Transport Canada Commercial Bus HVEDR Feasibility Study (File No. T8080-160062) Deliverable No. 6:

Commercial Bus HVEDR Feasibility Report

"*Submission of a discussion paper on the feasibility of developing a commercial passenger bus EDR standard for Canada*"

Mecanica Scientific Services Corporation

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12. ABSTRACT The complexity of today's vehicles can make crash analysis difficult without an event data recorder (EDR) or heavy vehicle event data recorder (HVEDR). The following report examines the feasibility of standardizing HVEDR for commercial buses through two prevalent engineering and design methods: the use of add-on, aftermarket data-recording devices or maximizing original equipment manufacturer (OEM) electronic control units (ECUs) that already feature HVEDR functionality. Whether the HVEDR function is equipped in an OEM ECU or aftermarket device, a number of standardization objectives need be considered, including a common reporting format with standardized data elements and clock; adoption of a common reporting frequency, duration and thresholds; design for crash survivability and data preservation; and development of a common data-retrieval tool compatible with any commercial vehicle. This report concludes the more feasible option for standardizing commercial bus HVEDR may lie in utilizing the HVEDR functionality already present in major OEM ECUs, which have been moving in the direction of the Society of Automotive Engineers (SAE) J2728: HVEDR standard without regulation. Also discussed are the implications that HVEDR standardization has on fast-growing safety technologies, such as various advanced driver assistance systems (ADAS).		
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1.0 INTRODUCTION

It has been shown that the complexity of today's vehicles can make it difficult to analyze pre-crash physical evidence to understand how accidents occur. As discussed in Deliverable No. 3, "Summary Report of Facts," there is no independent way to determine driver operations and responses in the moments leading up to a collision without an **event data recorder (EDR)**.

As vehicles become increasingly advanced with the advent of automated driving systems (ADS), such as lane keeping assist (LKA) and forward and rearward automatic emergency braking (AEB), as well as advanced driver assistance systems (ADAS) like General Motors, Cadillac Division's *SuperCruise*®, it will be even more important to analyze EDR data to determine driver inputs or if an ADS or ADAS system did (or did not) intervene in the moments leading up to a crash.

Even without federal regulations, the industry has increasingly headed in the direction of standardizing **heavy vehicle event data recorder (HVEDR)** functionality. This industry standardization has been largely driven by manufacturers' needs to examine warranty claims and product performance in the field, as well as commercial carriers' general demand for data to improve fleet performance and driver safety.

The following report examines the feasibility of standardizing HVEDR for motorcoaches, buses and school buses within the context of both original equipment manufacturer (OEM) and add-on aftermarket advancements in heavy vehicle data recording.

2.0 EXECUTIVE SUMMARY

The following report is the submission for Transport Canada, *T8080-160062 Feasibility Study of Event Data Recorders for Commercial Buses*, Deliverable No. 6, which is a discussion of the feasibility of developing a commercial passenger bus EDR standard for Canada.

The following sections discuss the feasibility of mandating and standardizing EDR/HVEDR in motorcoaches, buses and school buses. While both benefits and challenges to different implementation methods are addressed, it should be noted that in Mecanica's combined 65 years of highway accident investigation and research, technical reasons against EDR/HVEDR implementation and standardization have not been discovered.

From an engineering and design perspective, two major HVEDR standardization implementation methods are considered. The first consideration examines the uses of aftermarket devices, both non-mandated (such as video data recorders [VDRs] and telematics systems) and mandated systems (such as electronic logging devices [ELDs]). Of particular interest with these add-on devices is how ELDs have already been mandated in the U.S. with a schedule for compliance to reach full effect by 2019. The ELD mandate provides a mandatory compliance framework and policy infrastructure for data standardization and transferability, as well as data privacy protection, which are shared priorities for HVEDR standardization and can be maximized for its implementation. The immediate downside to leveraging the ELD device as a “host” for an HVEDR function, however, is that not all bus, motorcoach or school bus operations would be required to operate with an ELD.

The second consideration therefore explores an alternative to aftermarket, stand-alone data recorders and examines the potential of maximizing OEM data-recording devices, such as the OEM chassis/engine/drivetrain safety electronic control units (ECUs) already installed in all heavy-duty vehicles and typically equipped with some HVEDR functionality. While the challenges of standardizing OEM-based HVEDR are considered, the significant advantages to utilizing such factory-equipped technology, such as OEM contributions and involvement in this standardization, render this option preferable.

Regardless of whether the HVEDR function is equipped in either an OEM ECU or an aftermarket add-on device, a common reporting format including standardized data elements and reporting frequency must be adopted, and a common data-retrieval tool compatible with any commercial vehicle, regardless of the commercial vehicle (or engine) manufacturer, need be developed. Such a model has been demonstrated with U.S. 49 CFR Part 563-compliant light-duty vehicles as 90% of NAFTA-market light-duty vehicles with EDR can be accessed with a common EDR data-imaging tool, the Bosch Crash Data Retrieval (CDR) Tool.

Finally, this report includes an important discussion regarding fast-growing safety technology (including ADAS) such as lane departure warning (LDW) and the aforementioned lane keeping assist (LKA) and automatic emergency braking (AEB) systems. Other advanced systems include the many facets of the intelligent transportation system (ITS), vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications and inputs to vehicles over dedicated short-range communications (DSRC) protocols.

3.0 COMMERCIAL PASSENGER BUS HVEDR FEASIBILITY

In accordance with SAE J2728, “Heavy Vehicle Event Data Recorder (HVEDR) Standard – Tier 1,”[1] the industry has moved in the direction of HVEDR standardization largely without regulation. A vast majority of commercial vehicle 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. A majority of HVEDR-type data in the U.S. are sourced from OEM-supplied HVEDR, which utilizes 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

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[1]SAE International Surface Vehicle Recommendation, “Heavy Vehicle Event Data Recorder (HVEDR) Standard - Tier 1,” SAE Standard J2728, Iss. June 2010.

