	Date and Time Odometer
Volvo	Date and Time Odometer
International/Navistar Maxxforce	Date and Time ECM Total Distance and Trip Distance Engine Hours
PACCAR	Odometer Engine Hours

By utilizing these timestamps, a hard brake, last stop or DTC snapshot event can be tied to a specific incident. Generally, the time of an accident is known to a certain degree of accuracy. This can be checked against the date and timestamp of an incident-specific event to verify its relevance. The engine hours or odometer values may also be helpful in cases in which a vehicle has been towed or has not been moved since the accident occurred. In such cases, an incident-specific odometer stamp can be checked against the odometer value of the subject vehicle to verify whether the event is related to the accident. Prior to applying this methodology, the incident specific-events and timestamps must be verified for accuracy and checked for data anomalies.

Over the years, engine manufacturers have continuously updated and revised their ECU and software technologies, leading to varying data availability depending on the engine build date. For instance, there have been several generations of Detroit Diesel series ECUs and software, including DDEC III, DDEC IV, DDEC V, DDEC VI, DDEC 10, DDEC 13 and DDEC 16. Other engine manufacturers have followed this same iterative design process as their technology improves. This data is made available to trained analysts through proprietary software but must be tested independently to validate accuracy.[30] As with other developing technologies, there are known and documented error issues with respect to incident-specific events and timestamps. Austin and Farrell documented one such case in their 2011 paper “An Examination of Snapshot Data in Caterpillar Electronic Control Modules.” See Appendix C for tables excerpted from their

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[30] Plant, D., Cheek, T., Austin, T. P., Steiner, J., et al., “Timing and Synchronization of the Event Data Recorded by the Electronic Control Modules of Commercial Motor Vehicles - DDEC V,” *SAE Int. J. Commer. Veh. 6*(1):209-228, 2013.

work that summarize data anomalies that can be found when imaging data from various Caterpillar ECUs.

Another documented data issue involved Cummins engine ECUs and was explored by Bortolin, van Nooten, Scodeller, Alvar, et al. in the 2009 paper “Validating Speed Data from Cummins Engine Sudden Deceleration Data Reports.” The data anomaly was a calibration error that caused the Sudden Deceleration report to record data every 0.2 seconds instead of every 1 second. Ordinarily, a Cummins Sudden Deceleration report will record 59 seconds of pre-trigger data and 15 seconds of post-trigger data. However, if affected by this timing issue, the report will only record 11.8 seconds of pre-trigger data and 3 seconds of post-trigger data. Although the x-axis data values will be correct, the time scale will be artificially compressed. This issue can affect the Sudden Deceleration records of ISX 07 and ISM 07 engines that were built for the 2007 EPA certification. Furthermore, this issue should only affect ECUs that are programmed with ECU codes “AT” or “AV.”

These types of data anomalies highlight the need for third-party data validation to ensure accuracy and proper reporting methods prior to utilization. Notwithstanding, vehicle event data is accurate and can prove invaluable in an investigation when properly interpreted.[31]

This highlights a pertinent point to be discussed later in the research regarding the importance of up-to-date, recurrent training for highway safety investigators, law enforcement officers and accident reconstructionists to keep pace with this data technology.

3.5.3 Data Elements, Vehicle & Event Identification Accuracy

The previous sections explored the types of incident-specific events that can be stored by OEM ECUs. The process of accurately identifying whether the data belong to a particular vehicle as well as if a particular incident-specific event is relevant was also discussed. The question that remains is whether the data are accurate. A few previously presented cases demonstrated how certain data can experience anomalies based on the engine manufacturer. This section will further explore those anomalies and how to account for them in order to interpret the data retrieved from the vehicle accurately.

One of the most important features of incident-specific event data is that the data are time-stamped. The majority of ECUs have an internal clock that time-stamps these events when triggered. This clock, if equipped, is in turn used by the analyst to determine whether an event is relevant to the incident under investigation. In order to do so, the clock must first be verified as accurate. A common occurrence with internal ECU clocks is that, if not consistently updated, they eventually fall out of sync with “real time,” a phenomenon called *clock drift*. There are a number of ways to account for clock drift when analyzing event data. The most efficient way is to synchronize the clock of the laptop used to image the data to UTC time and a known accurate clock such as a sync with the U.S. NIST atomic clock server or a Microsoft Windows time server

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[31] Lee, W. and Han, I., "Development of an Event Data Recorder and Reconstruction Analysis," SAE Technical Paper 2004-01-1180, 2004.

sync via the Windows operating system. Using this method, the internal clock of the ECU can be compared against the synchronized clock of the laptop to determine the degree of clock drift. Relatedly, one must be aware of the ECU clock's time zone when verifying the clock's accuracy. Different engine manufacturers time-stamp incident-specific events with different time zones, which must be accounted for when determining the relevance of an event.

In some cases, the internal clock of an ECU may be off by several days, weeks, or even years. When this occurs, additional factors, including Daylight Savings Time and leap years, must be taken into account. Cases such as this make it imperative that clock drift be accurately calculated and rectified to prove that an event is relevant as a single missed day could lead to improper data interpretation.

In addition to internal ECU clock timestamps, other parameters can be used to determine the relevance of an incident-specific event. As previously listed, these parameters include odometer values, engine hours, ECU distance, and ECU hours. These parameters supplement the internal ECU clock date and timestamps and, in some cases, are the only method for determining the relevance of an event. Cummins engines, for instance, do not stamp their Sudden Deceleration events with a date and timestamp; rather, the field for the occurrence date is marked "N/A." Instead, the Cummins ECU documents runtime at occurrence in hours, minutes and seconds and the occurrence distance in miles. By comparing these parameters to the total values listed in the data, an incident-specific event can be determined to be relevant or not.[32]

Once the data have been validated, they can be analyzed to help understand the nature of the incident under review. Of particular interest is the vehicle speed record. This detail is typically found in the hard brake and last stop data records. Additionally, fault code records can include speed data related to the incident under study.

