Development of Requirements and Functional Specifications for Crash Event Data Recorders

Final Report

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16. Abstract

The U.S. DOT has conducted research on the requirements for a Crash Event Data Recorder to facilitate the reconstruction of commercial motor vehicle crashes. This report documents the work performed on the “Development of Requirements and Functional Specifications for Crash Event Data Recorders” project, performed under U.S. DOT Contract: DTFH61-01-C-00182, Task Number: BZ82B007. It includes the results from the three program tasks: Task 1 – Develop Requirements for an EDR through Crash Analysis, Task 2 – Review Previous and Ongoing Efforts with Respect to Event Data Recorders (EDRs) and Vehicle Data Recorders (VDRs), and Task 3 – Develop Functional Specifications for an Event Data Recorder (EDR) for Commercial Motor Vehicles.

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FOREWORD

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ACRONYMS AND ABBREVIATIONS

ACRONYM	DEFINITION
3D	Three Dimensional
ΔV	Delta V, Change in Velocity
ABS	Anti-Lock Braking System
AC	Alternating Current
ACC	Automatic Cruise Control
Ack	Acknowledge
ACN	Automatic Collision Notification
AMPS	Advanced Mobile Phone Service
APP	Accelerator Pedal Position
ASCII	American Standard Code for Information Exchange
ASR	Acceleration Slip Regulation
ATA	American Trucking Associations
ATC	Automatic Traction Control
AVSC	Automatic Vehicle Speed Control
BCI	Bulk Current Injection
BTU	British Thermal Units
CCVS	Cruise Control/Vehicle Speed
CCW	Counterclockwise
CFC	Channel Frequency Class
CMV	Commercial Motor Vehicle
CTI	Central Tire Inflation
CVR	Cockpit Voice Recorder
CW	Clockwise
DC	Direct Current
DDU	Driver Display Unit
DED	Data Element Definition
DERM	Diagnostic Energy Reserve Module
DIU	Driver Interface Unit
DL	Driver's License
DOF	Degree-of-Freedom
DRL	Daytime Running Lamps
DSRC	Dedicated Short Range Communication
EBS	Electronic Braking System
ECBS	Electronically Controlled Braking System
ECM	Electronic/Engine Control Module
ECU	Engine Control Unit/ Electronic Control Unit
EDR	Event Data Recorder
EEPROM	Electrically-Erasable Programmable Read-Only Memory
EMI	Electromagnetic Interference
EMS	Emergency Medical Services
ESN	Electronic Serial Number
ESV	Enhanced Safety Vehicle
FAA	Federal Aviation Administration
FARS	Fatal Accident Reporting System

ACRONYM	DEFINITION
FCWS	Forward Collision Warning System
FDR	Flight Data Recorder
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FOT	Field Operational Test
g	Acceleration of Gravity
GES	General Estimates System
GHz	GigaHertz
GIS	Geographic Information System
GM	General Motors
GMT	Greenwich Mean Time
GPRMC	Recommended Minimum Specific GPS/Transit Data
GPS	Global Positioning System
GVWR	Gross Vehicle Weight Rating
HDOP	Horizontal Dilution of Precision
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz
I/O	Input/Output
ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IrDA	Infrared Data Association
ISM	InterStellar Medium
ISO	International Standards Organization
ITS/JPO	Intelligent Transportation Systems/Joint Program Office
IVI	Intelligent Vehicle Initiative
IWI	Independent Witness Incorporated
JPL	Jet Propulsion Laboratory
kbps	Kilobits Per Second
KHz	KiloHertz
kW	Kilowatt(s)
Lat	Latitude
LDWS	Lane Departure Warning System
LED	Light-Emitting Diode
Long	Longitude
LRMS	Location Reference Message System
LTCCS	Large Truck Crash Causation Study
MB	Megabytes
Mbps	Mega-Bits Per Second
MHz	MegaHertz
MMUCC	Model Minimum Uniform Crash Criteria
MV	Motor Vehicle
MVEDR	Motor Vehicle Event Data Recorder
N	Newton
NASA	National Aeronautical and Space Administration
NASS	National Automotive Sampling System