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.

As discussed in this series of research (Deliverable No. 3, "Summary of Facts"), extensive research, testing and validation have been conducted on both OEM device-based EDR/HVEDR functions as well as aftermarket device-based EDR/HVEDR data accuracy and reliability. The sum of the research has identified limitations in the data recorded by OEM EDR/HVEDR but has concluded OEM EDR data are generally accurate and useful in crash analysis. Similar findings have been found for aftermarket EDR devices.

3.1 Add-On, Aftermarket Devices

A number of ELDs have expanded the incident-specific data elements they report in addition to continuous monitoring. Although an add-on device, such as an ELD with HVEDR programmed functionality, may feature improved data reliability, accuracy, recording and reporting resolution, the improved data quality comes at a significant per-vehicle cost for the device and for the labor to install, configure and calibrate it.

A number of ELDs manufactured by providers holding the largest share of the add-on data recorder market were explored in detail in Deliverable No. 4, "All Devices Summary Report." As discussed, the ELD mandate was inaugurated to enforce Federal Motor Carrier Safety Administration (FMCSA) standards for drivers' record of duty status (RODS) and hours of service (HOS) to improve driver safety specifically and highway safety generally. In addition to recording on- and off-duty status, ELDs are required to store pertinent HOS compliance data like driver identification, GPS location, date and time, timestamp for commercial motor vehicle (CMV) engine power-up or -down, engine hours, vehicle miles, duty status, vehicle information, motor carrier identification and authenticated user data.

As seen in Deliverable No. 4, many ELDs are increasingly equipped with additional capabilities for recording data pertinent to collision events. For example, event triggers like hard braking are recorded by SmartDrive's SmartIQ system while SmartWitness's three-axis g-force sensors record detailed data on collision events and driver operational behavior. SmartDrive's SmartIQ additionally features some aforementioned ADAS capability, such as LDW systems, following-distance monitoring and collision avoidance.

FMCSA requirements for ELD devices to meet compliance feature priorities shared by HVEDR standardization. As discussed in Deliverable No. 3, the largest concern for EDR/HVEDR devices is not technical feasibility but legal debate over data privacy, access and usage. In response to concerns over data access, the ELD mandate has outlined regulatory specifications limiting law enforcement agencies to accessing and using data to enforce HOS compliance only. Additionally, a Supplemental Notice of Proposed Rulemaking (SNPRM; 79 FR 17656) included language specifically preventing CMV carriers from using data to harass drivers.

It must be remembered that in the U.S., however, not all carriers are mandated to equip CMVs with ELDs, and a requirement for mass implementation of HVEDR must account for the type of device that would satisfy both HVEDR standardization and privacy rights. Additionally, for those CMVs required to meet ELD compliance, FMCSA does not require crash survivability for these devices nor their data despite NTSB recommendations.[2] FMCSA has determined that crash survivability would require ELDs withstand high-impact or crash forces, be water resistant and withstand extended exposure to open flame. FMCSA highlighted their intentionality in setting standards that can be met by reprogramming currently existing devices with low additional cost to carriers. Adding HVEDR software to existing ELDs would change requirements for sustaining high-impact and crash forces and significantly increase costs for ELD manufacturers as well as commercial purchasers of these devices; avoiding these complications and costs are FMCSA's stated reasons for precluding this requirement in ELDs altogether.

A standalone data recorder designed specifically to meet crash survivability and analysis requirements provides an alternative to using ELD devices as a "host" for HVEDR software. The Kienzle Argo GmbH *Unfalldatenspeicher* (UDS), or "accident data recorder (ADR)," is one such example, and the UDS has been the foundational data recorder of several published highway safety and commercial fleet safety studies in Europe. The UDS-AT is the new generation of UDS, with "AT" signifying "advanced technology." Compared to other recording devices, the UDS-AT is unique in that is does not rely solely on vehicle CAN-bus networks but also its own internal sensors to record and report vehicle critical-event data.

A significant advantage to this device is that it has a resolution recording/reporting rate of 512 Hz but can be triggered into a higher resolution mode of 1 kHz should sensors detect a critical event or preprogrammed trigger. However, the 800-1000€ (1200-1600 CAD, 1000-1250 USD) per-vehicle cost of installation is a considerable downside. Such costs would require significant substantiation from regulatory accounting offices and would result in heavy fleet pushback regardless of regulatory justification.

3.2 OEM-Based Devices

While cost analysis is beyond the scope of this report, less cost, significant design benefits and already widespread HVEDR-functionality are but a few advantages of using OEM-based HVEDR for standardization in motorcoaches, commercial buses and school buses.

The most significant positive attribute of OEM-based EDR/HVEDR devices is that the EDR/HVEDR is a software function added to a pre-existing ECU that is original to the vehicle and required for its operation. The OEM EDR/HVEDR function leverages sensors and data that are already on the vehicle and required for vehicle operation to meet federal regulations, such as emissions requirements. A degree of HVEDR functionality already exists within 90% of all NAFTA market vehicles and 99% of heavy vehicles specifically. Leveraging current OEM ECUs for HVEDR purposes is a less costly option for OEMs to phase into compliance over time and would

[2]FMCSA, Electronic *Logging Device (ELD) Test Plan and Procedures*, Apr. 2016.

receive the least pushback of all alternatives.

When examining OEM-based HVEDR feasibility, however, it must be noted that a considerable downside for these devices is that there tend to be more data limitations and potential for reduced data accuracy when the vehicle's OEM data network and sensors are leveraged, as opposed to a purpose-built, independent data recorder like the Kienzle Argo UDS essentially serving as a data-acquisition system. Additionally, an OEM-based HVEDR standardization must effectively address the currently wide variation in HVEDR functionality across OEM ECUs as well as variation in data elements, reporting frequency, duration and thresholds.