In particular, the vehicle speed, along with other recorded values, can be utilized to set up a time history analysis of the incident under study. Most incident-specific events will record data at 1 Hz and generally record between 1 to 2 minutes of data. The exact manner of recording data varies among engine manufacturers but generally contains some form of speed data. For example, Detroit Diesel records two hard brake and one last stop event. The hard brake events record 60 seconds of activity prior to the trigger and 15 seconds after the trigger while the last stop event will record 1 minute and 44 seconds prior to stopping and 15 seconds after. Both of these events record in 1-second intervals.[33] Volvo records one acceleration triggered event and one last stop event, both of which record 90 seconds of data at quarter second intervals. However, the acceleration triggered event records 60 seconds of data prior to the trigger and 30 seconds after, whereas the last stop event records 90 seconds of data prior to stopping and no post-trigger data.[34]

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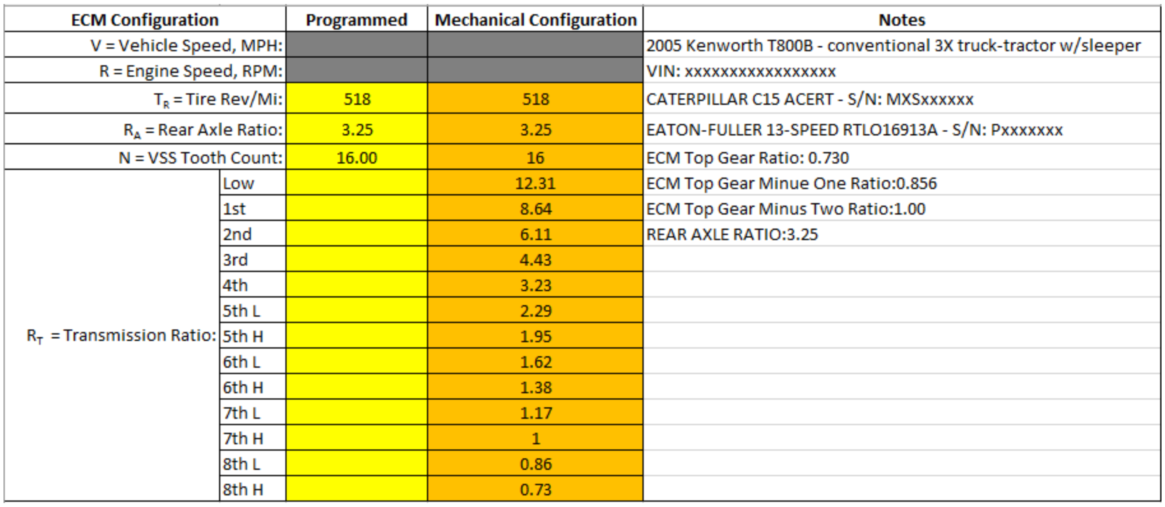
[32] Austin, T., Cheek, T., Plant, D., Steiner, J., and Lackey, L., "SAE C1022," Module 14.

[33] Ibid., Module 4.

[34] Ibid., Module 8.

As previously noted, vehicle speed is a crucial component of the ECU data-imaging record and the investigation and analysis of incident-specific events. Therefore, it is important to verify that the speed data is correct with respect to all elements of the investigation, such as vehicle configuration, physical evidence and witness testimony. To verify the speed data, a comparison of the mechanical configuration of the vehicle and the ECU programmed parameters is required. During a physical inspection of the vehicle, the transmission tag, the tone ring mounted on the rear of the transmission, the VSS mounted on the tone ring, the rear axle tags and the drive axle tires should all be documented. As the device that measures the speed of the vehicle, documentation of VSS is critical. On manual transmission vehicles, the VSS is typically mounted on the drive shaft. During vehicle operation, this tone ring rotates, and the VSS creates a digital signal measured in pulses/second. The VSS tooth count value is programmed into the ECU, which in turn calculates the pulse/second value. The ECU then divides the programmed pulse/second by pulse/mile to determine the speed in mph. The pulse/mile value is also a programmed value within the ECU. Mechanically speaking, the value is calculated by multiplying the rear axle ratio by the tire revolutions per mile then by the VSS tooth count. Different engine manufacturers will report this information differently in the data-imaging report. Volvo, for instance, reports only the pulse/mile while Cummins lists the rear axle ratio, tire size and tooth count individually. To verify the reported speed values in an event, the mechanical values and the ECU values have to be compared.

As described above, all ECU values are reported within the data in one form or another. The mechanical values of the vehicle must be documented during the physical inspection. The tire revolutions per mile is based upon the make, model, size, and load range of the tire, and the revolutions per mile are provided by the tire manufacturer. The same is true of the transmission gear ratios. Once found, all these values can be compared to determine speed accuracy. Figures 3.5.3-1 and 3.5.3-2 below demonstrate one way to compare these values using a spreadsheet program and speed calculation formula.