ACRONYM	DEFINITION
NAV	Navigation System
NCHRP	National Cooperative Highway Research Program
NCIC	National Crime Information Center
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
NMEA	National Maritime Electronics Association
NTSB	National Transportation Safety Board
NVM	Non-Volatile Memory
OEM	Original Equipment Manufacturer
OMC	Office of Motor Carriers
PAR	Police Accident Report
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PCU	Pressure Control Unit
PDA	Personal Digital Assistant
PDOF	Principal Direction of Force
PGN	Parameter Group Number
PID	Perimeter Identification
POI	Point of Impact
PSD	Power Spectral Density
PTO	Power Take Off
RF	Radio Frequency
RH	Relative Humidity
ROM	Read Only Memory
RP	Recommended Practice
RPM	Revolutions Per Minute
SAE	Society of Automotive Engineers
SCI	Special Crash Investigation
SDM	Sensing Diagnostic Module
SPN	Suspect Parameter Number
SRS	Supplemental Restraint System
T&B	Truck and Bus
TCD	Traffic Control Device
TMA	Truck Manufacturers Association
TMC	Technology and Maintenance Council
TRB	Transportation Research Board
US	United States
USB	Universal Serial Bus
USDOT	United States Department of Transportation
UTC	Universal Time Coordinated
VDC	Volts Direct Current
VDR	Vehicle Data Recorder
VIN	Vehicle Identification Number
VRTC	Vehicle Research and Test Center
WG	Working Group

EXECUTIVE SUMMARY

This report presents the results of a Federal Highway Administration (FHWA) Intelligent Transportation Systems/Joint Program Office (ITS/JPO) project, in collaboration with the Truck Manufacturers Association (TMA). In this project, a comprehensive requirements analysis defined specific crash event data recorder (EDR) requirements and functional specifications to facilitate the reconstruction of crashes involving large trucks. These requirements and specifications were developed through a review of previous and on-going EDR work and an analysis of CMV crash data. Using this information, specific data elements were ranked in the following three tiers to define crash characteristics in crashes involving commercial motor vehicles (CMVs):

Tier 1 – The minimum required data elements for a crash EDR on CMVs.
Tier 2 – Additional data elements to the data elements in tier 1 that would permit further analysis of crashes involving CMVs.
Tier 3 – A complete set of data crash elements to thoroughly analyze crashes involving CMVs, including the data elements listed in tiers 1 and 2 above.

After the tiers of data elements were established, a cost effectiveness analysis was conducted to estimate the costs of the data elements in each of the three tiers and to determine whether one or more data elements would significantly increase the cost of an EDR.

Tier 1 data elements included:

- Acceleration (Longitudinal, Lateral, and Vertical)
- Accelerator Pedal Position/Time History
- Brake Status/Pressure/Time History (includes Antilock Brake System)
- Belt Status
- Engine Speed
- Steering Wheel Angle/Time History
- Time/Date
- Transmission Gear Selection
- Vehicle Speed
- Wheel Speeds
- Vehicle Identification
- Vehicle Path

Tier 2 data elements, in addition to Tier 1 data elements, included:

- Airbag Status
- Battery and System Voltage
- Cruise Control Status
- Engine Retarder System Status
- Traction Control Status
- Clutch Position
- Headlight Status
- Running Light Status
- Turn Signal Status

- Warning Light Status
- Windshield Wiper Status
- Vehicle Load, Stability Control, Yaw and Tilt Angle (Advanced sensor installation)

Tier 3 included data elements, in addition to Tier 1 and 2 data elements, as well as:

- Brake Stroke
- Brake System Pressure
- Distance to Intersection
- Driver – Eye Glance Position
- Driver – Fatigue Status
- Horn Use / Status
- Roadway Surface Friction
- Running Light Status
- Side Object Detector
- Tire Pressure
- Truck Headway
- Truck Lane Position
- Video Imaging – Driver
- Video Imaging – Roadside Environment

In addition to the data elements tiers, requirements were also developed for EDR components, hardware, software, sensors, and databases. Furthermore, the project addressed issues such as, the physical attributes of the device, crash/environmental survivability, availability of appropriate sensors; data storage and retrieval; crash event trigger algorithms; accuracy and reliability; calibration; and maintainability. In summary, the Development of Requirements and Functional Specifications for Crash Event Data Recorders project can provide a foundation for a future design of a crash EDR for CMVs.