3.2.1 Multiple Recording Units

Standardization of HVEDR through an OEM-based solution must account for the variations in HVEDR functionality across OEM ECUs. While beneficial that OEM ECUs essentially record the same data, many physically record in different modules.

For example, iterations of Detroit Diesel's DDEC system have seen additional modules added to trucks to compensate for increased complexity over time. The DDEC VI system introduced the two-module system using the common powertrain controller (CPC-2) and the renamed the engine-mounted module the motor control mount (MCM). The CPC is where DDEC data is stored while other modules store their own fault codes and configuration parameters. The DDEC 10 system kept the CPC and MCM but further introduced the aftertreatment control module (ACM) mounted under the cab. DDEC 13 introduced a fourth optional ECU, the TCM01T, which controls the also optional Detroit Diesel DT12 automatic transmission. Much like the DDEC VI system on Detroit Diesel engines, Mercedes-Benz engines (MBE) feature a two-module system using the vehicle control unit (VCU) and the *Pumpe Liene Dusse* (PLD), or engine-resident control unit. Data from MBE DDEC Reports are also stored within the VCU while clock and configuration data are stored in the PLD.

Similarly, Mack's Vehicle Management and Control (V-MAC) system started utilizing a two-module data recording system with the introduction of V-MAC III that continued up to 2007. The two-module system included the engine electronic control unit (EECU) to control engine functions and the vehicle electronic control unit (VECU) to control vehicle functions. V-MAC IV was introduced in 2006 and ran until 2013. In addition to redesigned EECUs and VECUs, this system added a third module called the Instrument Panel Electronic Control Unit (IPECU). Volvo's Legacy Version 2 electronic controls system utilized these three ECUs, namely the IPECU, EECU and VECU. Volvo trucks are furthermore equipped with a supplemental restraint system (SRS) ECU, an airbag system exclusive to Volvo trucks in the NAFTA market with capability of storing occupant restraint system performance data.

Standardizing HVEDR recording units, therefore, need not dictate in which ECU manufacturers choose to store the data. Rather, the objective would be to avoid dispersing all the data that would constitute an HVEDR report across different ECUs. It is preferable to record all data to a single ECU that can be accessed either via the preferred connection method (the diagnostic link connector [DLC], as defined by J1939/13 on a heavy truck) or direct to that single ECU if the vehicle sustains too much damage to connect via the DLC.

3.2.2 Varying Reporting Duration & Frequency

Reporting duration and frequency vary even more significantly across OEM ECUs than the number of recording units and complicate data aggregation into a common database for crash analysis research.

To illustrate, each DDEC hard brake event records 1 minute of activity prior to the trigger and 15 seconds after the trigger, with hard brake values being reported in 1-second intervals. CAT Quick Stops record 44 seconds of pre-trigger data and 15 seconds of post-trigger data at a similar rate of 1 Hz (1 sample per second). Bendix events record 20 seconds of data split into 10 seconds of pre-trigger data and 10 seconds of post-trigger data at 2 Hz intervals.

A DDEC last stop event records 1 minute and 44 seconds of data prior to stopping and 15 seconds after. It records the same values as the hard brake event and also reports in 1-second intervals. For Mack's V-MAC IV and V-MAC IV+, the acceleration-triggered event and the last stop event both record 90 seconds of data. The acceleration-triggered event records 60 seconds of pre-trigger data and 30 seconds of post-trigger data while the last stop event records 90 seconds of pre-trigger data. Both events also record and report data in 0.25 second increments (4 Hz). Comparably, Volvo's acceleration-triggered events and last stop event logs record 90 seconds of data at 4 Hz. The acceleration-triggered event records 60 seconds of pre-trigger data and 30 seconds of post-trigger data while the last stop event records 90 seconds of pre-trigger data. International/NAVISTAR last stop record is also stored at 1 Hz and includes 105 seconds of pre-event data, a snapshot at the time of stop and 15 seconds of post-event data. International/NAVISTAR acceleration-triggered event contains 105 seconds of pre-trigger data, a snapshot at the time the trigger occurred and 15 seconds of post-trigger data—all recorded in 1-second increments (1 Hz).

A Caterpillar (CAT) Diagnostic Snapshot generates 19 pre-trigger data points and 7 post-trigger data points at 0.48-second intervals (approximately 2 Hz sampling rate). Volvo Freeze Frames data are captured at 30 second intervals, so the two frames captured prior to fault code activation span anywhere from 0 and 30 seconds prior to 30 and 60 seconds prior, depending on when the fault occurred due to the nature of the circular buffer on which the data is captured.

A common reporting frequency and recording-time duration are an objective worthy of consideration given their importance to meaningful crash analysis.

3.2.3 Varying Event Trigger Thresholds

The triggering threshold for a Detroit Diesel hard brake event is set to 7 mph/sec by default but can be changed by the owner. Additionally, the vehicle speed must be above 10 mph and will not trigger if preceded or followed by an acceleration of more than 4 mph/sec. Cummins recording, however, is triggered when a preprogrammed acceleration is detected. The default trigger is 9 mph/sec but may be reprogrammed to a user-defined value. Mack's V-MAC IV and IV+ last stop event is triggered when the truck comes to a complete stop. A CAT snapshot file is created when a user-specified acceleration trigger or the "Quick Stop rate," is sensed. Caterpillar recommends that the Quick Stop trigger rate be set at 7 mph/sec.