ECM Configuration		Programmed	Mechanical Configuration	Notes
V = Vehicle Speed, MPH:				2005 Kenworth T800B - conventional 3X truck-tractor w/sleeper
R = Engine Speed, RPM:				VIN: xxxxxxxxxxxxxxxxx
T_R = Tire Rev/Mi:		518	518	CATERPILLAR C15 ACERT - S/N: MXSxxxxxx
R_A = Rear Axle Ratio:		3.25	3.25	EATON-FULLER 13-SPEED RTLO16913A - S/N: Pxxxxxxx
N = VSS Tooth Count:		16.00	16	ECM Top Gear Ratio: 0.730
R_T = Transmission Ratio:	Low		12.31	ECM Top Gear Minue One Ratio:0.856
	1st		8.64	ECM Top Gear Minus Two Ratio:1.00
	2nd		6.11	REAR AXLE RATIO:3.25
	3rd		4.43	
	4th		3.23	
	5th L		2.29	
	5th H		1.95	
	6th L		1.62	
	6th H		1.38	
	7th L		1.17	
	7th H		1	
	8th L		0.86	
	8th H		0.73	

Figure 3.5.3-1. Spreadsheet with mechanical and programmed speed calculation parameters[35]

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[35] Ibid., Module 15.

V = Vehicle Speed, MPH
R = Engine Speed, RPM
PPM = Pulses Per Mile
T_R = Tire REV/MILE (Provided by Tire Manufacturer)
R_A = Rear Axle Ratio
R_T = Transmission Ratio
N = VSS Tooth Count

Calculating PPM	Calculating V from R:
$PPM = T_R \times R_A \times N$	$V = \dfrac{(R) \times \left(\frac{60\ min}{1\ hr}\right)}{(T_R \times R_T \times R_A)}$

Figure 3.5.3-2. Speed calculation formulas[36]

The result is a VSS calibration analysis comparing the mechanical vehicle speed to the ECU reported speed plotted against the engine rpm. An example of the speed value comparison is depicted in Figure 3.5.3-3. The calculated tabular values are typically plotted graphically in a saw-toothed graph.

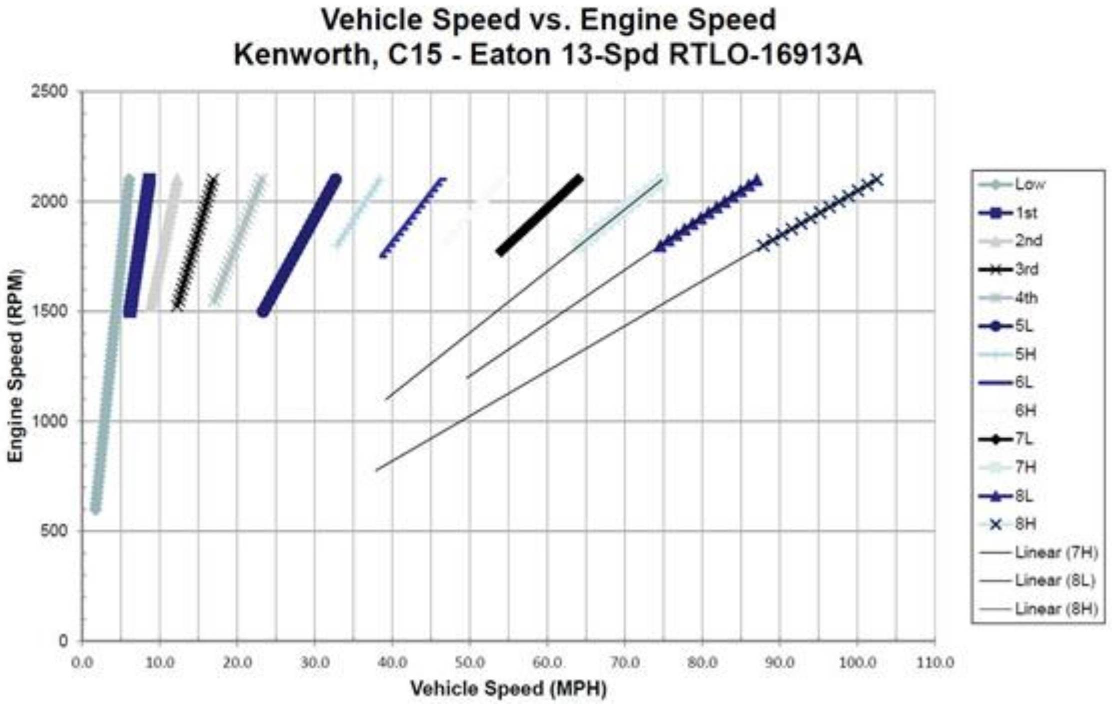

Figure 3.5.3-3. Speed calculation sawtooth graph[37]

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[36] Ibid.

[37] Ibid.

In the case depicted in Figure 3.5.3-3 above, the mechanical and ECM values match, thus verifying the ECU determined values and the accuracy of the imaged ECU data. However, values do not always match, perhaps due to mismatched programmed parameters such as tire revolutions per mile or rear end ratio. Considering the distance that heavy vehicles travel in their lifetime and the fact that components such as tires must be replaced, it is not unusual that the actual over-the-road speed values may differ from those determined by the ECU. If different tires are used, especially tires of different sizes, the speed of the vehicle may be under- or overreported. This only occurs if the ECU is not properly reprogrammed when new tires are installed on the vehicle. A considerably large change in tire revolutions per mile would be required to produce such an issue with the vehicle's speed reporting. If the rear axle is replaced without updating the ECU, however, this could cause a major error in speed reporting by the ECU, given that the ratio is different from what was originally programmed and built on the vehicle. This further reinforces the importance of data accuracy and verification.