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INTRODUCTION

Crash Event Data Recorders (EDRs) can provide critical information on crashes involving commercial motor vehicles (CMVs) to improve the current understanding of vehicle safety and support the development of future crash countermeasures. This Federal Highway Administration Intelligent Transportation Systems/Joint Program Office (FHWA ITS/JPO) project, in collaboration with the Truck Manufacturers Association (TMA), consisted of a comprehensive requirements analysis, which defined specific EDR requirements and functional specifications to facilitate the reconstruction of crashes involving large trucks (gross vehicle weight rating (GVWR) of more than 10,000 pounds). Specifically, the project built upon the findings of the National Highway Traffic Safety Administration (NHTSA) sponsored Truck and Bus Event Data Recorder Working Group (T&B EDR WG).

Three main tasks were performed in this project:

1. Task 1 – Develop Requirements for an EDR through Crash Analysis
2. Task 2 – Review Previous and Ongoing Efforts with Respect to EDRs and Vehicle Data Recorders (VDRs)
3. Task 3 – Develop Functional Specifications for an EDR for CMVs.

Task 1 consisted of initially analyzing the National Crash Sampling System's (NASS's) General Estimates System (GES) data to characterize large truck (GVWR of more than 10,000 pounds) crashes. Then, a profile of large truck crashes established through the use of NASS GES data was used to select crashes from the NHTSA/Federal Motor Carrier Safety Administration (FMCSA) Large Truck Crash Causation Study (LTCCS). 133 cases were selected from the LTCCS for in-depth crash analysis. The analysis of these cases resulted in a list of data elements that could be recorded by an EDR and be useful for crash reconstruction.

Task 2 consisted of reviewing EDR literature, uses, and recommendations from several government agencies and other stakeholders. The majority of the recommendations focused on the types of data elements that should be collected in an EDR. In addition, the data elements available on the in-vehicle data networks (Society of Automotive Engineers (SAE) J-1587 and SAE J-1939) were reviewed.

Task 3 involved using the information in Task 1 and 2 to rank data elements in the following three tiers to define crash characteristics in crashes involving CMVs:

Tier 1 – The minimum required data elements for a crash EDR on CMVs.
Tier 2 – Additional data elements to the data elements in tier 1 that would permit further analysis of crashes involving CMVs.
Tier 3 – A complete set of data crash elements to thoroughly analyze crashes involving CMVs, including the data elements listed in tiers 1 and 2 above.

After the categories of data elements were established, a cost effectiveness analysis was conducted to estimate the costs of the data elements in each of the three tiers and to determine whether one or more data elements would significantly increase the cost of an EDR. In addition, operational (environmental and electrical) specifications for an EDR were created, along with methods of communication with an EDR in order to off-load an EDR's data.

TASK 1 – ANALYZE CRASH DATA

INTRODUCTION

This section summarizes the work performed on Task 1 – Develop Requirements for an EDR through Crash Analysis. The basis for this analysis included previous work from NHTSA, FMCSA, National Transportation Safety Board (NTSB), along with a comprehensive requirements analysis to define specific EDR requirements and functional specifications for the reconstruction of crashes involving large trucks. A requirements-based approach applied large truck crash data from the NHTSA/FMCSA LTCCS to derive requirements for an EDR that would facilitate crash reconstruction. These findings were used to develop functional specifications and requirements for an EDR that could be successfully implemented in large trucks.