DDEC last stop events are triggered when the vehicle speed changes from drive state (vehicle speed greater than or equal to 1.5 mph and engine speed greater than zero for 2 seconds) to stop state (vehicle speed less than 1.5 mph or the ignition off) and remains stopped for 15 seconds. For Volvo, the last stop event is comparably triggered when the vehicle comes to a 0-mph stop. International/NAVISTAR last stop event data are recorded when the vehicle comes to a stop and the engine is shut down (ignition off), or the vehicle comes to a stop and the engine remains at idle for more than 2 minutes.

CAT Diagnostic Snapshots are similar to Quick Stop Snapshots and are created when an engine fault code is generated. Mack's acceleration-trigger threshold remains the same from V-MAC III, which is set at +/-10 mph/sec change in vehicle speed accompanied by a +/-50 rpm/sec change in engine speed. Volvo's acceleration-triggered event threshold is also the same as Mack, set at +/-10 mph/sec change in vehicle speed accompanied by a +/-50 rpm/sec change in engine speed. International/NAVISTAR acceleration triggered events are recorded when the programmable event trigger is exceeded. In addition to reaching the trigger threshold for recording, testing has found that, with the trigger set at 5.5 mph/sec, the vehicle must travel at greater than 14.29 mph to record event data. With the trigger set at 9.5 mph, the vehicle must travel at a speed greater than 28.58 mph to record event data.

Bendix EC-60/EC-80 systems built in 2013 and later trigger events when the magnitude of lateral and/or longitudinal acceleration exceeds .5 g in any direction (acceleration >.5 g), when vehicle speed is reduced by 6.9 mph or greater in one second (hard brake), when there is a Wingman Advanced system brake intervention, or when active cruise with braking (ACB) is set and either the takeover alert (or impact alert) or the driver overrides the system.

See Table 3.2.3 for comparisons of OEM event trigger thresholds, recording durations and frequency.

Table 3.2.3. OEM HVEDR-Type Triggers and Recording

	Daimler Trucks North America Detroit Diesel/Mercedes-Benz	Volvo Group North America (Mack, Volvo, Volvo Bus/Prevost)	Caterpillar
Engine/ Modules	**DDEC 16 (CPC04T) & Mercedes OM471**	**Mack V-MAC IV+ Volvo Version 3 Controls**	**CAT C15 EPA 07; ADEM IV Module**
Year	2016 to current	2013 to current	2010
Recording Durations	Hard Brake: 1 min (pre), 15 sec (post) Last Stop: 1 min 44 sec (pre),15 sec (post)	Acceleration Triggered: 1 min (pre), 30 sec (post) Last Stop: 90 sec	44 sec (pre), 15 sec (post)
Recording Frequency	1 Hz	4 Hz	1 Hz
Hard Brake Trigger	Factory set to 7 mph/s; Configurable by owner	+/- 10 mph/sec	Factory set to 7 mph/s; Configurable by owner
Last Stop Trigger	Vehicle speed changes from greater than 1.5 mph to less than 1.5 mph and is stopped for 15 sec.	0 mph/s	N/A
Trigger Conditions	Vehicle speed must be above 10 mph; will not trigger if preceded or followed by acceleration of more than 4 mph/s.	No trigger conditions for acceleration triggered events. Last Stop requires vehicle to exceed 5 km/hr (3.1 mph) for Last Stop to be written.	No special conditions.
Power	With all DDECs, removing the ECMs from the chassis does not affect the storage of any Hard Brake, Last Stop, or other DDEC Report data. For Last Stop, key cycle required; for Hard Brake, key cycle not required.	Last Stop Record: ECM appears to require up to 2 min of power to write a new Last Stop record without an elegant shutdown. If there is a key off, approximately 20 sec of power are needed to write a new file. Hard Brake Record: ECM appears to require approximately 15 sec for power following a Hard Brake event to write a new data file.	Refer to peer-reviewed SAE Technical Paper No. 2011-01-0807, “An Examination of Snapshot Data in Caterpillar Electronic Control Modules,” by T. Austin regarding power loss.
Comments	For DDEC 13 and newer, Hard Brake records and Last Stop records are written to EEPROM immediately after an event. *Note*. Additional data recording, including imagery recording, may be found in Freightliner/Detroit Diesel "Detroit Assurance" safety systems.	Mack/Volvo refers to "Hard Brake Events" as "Acceleration Triggered Incident Logs." Writes incident log data to EEPROM at trigger.	Refer to peer-reviewed SAE Technical Paper No. 2011-01-0807, “An Examination of Snapshot Data in Caterpillar Electronic Control Modules,” by T. Austin regarding special considerations and data anomalies in reviewing Caterpillar data.