Certain conditions, such as wheel slip, can directly affect and degrade the accuracy of the recorded wheel speed. Wheel slip occurs when the force applied to a tire exceeds the traction available between the tire and roadway interface. This is commonly referred to as "skidding." The main implication wheel slip has on recorded data is that the speed may be underreported. Studies have shown that vehicle speed recorded by HVEDR is underreported when the VSS senses a slowdown due to wheel lock-up/drive shaft lock-up while the vehicle is skidding. This results in the vehicle moving/skidding at a speed greater than the speed reported by the ECU. The analyst must be aware that this phenomenon exists and determine how to address the problem. Numerous published technical papers (provided in Deliverables No. 1 and 2) treat this issue and present methodologies, such as calculating a slip number, to correct the data when a wheel slip has occurred. It should be noted that the percent error dramatically increases for speeds under 5 mph. The reported speed of a vehicle below 5 mph is overreported when compared to the actual ground speed, which is mainly due to the low operating speeds involved and any noise sourced from vibration or suspension effects. It should also be noted that a Sudden Deceleration record would not be produced if the vehicle never exceeds the programmed trigger threshold for a hard brake event.[38]

Absent significant wheel slip and whether the truck or bus's VSS is properly calculated, recorded vehicle speeds at typical highway speeds can generally be as accurate as +/- 0.40 kph (0.25 mph).

Another aspect of event data accuracy that has been studied is the synchronicity of the data elements for an incident-specific event. Testing has been completed to assess the synchronization and timing of various event data for HVEDR vehicles. One series of tests in particular involved the DDEC V ECU from a Detroit Diesel powered engine. These tests were completed, recorded and reported by Austin, Cheek, Farrell, Plant, et al. in the 2013 paper "Timing and Synchronization of the Event Data Recorded by the Electronic Modules of Commercial Motor Vehicles - DDEC V." Although the hard brake and last stop events of a DDEC V record data at 1

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[38] Steiner, J., Cheek, T., and Hinkson, S., "Data Sources and Analysis"; see also Messerschmidt, W. and Muttart, J., "A Statistical Analysis of Data from Heavy Vehicle Event Data Recorders," *SAE Int. J. Commer. Veh. 2(*1):39-48, 2009.

Hz, the information is actually broadcast over J1939 CAN at higher rates. For instance, vehicle speed is transmitted at 10 Hz while percent accelerator pedal position is transmitted at 20 Hz. In order to observe these differing broadcast rates, the following steps were taken. To assist in determining timing and synchronicity issues, one procedure installed a switch to simultaneously change signals. With the DDEC V, a four-pole double throw (4PDT) switch was used to distinguish differences between the sensor information, J1939 CAN transmissions and HVEDR data with respect to timing and synchronization. The data were gathered using a VBOX III GPS 100 Hz Data Logger.

After the data were collected, a potentially substantial lag between when the voltage is delivered from the throttle position sensor (TPS) to the ECU was noted. This lag over the vehicle's J1939 CAN was found to be as long as 0.73 seconds. In addition, the minimum time between reported changes in value for engine speed was 0.01 seconds or less due to limitations in the study. Various tests were run on other parameters, which concluded that, for most sensors, there is a lag between 0.01 seconds and 2 seconds.

These findings further emphasize the need for independent testing and verification of data, particularly for incident-specific events.[39]

4.0 CONCLUSION

This literature review concludes *T8080-160062 Transport Canada Commercial Bus HVEDR Feasibility Study,* Deliverable No. 3: "Summary Report of Facts." The Summary Report reviewed technical papers, studies, reports and regulations pertaining to HVEDRs as they may be found in buses, motorcoaches or school buses. This report also reviewed the extensive research and publications found regarding HVEDR technology, including data elements, data limitations and accuracy of HVEDR-sourced data, as well as studies pertaining to the potential impact EDR and HVEDR have on highway safety, their deployment in a commercial fleet, and the observed improvements in that commercial fleet's accident rates and driver safety. Finally, legal implications and international regulations were briefly reviewed.

Journey recorders and tachographs are predecessors of EDR/HVEDR technology. Unlike EDR/HVEDR, which must be triggered by a pre-programmed event to start recording data, journey recorders and tachographs consistently record over time and log such information as driver's rest periods and vehicle speed. Currently, only electronic tachographs have been standardized and mandated in commercial trucks, coaches, and buses in the United Kingdom and European Union member states.

North American regulations have proceeded in the direction of standardizing mandatory HVEDR technology in trucks, motorcoaches, and buses. Since model year 2000, a vast majority of commercial vehicle trucks and buses have been equipped with OEM HVEDR-type functions capable of recording extensive data when triggered by hard brake or other collision events. A

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[39] Plant, D., Cheek, T., Austin, T. P., Steiner, J., et al., "Timing and Synchronization."

majority of HVEDR-type data in the United States is sourced from OEM-supplied HVEDR, which functions by utilizing the vehicle's factory-equipped ECU, communications network and sensor; no additional equipment is purchased or installed on the vehicle. Within the NAFTA market, there also exist commercial fleet aftermarket tracking/dispatch devices and ELDs that can record incident-specific data. These systems do not use their own sensors but rather tap into the vehicle's CAN bus and are configured to monitor these channels for data.

Over the years, engine manufacturers have continuously updated and revised their ECU and software technologies, leading to varying data availability depending on the engine build data. Many manufacturers have used this iterative process as their technology improves, and continuous updates to ECU software technologies lead to varying data availability. Standardized data retrieval methods, standardized data formats, and universal hardware have been proposed to maintain data quality, which may also address data anomalies in event record databases. Of additional concern is maintaining data integrity when transferring data from accident-involved vehicles to databases. It has been proposed that the potential for data- and database-related errors may be addressed by stronger third-party calibration and verification protocols; such measures are important when considering data aggregation for shared national and international crash-accident database systems to be accessed by emergency responders, researchers and state and federal authorities.