LARGE TRUCK CRASH PROFILE

In order to select a proper population of truck crashes for analysis, an evaluation of the large truck crash population was performed using the NASS GES. GES data come from a nationally representative sample of police reported motor vehicle crashes of all types, from minor to fatal. The GES began operation in 1988 to identify traffic safety problem areas, provide a basis for regulatory and consumer initiatives, and form the basis for cost and benefit analyses of traffic safety initiatives. The information is used to estimate how many motor vehicle crashes of different kinds take place and what happens when they occur. Although various sources suggest that about half of the motor vehicle crashes in the country are not reported to the police, the majority of these unreported crashes involve only minor property damage and no significant personal injury. By restricting attention to police-reported crashes, GES concentrates on those crashes of greatest concern to the highway safety community and the general public.

GES data are used in traffic safety analyses by NHTSA and other USDOT agencies. In order for a crash to be eligible for the GES sample, a police accident report (PAR) must be completed where the crash involved at least one motor vehicle traveling on a trafficway, resulting in property damage, injury, or death. These crash reports are chosen from 60 areas that reflect the geography, roadway mileage, population, and traffic density of the United States. GES data collectors make weekly visits to approximately 400 police jurisdictions in the 60 areas across the U.S., where they randomly sample about 50,000 PARs each year. The data collectors obtain copies of the PARs and send them to a central contractor for coding. No other data are collected beyond the selected PARs.

Trained data entry personnel interpret and code data directly from the PARs into an electronic data file. Approximately 90 data elements are coded into a common format. Some element modification takes place every other year in order to meet the changing needs of the traffic safety community. To protect individual privacy, no personal information, such as names, addresses, or specific crash locations, is coded. During coding, the data are checked electronically for validity and consistency. After the data file is created, further quality checks are performed on the data through computer processing and by the data coding supervisors.

To understand an EDR’s utilization environment, an evaluation of GES data was conducted to determine the type of crashes that large trucks are currently involved in. For this analysis, two years of GES data, from 2000 and 2001, were examined to determine if the trends observed in the data were consistent across a two year period or if a “spike” in the data record. After an examination of these results, data spikes were not apparent in the data, and the two years of data were believed to be sufficient for this analysis.

In 2000 and 2001, over 11 million vehicle crashes were recorded in GES. As shown in Table 1, medium/heavy truck crashes constituted 3.4% and 3.5% of the population in 2000 and 2001, respectively. (Medium/heavy trucks in GES are defined as large trucks with a GVWR of more than 10,000 pounds.) The data for these various large truck body types are also shown in Table 2. The crash analysis for this project focused on these vehicles.

Table 1
Crash Frequency by Body Type for GES Years 2000 and 2001

Body Type	2000 GES Frequency	2000 GES Percent	2000 GES Cum. Percent
Automobiles and Derivatives	6,730,902	59.3	59.3
Utility Vehicles	1,080,662	9.5	68.8
Light Trucks	2,814,394	24.8	93.6
Bus – School Bus	26,510	0.2	93.8
Bus – Transit, Intercity, etc.	26,749	0.2	94.0
Bus – Unknown	2,573	0.0	94.0
Medium/Heavy Truck – Step Van	1,786	0.0	94.0
Medium/Heavy Truck – Straight Truck	140,769	1.2	95.2
Medium/Heavy Truck – Motor Home	3,011	0.0	95.2
Medium/Heavy Truck – Tractor/Trailer	208,466	1.8	97.0
Medium/Heavy Truck – Unknown	48,885	0.4	97.4
Motorcycles	68,640	0.6	98.0
Other/Unknown Body Type	192,863	1.7	99.7
Total	**11,346,210**	**99.7**	**99.7**