Table 3.2.3 (Continued). OEM HVEDR-Type Triggers and Recording

	Navistar International	Cummins	PACCAR	Bendix
Engine/ Modules	**Navistar A26**	**X15 Engine; CM2350**	**MX-11 Engine (EPA 2013)**	**EC-80 Module**
Year	2018 to current	2017 to current	2010 to 2017*	2011 and later
Recording Durations	105 sec (pre), 15 sec (post)	59 sec (pre), 15 sec (post)	5 sec (pre), 5 sec (post)	10 sec (pre), 10 sec (post)
Recording Frequency	1 Hz	1 Hz	4 Hz	2 Hz
Hard Brake Trigger	7.4 mph/s	9 mph/sec	8.95 mph/sec	0.55 g triggers Bendix Data Recorder Log; 0.75 g triggers and locks.
Last Stop Trigger	Vehicle comes to a stop and engine is shut down, or vehicle comes to a stop and engine remains idle for more than 2 min.	N/A	N/A	N/A
Trigger Conditions	Minimum vehicle speeds may be required; currently being determined.	9 mph/sec default; most are not programmable.	N/A	When the magnitude of lateral and/or longitudinal acceleration exceeds 0.5g in any direction. (acceleration > 0.5 g); when vehicle speed is reduced by 6.9 mph or greater in 1 sec (Hard Brake); when there is a Wingman Advanced system brake intervention; when Active Cruise with Braking (ACB) is set, and the takeover alert (or impact alert) and driver are overriding the system.
Power	<u>Last Stop Record:</u> ECM requires up to 2 min of power to write a new file. When there is a key off, approximately 20 sec of power are needed to write a new file. <u>Hard Brake Record:</u> ECM requires approximately 15 sec of power following a Hard Brake incident to write a new data file.	If power is interrupted, then Sudden Deceleration data records will not be saved to non-volatile memory and will be lost.	N/A	Effect of power loss on recorded data by ECU written to non-volatile memory in less than 0.5 sec. <u>Bendix AutoVue/SafetyDirect ECU</u>: Power interruptions may result in loss of video or data that has not completed transfer to flash memory.
Comments	<u>Hard Accel/Decel Record</u>: Stores two most recent. <u>Last Stop Record</u>: Stores two most recent.	Up to three Sudden Deceleration records can be stored.	PACCAR PX series engines are rebranded Cummins, and Cummins software and protocols should be used for data imaging. *<u>Note</u>.* For 2017 and newer models, PACCAR disabled the Fast Stop Recorder function due to a problem with the data reporting frequency.	Stores four or more events; SafetyDirect on-board data logger captures and broadcasts event data, including Hard Brake events with speed, timestamp and location.

3.3 Common Data Elements & Reporting

The current OEM HVEDR capabilities examined in Section 3.2 are actually on track to be in line with SAE Recommended Practice (RP) J2728. Most heavy vehicles on the road today are already equipped with data recorders that write more than 30 seconds of data. As shown, the most glaring departure from the RP is the level of reporting frequency. SAE J2728 recommends a record rate of 10 Hz, but the highest resolution data found on current OEM HVEDR is the 4 Hz data found on Mack and Volvo incident logs and the Paccar Fast Stop Recorder. In fact, most OEM HVEDRs record at 1 Hz, a considerably low resolution.

OEM HVEDRs, however, typically exceed the 30 seconds of data that J2728 recommends. Detroit Diesel, for instance, records 75 seconds of hard brake data and 120 seconds of last stop data. It should be noted that, in this case, J2728 does not require OEM HVEDRs to reduce their recording time; rather the 30 seconds (15 seconds pre-trigger and 15 seconds post-trigger) is a minimum value for recorded time surrounding an event.

SAE J2728 does, however, recommend several additional data elements that current OEM HVEDRs do not report. Current OEM HVEDRs typically record vehicle speed, engine speed, brake switch application, clutch switch application and cruise control state. In addition to these, SAE J2728 recommends more coverage of vehicle systems such as ABS status, transmission gear and engine retarder status. The RP also requires several header recorded values. These single-value data entries describe both the event and the OEM HVEDR in general while also featuring the date and timestamp for the event. Other headers include trigger threshold, the trigger count and whether the event data record is complete.

The inclusion of data elements from ADS such as forward AEB systems that are specific to accident reconstruction need to be included.

Leveraging these OEM HVEDRs is the most efficient method towards achieving the SAE J2728 standard and are therefore the most efficient gateway to HVEDR standards for commercial buses.

3.4 Common Clock

In 2002, NTSB reported crash analysis results from a motorcoach accident that occurred outside Canon City, Colorado.[3] The NTSB report not only lamented that only two fault codes were retrievable from DDEC VI's ABS ECU, but that "additional fault codes may have been present but ignored or overwritten by the ECU." Furthermore, the two available fault codes lacked date and timestamps in addition to 'active' or 'inactive' status labels. Because of the lack of date and timestamps, crash analysis investigators could not "determine when the fault occurred or whether the fault had any effect on the operation of the bus before the accident." This resulted in NTSB Safety Recommendation H-02-35, which called for the Institute of Electrical and Electronics Engineers (IEEE) and SAE to collaborate to develop a "recognized clock synchronized with other

[3]Detailed discussion of this event can be found in detail in Deliverable No. 3, "Summary Report of Facts," Section 3.2.2.3.

on-board event data recording devices"[4] that precisely records down to the second for hard brake, diagnostic fault code and last stop events.

In 2008, NTSB indicated disappointment that no work had been accomplished for these recommended standards by IEEE due to lack of interest in the IEEE 1616 technical working group. NTSB thus closed Safety Recommendation H-02-35. In 2013, NTSB endorsed SAE's work in producing a comprehensive list of data elements and data requirements for accident reconstruction and standards with the publication of SAE RP J2728, as discussed in 3.3. However, NTSB lamented persistent lack of a "recommended synchronizing standard" a decade after a common clock was recommended in the first issuance of H-02-35. As SAE J2728 fell short of a common clock, Safety Recommendation H-02-35 was reopened.[5]

Each commercial vehicle OEM dates and timestamps incident events differently, resulting in significant inconsistency in date and timestamps and justifying the need for a common clock. DDEC's hard brake events and the last stop event are stamped with the date and time of the trigger as well as the odometer value at the time of recording. Cummins Sudden Deceleration Data records are also timestamped with ECM time and odometer at occurrence. Cummins Fault Code Snapshots may also provide incident-specific data if the fault was triggered at the time of the subject incident. However, the fault code will be timestamped with electronic hour meter (ECM) runtime; thus the moment the fault code becomes active may not be the moment that the actual fault occurred.