As rights to privacy in the United States and Canada differ constitutionally from those in the United Kingdom and Europe, legal concerns have been flagged regarding EDR data ownership and privacy. Numerous studies and research agencies have highlighted privacy concerns over who owns and accesses such data. Recommendations for maintaining privacy protections have ranged from limiting access to data by retrieving event-related data only within the few seconds before, during, and after the event, to instituting law enforcement training for accessing and using event data, as well as keeping current with engine manufacturer's iterative technology updates.

Only one of the reviewed studies could not confirm EDR/HVEDR benefits, and this appeared to be due to technical complications of study design and validity and not due to the technology itself. Similarly, although the Australian NTC could not recommend mandating mass telematics regulations without a greater cost-benefit justification, it acknowledged telematics' benefits for improving driver safety on a voluntary commercial basis.

So long as legal solutions to data ownership and privacy for HVEDR can be determined and regulated, the research has generally concluded EDR/HVEDR's potential benefit for improving highway safety, including collecting and analyzing accident data to better define safety problems and hazards for researchers, manufacturers, and regulators; facilitating more speedy and effective categorization and triage by emergency responders and rescuers; improving accuracy, time-efficiency and cost-efficiency of accident investigations; providing evidence for resolving legal proceedings and lawsuits, as well as recovering costs for damage repairs to highway infrastructure; and influencing drivers to behave more safely and consistently on the road.

APPENDIX A - ACRONYMS

ABS	Anti-Lock Brakes System
ACCTYPE	Accident Type
ACM	Air Bag Control Module
ACN	Automatic Crash Notification
ACRS	Air Cushion Restraint System
ADAS	Advanced Driver Assistance Systems
ADEM	Advanced Diesel Engine Management (Caterpillar)
ADL	Alexander Dennis Limited
ADR	Accident Data Recorder
AEB	Automatic Emergency Braking
APTA	American Public Transportation Association
ATA	American Trucking Association
AV	Automated Vehicle
Ax, Ay	Longitudinal, Lateral Acceleration Change (g)
BAGDEPLY	airBag System Deployment
CADaS	Common Accident Data Set
CAN	Controller Area Network
CARE	Community Road Accident Database
CCTV	Closed-Circuit Television Camera
CDC	Collision Deformation Classification
CDR	Crash Data Retrieval
CDS	Crashworthiness Data System
CFR	Code of Federal Regulations
CIREN	Crash Injury Research and Engineering Network
CISS	Crash Investigation Sampling System
CMVs	Commercial Motor Vehicles
D	Deployment (event)
D/DL	Deployment and Deployment-Level (event)
D/N	Deployment and Non-Deployment (event)
DARR	Digital Accident Research Recorder (Volvo)
DDEC	Detroit Diesel Electronic Controls
Delta V (ΔV)	Change in velocity (mph)
DERM	Diagnostic & Energy Reserve Module (General Motors specific)
DL	Deployment-Level (event)
DLC	Diagnostic Link Connector
DoCAN	Diagnostic Communication Over Controller Area Network
DOT	Department of Transportation
DTC	Diagnostic Trouble Code
DVLAT	Lateral component of delta V
DVLONG	Longitudinal component of delta V
EC	European Commission
ECBOS	Enhanced Coach and Bus Occupant Safety
ECM	Engine Control Module
ECU	Electronic Control Unit
EDR	Event Data Recorder

EDS	Electronic Data System
ELD	Electronic Logging Device
EPA	Environmental Protection Agency
ERSO	European Road Safety Observatory
ESC	Electronic Stability Control
ETC	Electronic Throttle Control
ETN	Enlaces Terrestres Nacionales (Mexico)
FARS	Fatality Analysis Reporting System
FAST Act	Fixing America's Surface Transportation Act
FCA	Fiat Chrysler Automobiles -DaimlerChrysler formerly.
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulations
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GIT	Global Information Technology
GM	General Motors
GPS	Global Positioning System
GVWR	Gross Vehicle Weight Rating
HCV	Heavy Commercial Vehicle
HGV	Heavy Goods Vehicle
HVEDR	Heavy Vehicle Event Data Recorder
IMPETUS	Greece's Consultants bureau
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
IVDR	In-Vehicle Data Recorder
JDR	Journey Data Recorder
JPL	Jet Propulsion Laboratory
kph	kilometers per hour
LCV	Light Commercial Vehicles
LDW	Lane Departure Warning
LER	Locomotive Event Recorder
LLC	Limited Liability Company
LRC	Light, Rapid, Comfortable
LTCCS	Large Truck Crash Causation Study
MANEUVER	Attempted Avoidance Maneuver
MANUSE	Manual (Active) Belt System Use
MCMIS	Motor Carrier Management Information System
MIRA	Motor Industry Research Laboratory
MMUCC	Model Minimum Uniform Crash Criteria
MOT	Ministry of Transport
MOU	Memorandum of Understanding
mph	miles per hour
ms	milliseconds
MSSC	Mecanica Scientific Service Corporation
MVEDR	Motor Vehicle Event Data Recorder
MVEDRCLA	Motor Vehicle Event Data Recorder Connector Lockout Apparatus
MVSRAC	Motor Vehicle Safety Research Advisory Committee