Body Type	2001 GES Frequency	2001 GES Percent	2001 GES Cum. Percent
Automobiles and Derivatives	6,518,991	58.3	58.3
Utility Vehicles	1,169,740	10.5	68.7
Light Trucks	2,822,651	25.2	94.0
Bus – School Bus	25,695	0.2	94.2
Bus – Transit, Intercity, etc.	25,925	0.2	94.4
Bus – Unknown	2,078	0.0	94.4
Medium/Heavy Truck – Step Van	1,844	0.0	94.4
Medium/Heavy Truck – Straight Truck	139,880	1.3	95.7
Medium/Heavy Truck – Motor Home	828	0.0	95.7
Medium/Heavy Truck – Tractor/Trailer	195,888	1.8	97.5
Medium/Heavy Truck – Unknown	47,379	0.4	97.9
Motorcycles	72,089	0.6	98.5
Other/Unknown Body Type	164,956	1.5	100.0
Total	**11,187,944**	**100.0**	**100.0**

Table 2
Crash Frequency by Body Type

Body Type	2000 GES Frequency	2000 GES Percent	2000 GES Cum. Percent
Medium/Heavy Truck – Step Van	1,786	0.4	0.4
Medium/Heavy Truck – Straight Truck	140,769	34.9	35.3
Medium/Heavy Truck – Motor Home	3,011	0.7	36.0
Medium/Heavy Truck – Truck/Tractor	208,466	51.7	87.7
Medium/Heavy Truck – Unknown	48,885	12.1	99.8
Total	**402,917**	**99.8**	**99.8**

Body Type	2001 GES Frequency	2001 GES Percent	2001 GES Cum. Percent
Medium/Heavy Truck – Step Van	1,844	0.5	0.5
Medium/Heavy Truck – Straight Truck	139,880	36.2	36.7
Medium/Heavy Truck – Motor Home	828	0.2	36.9
Medium/Heavy Truck – Truck/Tractor	195,888	50.8	87.7
Medium/Heavy Truck – Unknown	47,379	12.3	100.0
Total	**385,819**	**100.0**	**100.0**

The GES data file also provided the identification of crash configurations, which described the relative motion of each vehicle in multiple vehicle crashes or other descriptive features in single vehicle crashes. Table 3 and Table 4 illustrate the crash configurations for data years 2000 and 2001. The crash configurations were consolidated into the major descriptions within each configuration.

Table 3
Crash Frequency by Crash Configuration – 2000 GES

Cat. No.	Code	Category	Configuration	Description	Frequency	Percent
-	0	No Impact	N/A		11,548	
				Total: No Impact	**11,548**	**4.9**
I	1	Single Driver	A: Right Roadside Departure	Drive off road	16,320	
	6		B: Left Roadside Departure	Drive off road	4,237	
	11		C: Forward Impact	Parked vehicle	17,204	
				Total: Single Driver	**37,761**	**15.9**
II	20	Same Trafficway, Same Direction	D: Rear End	Stopped	44,637	
	34		E: Forward Impact	This vehicles strikes another vehicle	30	
	44		F: Sideswipe/Angle	Straight ahead on left	54,565	
				Total: Same Trafficway, Same Direction	**99,232**	**41.9**
III	50	Same Trafficway, Opposite Direction	G: Head on	Lateral move (left/right)	1,462	
	54		H: Forward Impact	This vehicle strikes another vehicle	8	
	64		I: Sideswipe/Angle	Lateral move (left/right)	7,638	
				Total: Same Trafficway, Opposite Direction	**9,108**	**3.8**
IV	68	Changing Trafficway, Vehicle Turning	J: Turn Across Path	Initial opposite direction (left/right)	25,048	
	76		K: Turn Into Path	Turn into same direction (turning left)	16,117	
				Total: Changing Trafficway, Vehicle Turning	**41,165**	**17.4**
V	86	Intersecting Paths (Vehicle damage)	L: Straight Paths	Striking from the right	7,450	
				Total: Intersecting Paths (Vehicle damage)	**7,450**	**3.1**
VI	92	Miscellaneous	M: Backing	Backing vehicle	30,563	
				Total: Miscellaneous	**30,563**	**12.9**
				Total	**236,827**	**99.9***

*Sum not equal to 100% due to rounding.