For Mack V-MAC III/IV/IV+ systems, both incident-specific events are dated and timestamped with the date and time when the data was imaged as well as the date and time of the incident trigger. For V-MAC III there is also a mileage stamp reporting the mileage at the time of data imaging and not specific to the incident. For Mack V-MAC IV and V-MAC IV+ versions, the incident log's mileage stamp is directly related to the mileage at the incident trigger as opposed to the mileage at data imaging. Volvo's two incident logs are also timestamped the same way that Mack V-MAC IV/IV+ incident logs are stamped; each incident log is stamped with the date and time of the data imaging and the incident trigger, and the mileage is stamped at the time of the incident trigger. International/Navistar Freeze Frames are stamped with the odometer and engine hours at occurrence. Last stop event timestamps at occurrence include real-time clock value, ECM total distance and trip distance, and engine hours. Bendix events are timestamped using engine hours. Although these events are date and timestamped as such, testing and research has revealed inconsistencies within the ECU internal clocks themselves.

Reporting errors have further been found to confound timestamping accuracy. For example, CAT engines equipped with ADEM 2000 and ADEM III ECUs have been found to timestamp all snapshots 24 hours ahead of real time, as well as found to date snapshots recorded on the 31st of a given month with the date of December 31, 1969 or January 1, 1970 instead. Some ADEM 2000, ADEM III Bridge, ADEM IV MXS/NXS and ADEM IV-controlled engines have encountered

[4]NTSB Safety Recommendation H-02-35, iss. 2002.

[5]NTSB, "Safety Recommendation H-02-035," accessed Feb. 2018

a time-reporting error in which the time step between data entries is approximately double the actual duration. Another example is the Mack V-MAC III system clock, which lacks an internal battery backup; if power is interrupted, the clock may return a random value or revert to a previous value upon imaging. The V-MAC III clock accuracy also degrades over time because of this lack of an internal battery.

To address timestamp inconsistencies in satisfaction of NTSB recommendations, it should be noted that most heavy vehicles are equipped with GPS fleet management devices. The most pertinent element of GPS is its event timestamping accuracy in accordance with a universal standard. Timestamping of actual events is recorded in various formats (for example, a police or traffic collision report records 19:50 on a 24-hour clock, or local time of Los Angeles 7:50 pm PST, etc.) based on the date and location of the event. Vehicles with GPS modules record timestamping via Greenwich Mean Time (GMT), also known as Coordinated Universal Time (UTC). Therefore, the actual event timestamp from GPS recording could serve as the recommended common clock, and the analysis should rely on the recorded GPS date/time and corresponding latitude/longitude measurements. Mecanica proposes that the available common GPS date and timestamp, along with latitude/longitude location pinpointing, be used as the NTSB-recommended common clock as most trucks are currently able to store this data. The GPS timestamp is significantly more accurate than alternative timestamps.

3.5 Common Data-Imaging Tool

Standardizing HVEDR across OEMs necessitates a common tool so that government agencies, researchers, fleet managers, law enforcement agencies and independent consultants do not have to purchase and train on multiple tools for imaging data from commercial trucks and buses.

Today, an agency or organization will spend approximately 9,000 USD initially in addition to recurring annual licensing fees for all current truck diagnostic software, and an additional 1,000 USD for one of a few available TMC RP1210-compliant vehicle interfaces to be able to connect physically to the truck. By establishing one common tool to connect to all commercial truck and bus-type vehicles, the cost to invest in the hardware and software to image HVEDR can be significantly reduced.

Additionally, by standardizing on a common data imaging tool for HVEDR, training can be greatly simplified. Currently, extensive time is required to train on the nine separate diagnostics software applications for Allison, Bendix, Caterpillar, Cummins, Detroit Diesel/Mercedes-Benz, Eaton, International/Navistar, PACCAR, Volvo/Mack and WABCO.

The common EDR imaging tool already well established *for light-duty passenger vehicles* equipped with Part 563-compliant EDR functionality is the Crash Data Retrieval Tool designed, built and sold by Bosch Automotive Service Solutions, Inc. (Santa Barbara, California, USA).[6] The Bosch CDR Tool covers approximately 90% of vehicles equipped with EDR in the NAFTA market,

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

and the CDR Tool stays current through regularly received updates from manufacturers through the annual BOSCH OEM Summit.

Currently, there is not a single, common tool compatible with a majority of NAFTA-market commercial truck and bus manufacturers. However, Synercon Technologies (Tulsa, Oklahoma, USA) has designed, built and sells the Forensic Link Adapter (FLA). The FLA is a rugged computer capable of downloading HVEDR data from older Detroit Diesel, Mercedes, PACCAR MX, Navistar MaxxForce and all Caterpillar ECUs. The universal device also functions as a RP1210-compliant interface for communicating with OEM software. Communicating over the J1939 and J1708 networks, the Synercon Technologies detection algorithm scans the vehicle's networks for data specific to the engine, such as CAT Snapshots or DDEC hard brake event records, and images the data. FLA encrypts data during retrieval to verify data authenticity and integrity. The FLA's 16 GB of memory indefinitely stores the data until it can be uploaded to, decoded and displayed on the Synercon Technologies server.

The University of Tulsa conducted a joint study with the Institute for Police Technology and Management utilizing the FLA to retrieve data from a 2001 Caterpillar 3126 diesel engine school bus, serial number prefix CKM. The study simulated a crash between a school bus and transit bus that was severe enough to compromise the school bus electrical system. The study found that the FLA was able to extract QuickStop event data and other snapshots where the CAT ET maintenance software could not.[7]

The device's claimed universality falls short in reliability, however, as the device's design did not receive OEM manufacturer input or proprietary contributions to guarantee optimal compatibility with OEM ECUs.

3.6 Crash Survivability

HVEDR crash survivability is a significant objective for standardization given NTSB recommendations that HVEDR memory be able to withstand significant collision. NTSB has indicated that a crucial component of data retrieval lies in setting requirements particularly for fire survivability. In nearly all collisions in which fire compromised the ECM, memory was not retrievable from the module. Fire survivability has therefore been emphasized as essential for preserving data and a major requirement for total ECM crash survivability.