MY	Model Year
NAFTA	North American Free Trade Agreement
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASS	National Automotive Sampling System
NASS-CDS	National Automotive Sampling System’s Crashworthiness Data System
NCAP	New Car Assessment Program
NCHRP	National Cooperative Highway Research Program
NCSA	National Center for Statistics and Analysis
NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
No	Number
NOX	Nitrous Oxide
NPRM	Notice of Proposed Rulemaking
NTC	National Transport Commission (Australia)
NTSB	National Transportation Safety Board
OBD	On-Board Diagnostic
OEM	Original Equipment Manufacturer
PACCAR	Pacific Car and Foundry Company
PDOF	Principal Direction of Force (1st)
PDOF1	Clock Direction for PDOF in Degrees (Highest CDC)
PRE	Preliminary Regulatory Evaluation
R&D	Research and Development
RCM	Restraint Control Module
RF	Right-Front
rpm	revolutions per minute
SAE	Society of Automotive Engineers
SAMOVAR	Safety Assessment Monitoring On-Vehicle with Automatic Recording
SCI	Special Crash Investigations
SDM	Sensing and Diagnostic Module (General Motors)
sec	seconds
SVMs	Small Volume Manufacturers
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Netherlands) (Dutch: Institute for Road Safety Research)
t	time (seconds)
T&B	Truck and Bus
TIFA	Trucks Involved in Fatal Accidents
TMC	Truck Maintenance Council
TPS	Throttle Position Sensor
TRB	Transportation Research Board
TRL	Transport Research Laboratory
TSB	Transportation Safety Board of Canada
UDS	Universal Documentation Service
UMTRI	University of Michigan Transportation Research Institute
US DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDO	Vereinigte DEUTA - OTA (Company Name)

VDR	Vehicle Data Recorders
VERONICA	Vehicle Event Recording based on Intelligent Crash Assessment
VIN	Vehicle Identification Number
VRU	Vulnerable Road Users
VSS	Vehicle Speed Sensor
Vx (ΔVx)	Longitudinal delta V (mph)
Vy (ΔVy)	Lateral delta V (mph)
WBO	Verband der Württembergisch-Badischen Omnibusunternehmen-Bus Co. (Germany)
WG	Working Group
XML	Extensible Markup Language

APPENDIX B - DEFINITION OF 2007/46/EC VEHICLE CATEGORIES

From 2007/46/EC as last amended by 385/2009

Vehicle categories are defined according to the following classification: (Where reference is made to "maximum mass" in the following definitions, this means "technically permissible maximum laden mass" as specified in item 2.8 of Annex I of the above Directive.)

Category M: Motor vehicles with at least four wheels designed and constructed for the carriage of passengers.

- Category M1: Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.
- Category M2: Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes.
- Category M3: Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes.

The types of bodywork and codifications pertinent to the vehicles of category M are defined in Part C of this Annex paragraph 1 (vehicles of category M1) and paragraph 2 (vehicles of categories M2 and M3) to be used for the purpose specified in that Part.

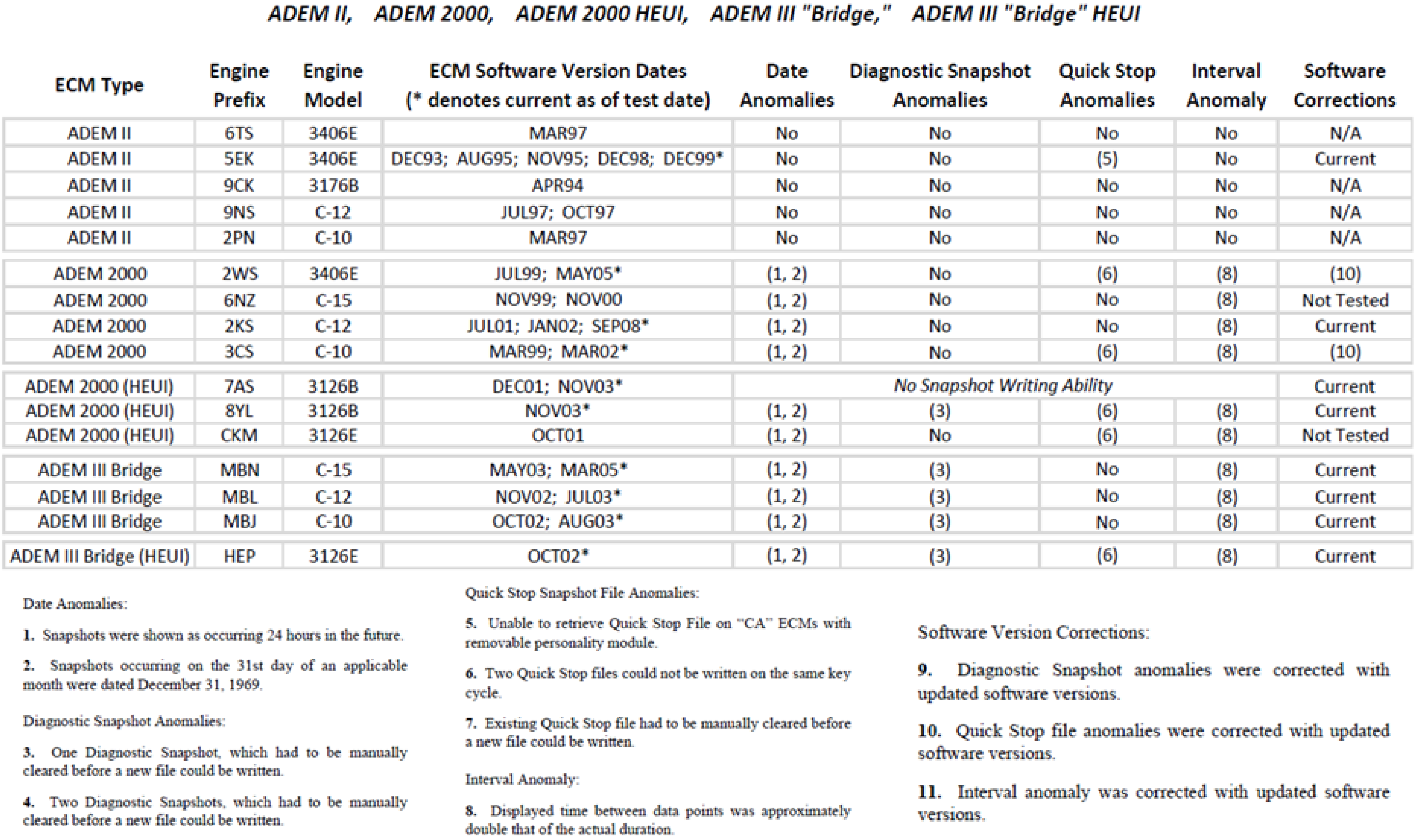
Category N: Motor vehicles with at least four wheels designed and constructed for the carriage of goods.

- Category N1: Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3,5 tonnes.
- Category N2: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3,5 tonnes but not exceeding 12 tonnes.
- Category N3: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tonnes.

Category O: Trailers (including semi-trailers).

- Category O1: Trailers with a maximum mass not exceeding 0,75 tonnes
- Category O2: Trailers with a maximum mass exceeding 0,75 tonnes but not exceeding 3,5 tonnes.
- Category O3: Trailers with a maximum mass exceeding 3,5 tonnes but not exceeding 10 tonnes.
- Category O4: Trailers with a maximum mass exceeding 10 tonnes.

APPENDIX C - CATERPILLAR ECU DATA ANOMALIES



ADEM II, ADEM 2000, ADEM 2000 HEUI, ADEM III "Bridge," ADEM III "Bridge" HEUI

ECM Type	Engine Prefix	Engine Model	ECM Software Version Dates (* denotes current as of test date)	Date Anomalies	Diagnostic Snapshot Anomalies	Quick Stop Anomalies	Interval Anomaly	Software Corrections
ADEM II	6TS	3406E	MAR97	No	No	No	No	N/A
ADEM II	5EK	3406E	DEC93; AUG95; NOV95; DEC98; DEC99*	No	No	(5)	No	Current
ADEM II	9CK	3176B	APR94	No	No	No	No	N/A
ADEM II	9NS	C-12	JUL97; OCT97	No	No	No	No	N/A
ADEM II	2PN	C-10	MAR97	No	No	No	No	N/A
ADEM 2000	2WS	3406E	JUL99; MAY05*	(1, 2)	No	(6)	(8)	(10)
ADEM 2000	6NZ	C-15	NOV99; NOV00	(1, 2)	No	No	(8)	Not Tested
ADEM 2000	2KS	C-12	JUL01; JAN02; SEP08*	(1, 2)	No	No	(8)	Current
ADEM 2000	3CS	C-10	MAR99; MAR02*	(1, 2)	No	(6)	(8)	(10)
ADEM 2000 (HEUI)	7AS	3126B	DEC01; NOV03*	*No Snapshot Writing Ability*				Current
ADEM 2000 (HEUI)	8YL	3126B	NOV03*	(1, 2)	(3)	(6)	(8)	Current
ADEM 2000 (HEUI)	CKM	3126E	OCT01	(1, 2)	No	(6)	(8)	Not Tested
ADEM III Bridge	MBN	C-15	MAY03; MAR05*	(1, 2)	(3)	No	(8)	Current
ADEM III Bridge	MBL	C-12	NOV02; JUL03*	(1, 2)	(3)	No	(8)	Current
ADEM III Bridge	MBJ	C-10	OCT02; AUG03*	(1, 2)	(3)	No	(8)	Current
ADEM III Bridge (HEUI)	HEP	3126E	OCT02*	(1, 2)	(3)	(6)	(8)	Current

Date Anomalies:

1. Snapshots were shown as occurring 24 hours in the future.

2. Snapshots occurring on the 31st day of an applicable month were dated December 31, 1969.

Diagnostic Snapshot Anomalies:

3. One Diagnostic Snapshot, which had to be manually cleared before a new file could be written.

4. Two Diagnostic Snapshots, which had to be manually cleared before a new file could be written.

Quick Stop Snapshot File Anomalies:

5. Unable to retrieve Quick Stop File on "CA" ECMs with removable personality module.

6. Two Quick Stop files could not be written on the same key cycle.

7. Existing Quick Stop file had to be manually cleared before a new file could be written.

Interval Anomaly:

8. Displayed time between data points was approximately double that of the actual duration.

Software Version Corrections:

9. Diagnostic Snapshot anomalies were corrected with updated software versions.

10. Quick Stop file anomalies were corrected with updated software versions.

11. Interval anomaly was corrected with updated software versions.

Figure C-1. Caterpillar data anomalies for ADEM II, ADEM 2000 and ADEM III[40]