Other factors to consider for total survivability include cost, data preservation, impact shock, temperature, fluid immersion, penetration and location. In the 2002 Volume II of their *Final Report*,[8] the NHTSA EDR Working Group identified cost as a primary HVEDR survivability issue for the school bus industry in particular and voiced concern over whether this industry has sufficient funding to equip devices that meet survivability requirements. HVEDR survivability would similarly pose a burden on larger fleets due to the costs for outfitting each unit with

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[7] https://www.synercontechnologies.com/forensic-link-adapter/

[8] NHTSA EDR Working Group, *Event Data Recorders: Summary of Findings, Final Report, Volume II: Supplemental Findings for Trucks, Motorcoaches, and School Buses*, Report No. DOT HS 809 432, May 2002.

survivable modules. Cost of outfitting survivable modules has been a concern for the industry at large since NTSB first recommended it for the ELD mandate, which FMCSA ruled out for said costliness and complication.[9] However, HVEDR modules contain considerably far more data than ELDs, and the benefits of implementing survivability on HVEDR modules would proportionately justify the cost.

The NHTSA EDR Working Group further identified module location as the most important factor of EDR survivability. Location of the module determines how much damage and whether substantial crush is reached to compromise the module. Additionally, location significantly influences protection of the module from other factors, namely fire, fluid immersion, penetration and impact shock. The EDR Working Group found that EDRs should be capable of enduring a shock of 300 g for roughly 50 milliseconds. Also noted was the fact that HVEDR modules should be able to withstand shallow fluid immersion and a temperature of 40°F as independent events for 8 hours. Regarding crush and penetration, it was found the EDR should be capable of tolerating 500 lbs. of static crush and endure 200 lbs. dropped from 3 feet with a half-inch diameter impact area.

The 2010 SAE J2728 RP also touched upon HVEDR crash survivability and different factors that influence HVEDR during collision. The standard covered the same factors discussed in Volume II of EDR Working Group's *Final Report*, which were in turn derived from the SAE J1455 "Recommended Environmental Practices for Electrical Equipment Design in Heavy-Duty Applications." The sole electrical/environmental requirement from SAE J2728 is that the HVEDR survive collisions while still maintaining HVEDR compliance. This is a minimal approach compared to the EDR Working Group's over-and-above approach, which would require a significant increase in cost.

The 2002 Working Group's proposed solution is currently made by Safety Intelligence Systems and called a Mobile Acceleration Crash Box (MACBOX™), which can be triggered by an automatic or manual trigger. The MACBOX™ collects data that is vehicle-based and video-based (driver's view) and offers other EDR data aspects, such as wireless encrypted transmission during data collection, storage of the collected data and EDR data management. Aside from cost, a primary disadvantage of this device is that it requires more development, particularly in scaling.

Further research is still needed for larger highway vehicles, and additional costs associated with HVEDR data preservation need be assessed. Such research will not only facilitate a standard of collision severity that HVEDR modules can survive. For passenger-car EDR, the SAE J1698 committee established a baseline reference on how EDR should survive a FMVSS 208 or a NCAP test. No equivalent tests are presently available for determining a baseline reference of requirements for HVEDR module survivability. EDR module survivability findings specific to heavy vehicles must be considered in HVEDR crash tests to obtain nuanced understanding of the magnitude of crashes that HVEDR can reasonably withstand. The NTSB hopes to attain protection of these modules with little financial impact and significant safety returns.

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[9]FMCSA, *(ELD) Test Plan and Procedures*.

3.7 Independent Power

A final factor to consider is the effect of power interruptions on heavy vehicle EDR-type functionality and the ability to record events during and after a crash. The OEM EDR functions found on NAFTA-market trucks today are susceptible to the loss of electrical power data.

During some types of crashes, heavy vehicles may experience a temporary or permanent loss of electrical power due to vehicle damage. Power loss can also occur when first responders arrive at the collision scene and cut main battery cables to prevent post-collision fires. This loss of electrical power can result in compromised HVEDR functionality.

Unfortunately, the use of electrical power backup systems (in the form of small capacitors) such as those found in passenger car Airbag Control Modules (which host the EDR functionality and data storage) are not found in heavy truck and bus ECUs.

Two possible solutions can help mitigate the loss of data after a highway crash as a result of power loss:

1. Incorporating the use of a backup electrical supply, such as small surface mount capacitors incorporated into the ECU that could be used to provide a backup supply of electrical voltage for the EDR function to continue to write crash data even in the event of power loss.
2. The use of non-volatile EEPROM (Electrically Erasable Programmable Read-Only Memory) type memory for data storage so that a constant electrical source is not required to preserve data after a crash. It is commonly found that either just a few hours or few days after a crash, the commercial vehicle's main batteries have lost electrical power if first responders did not cut the main battery cables at the scene of the accident.

The recommendation for backup electrical power is discussed in SAE Recommended Practice J2728.

4.0 CONCLUSION

This report concludes *T8080-160062 Transport Canada Commercial Bus HVEDR Feasibility Study,* Deliverable No. 6: "Commercial Bus HVEDR Feasibility Study." To achieve standardized implementation of HVEDR in commercial buses and motorcoaches, two likely methods were explored, namely the use of add-on aftermarket data-recording devices and maximizing OEM ECUs that typically already feature HVEDR functionality.