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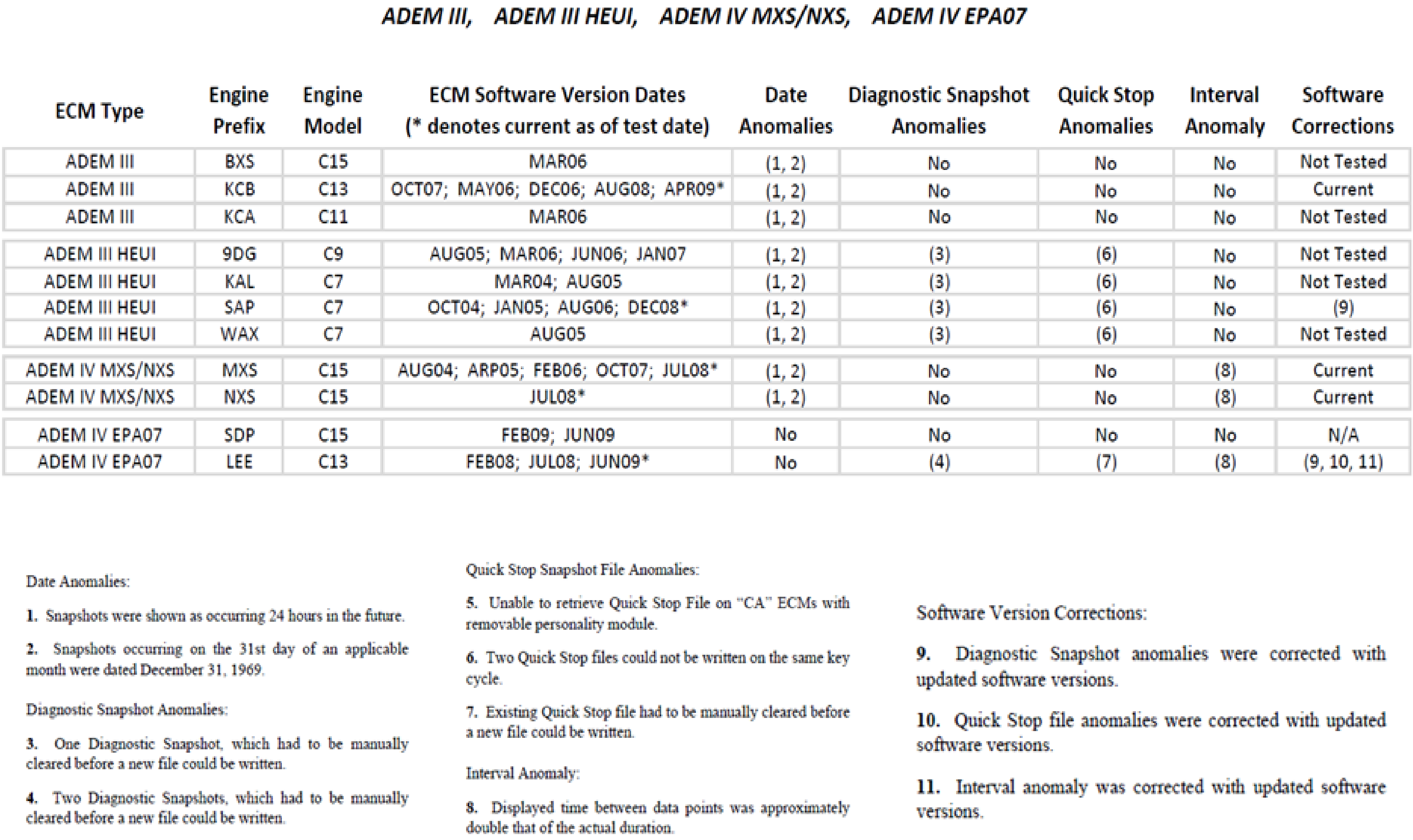
[40] Austin, T. and Farrell, M., "An Examination of Snapshot Data in Caterpillar Electronic Control Modules," *SAE Int. J. Passeng. Cars – Mech. Syst. 4*(1):611-635, 2011.



ADEM III, ADEM III HEUI, ADEM IV MXS/NXS, ADEM IV EPA07

ECM Type	Engine Prefix	Engine Model	ECM Software Version Dates (* denotes current as of test date)	Date Anomalies	Diagnostic Snapshot Anomalies	Quick Stop Anomalies	Interval Anomaly	Software Corrections
ADEM III	BXS	C15	MAR06	(1, 2)	No	No	No	Not Tested
ADEM III	KCB	C13	OCT07; MAY06; DEC06; AUG08; APR09*	(1, 2)	No	No	No	Current
ADEM III	KCA	C11	MAR06	(1, 2)	No	No	No	Not Tested
ADEM III HEUI	9DG	C9	AUG05; MAR06; JUN06; JAN07	(1, 2)	(3)	(6)	No	Not Tested
ADEM III HEUI	KAL	C7	MAR04; AUG05	(1, 2)	(3)	(6)	No	Not Tested
ADEM III HEUI	SAP	C7	OCT04; JAN05; AUG06; DEC08*	(1, 2)	(3)	(6)	No	(9)
ADEM III HEUI	WAX	C7	AUG05	(1, 2)	(3)	(6)	No	Not Tested
ADEM IV MXS/NXS	MXS	C15	AUG04; ARP05; FEB06; OCT07; JUL08*	(1, 2)	No	No	(8)	Current
ADEM IV MXS/NXS	NXS	C15	JUL08*	(1, 2)	No	No	(8)	Current
ADEM IV EPA07	SDP	C15	FEB09; JUN09	No	No	No	No	N/A
ADEM IV EPA07	LEE	C13	FEB08; JUL08; JUN09*	No	(4)	(7)	(8)	(9, 10, 11)

Date Anomalies:

1. Snapshots were shown as occurring 24 hours in the future.

2. Snapshots occurring on the 31st day of an applicable month were dated December 31, 1969.

Diagnostic Snapshot Anomalies:

3. One Diagnostic Snapshot, which had to be manually cleared before a new file could be written.

4. Two Diagnostic Snapshots, which had to be manually cleared before a new file could be written.

Quick Stop Snapshot File Anomalies:

5. Unable to retrieve Quick Stop File on "CA" ECMs with removable personality module.

6. Two Quick Stop files could not be written on the same key cycle.

7. Existing Quick Stop file had to be manually cleared before a new file could be written.

Interval Anomaly:

8. Displayed time between data points was approximately double that of the actual duration.

Software Version Corrections:

9. Diagnostic Snapshot anomalies were corrected with updated software versions.

10. Quick Stop file anomalies were corrected with updated software versions.

11. Interval anomaly was corrected with updated software versions.

Figure C-2. Caterpillar data anomalies for ADEM III, ADEM III HEU and ADEM IV[41]

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[41] Ibid.

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