FMCSA has effectively instituted commercial logging device compliance through the ELD mandate, with a schedule of compliance phases already in effect and set to reach full compliance by 2019. A number of ELDs have expanded their data-recording capabilities beyond HOS logging and now feature EDR-type recording of hard brake and other collision-type event data. Some of these devices furthermore feature advanced ADAS capability, such as LDW and collision avoidance systems. While possible to add programming that expands HVEDR functionality in these devices, it must be noted that not all motorcoaches, commercial buses and school buses will be required by the FMCSA mandate to be equipped with ELDs to render them a comprehensive “host” for HVEDR software in the bus and motorcoach sector. Additionally, crash survivability is not required of these devices, and use of crash survivable add-on devices would significantly increase equipment costs, resulting in fleet pushback.

Other add-on devices designed specifically to meet appropriate crash survivability and collision event data-recording requirements are also available, such as the Kienzle Automotive UDS that has featured prominently in a number of European studies with positive HVEDR findings. But while the UDS’s reporting rate and sensors make this an appealing HVEDR option, it comes with the considerable disadvantage of heavy per-vehicle cost of installation. While cost is beyond the scope of this study, it has been shown to play a significant factor in industry and fleet acceptance of a data-recording device standard.

A likely option for standardizing HVEDR in buses and motorcoaches lies in utilizing the HVEDR functionality already present across major OEM ECUs, which have been moving in the direction of the SAE J2728 HVEDR RP even without regulation.

To maximize this already-existing HVEDR functionality, a number of objectives need be considered. As the data that comprises an HVEDR report are often dispersed across different OEM ECU modules, recording all HVEDR data in a single module that is either accessible via DLC (as defined by J1939/13 on a heavy truck) or can be turned to if the vehicle sustains too much damage to connect via the DLC is preferable. Common HVEDR data reporting frequency, duration and thresholds, as well as a common clock possibly utilizing GPS timestamps, are also important objectives for standardization. A universal data-retrieval tool compatible across various OEM ECUs would simplify training on accessing HVEDR data, and archiving data in a common format would streamline accuracy of collected results for meaningful crash analysis. Staging compliance in phases, as seen with the FMCSA ELD mandate, further allows OEMs time to develop iterations meeting new requirements. Given the industry’s present direction towards standardization with SAE J2728, this OEM-based solution for HVEDR standardization in motorcoaches, buses and school buses may receive the least pushback.

The research has indicated that, regardless of whether the solution comes from aftermarket add-on devices or already HVEDR-functional OEM ECUs, a common reporting format including standardized data elements and reporting frequency must be adopted. The inclusion of data elements from ADS, such as forward and rearward AEB systems that are specific to accident reconstruction, need to be included. The commonly used 1-Hz recording rate is inadequate, and it is recommended that new systems record at rates of 10 Hz or greater, per SAE J2728. Finally, a common data-retrieval tool compatible with any commercial vehicle, regardless of the commercial vehicle (or engine) manufacturer, is needed.

APPENDIX A - ACRONYMS

ACB	Active Cruise with Braking
ACCTYPE	Accident Type
ACM	Air Bag Control Module
ADAS	Advanced Driver Assistance Systems
ADEM	Advanced Diesel Engine Management (Caterpillar)
ADR	Accident Data Recorder
ADS	Automated Driving Systems
AEB	Automatic Emergency Braking
AT	Advanced Technology
Ax, Ay	Longitudinal, Lateral Acceleration Change (g)
BAGDEPLY	airbag System Deployment
CAN	Controller Area Network
CDC	Collision Deformation Classification
CDR	Crash Data Retrieval
CDS	Crashworthiness Data System
CFR	Code of Federal Regulations
CIREN	Crash Injury Research and Engineering Network
CMVs	Commercial Motor Vehicles
CPC	Common Powertrain Controller
D	Deployment (event)
D/DL	Deployment and Deployment-Level (event)
D/N	Deployment and Non-Deployment (event)
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
DSRC	Dedicated Short Range Communications
DVLAT	Lateral component of delta V
DVLONG	Longitudinal component of delta V
ECM	Engine Control Module
ECU	Electronic Control Unit
EDR	Event Data Recorder
EDS	Electronic Data System
EECU	Engine Electronic Control Unit
ELD	Electronic Logging Device
ESC	Electronic Stability Control
FHWA	Federal Highway Administration
FLA	Forensic Link Adapter
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
g	grams
GM	General Motors
GMT	Greenwich Mean Time
GPS	Global Positioning Satellite
HOS	Hours of Service

HVEDR	Heavy Vehicle Event Data Recorder
Hz	hertz
IEEE	Institute of Electrical and Electronics Engineers
IPECU	Instrument Panel Electronic Unit
ITS	Intelligent Transportation System
kph	kilometers per hour
MANEUVER	Attempted Avoidance Maneuver
MANUSE	Manual (Active) Belt System Use
MBE	Mercedes Benz medium- and heavy-duty Engines
MCM	Motor Control Mount
MOU	Memorandum of Understanding
mph	miles per hour
ms	milliseconds
MY	Model Year
N	Non-Deployment (event)
NAFTA	North American Free Trade Agreement
NASS	National Automotive Sampling System
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
No	Number
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PDOF	Principal Direction of Force (1st)
PDOF1	Clock Direction for PDOF in Degrees (Highest CDC)
PLD	*Pumpe Liene Dusse*
RCM	Restraint Control Module
RF	Right-Front
RODS	Record of Duty Status
rpm	revolutions per minute
SAE	Society of Automotive Engineers
SDM	Sensing and Diagnostic Module (General Motors)
sec	seconds
SRS	Supplemental Restraint System
t	time (seconds)
TRB	Transportation Research Board
UDS	Universal Documentation Service
US DOT	United States Department of Transportation
UTC	Coordinated Universal Time
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VCU	Vehicle Control Unit
VDR	Vehicle Data Recorders
VECU	Vehicle Electronic Control Unit
VIN	Vehicle Identification Number
Vx (ΔVx)	Longitudinal delta V (mph)
Vy (ΔVy)	Lateral delta V (mph)

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