Table 4
Crash Frequency by Crash Configuration – 2001 GES

Cat. No.	Code	Category	Configuration	Description	Frequency	Percent
-	0	No Impact	N/A		15,092	
				Total: No Impact	**15,092**	**6.8**
I	1	Single Driver	A: Right Roadside Departure	Drive off road	11,135	
	6		B: Left Roadside Departure	Drive off road	3,751	
	11		C: Forward Impact	Parked vehicle	10,961	
				Total: Single Driver	**25,847**	**11.6**
II	20	Same Trafficway, Same Direction	D: Rear End	Stopped	44,049	
	34		E: Forward Impact	This vehicle strikes another vehicle	349	
	44		F: Sideswipe/Angle	Straight ahead on left	51,573	
				Total: Same Trafficway, Same Direction	**95,971**	**43.2**
III	50	Same Trafficway, Opposite Direction	G: Head on	Lateral move (left/right)	818	
	54		H: Forward Impact	This vehicle strikes another vehicle	46	
	64		I: Sideswipe/Angle	Lateral move (left/right)	10,549	
				Total: Same Trafficway, Opposite Direction	**11,413**	**5.1**
IV	68	Changing Trafficway, Vehicle Turning	J: Turn Across Path	Initial opposite direction (left/right)	22,695	
	76		K: Turn Into Path	Turn into same direction (turning left)	14,470	
				Total: Changing Trafficway, Vehicle Turning	**37,165**	**16.7**
V	86	Intersecting Paths (Vehicle damage)	L: Straight Paths	Striking from the right	5,624	
				Total: Intersecting Paths (Vehicle damage)	**5,624**	**2.5**
VI	92	Miscellaneous	M: Backing	Backing vehicle	31,162	
				Total: Miscellaneous	**31,162**	**14.0**
				Total	**222,274**	**99.9***

*Sum not equal to 100% due to rounding.

LARGE TRUCK CRASH LOCATIONS

GES crash data records also provided insight into the roadways where large truck crashes occur. Table 5 illustrates the distribution of vehicle crashes between the interstate highway system and other roadways. (An "Interstate Highway" is an FHWA designation for those roadways that are part of the Dwight D. Eisenhower System of Interstate and Defense Highways.) According to this data, approximately 21% of large truck crashes occurred on the interstate highways.

Table 5
Crash Location

Interstate Highway	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
No	317,335	78.8	303,459	78.7
Yes	85,210	21.2	82,109	21.3
Total	**402,545**	**100.0**	**385,568**	**100.0**

Table 6 provides additional data on the location of large truck crashes. The Relation to Roadway Variable in the GES system provided data on the location of the first harmful event where the first impact occurred. The results provided data that is linked to the truck's operational profile. While the predominant location for the first harmful event is on the roadway, several crashes occurred in the parking lane or on the roadside.

Table 6
Crash Relation to Roadway

Relation to Roadway	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
On roadway	341,780	84.8	334,860	86.8
On shoulder	5,926	1.5	3,659	0.9
On median	3,868	1.0	3,700	1.0
On roadside	24,068	6.0	18,420	4.8
Outside trafficway	4,141	1.0	3,216	0.8
Off-road, location unknown	4,989	1.2	6,788	1.8
In parking lane	16,377	4.1	14,414	3.7
Gore	612	0.2	368	0.1
Separator	585	0.1	28	0.0
Unknown	571	0.1	367	0.1
Total	**402,917**	**100.0**	**385,820**	**100.0**

As shown in Table 7, additional descriptive data regarding crash locations was provided by the Relation to Junction Variable within the GES. In 2000 and 2001, approximately 50 percent of large truck crashes occurred between intersections in non-interchange, non-junction areas.

Table 7
Crash Relation to Junction

Relation to Junction	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Non-interchange, non-junction	192,646	47.8	193,608	47.6
Non-interchange, intersection	60,736	15.1	60,900	15.8
Non-interchange, intersection-related	80,677	20.0	80,131	20.8
Non-interchange, drive, alley	35,223	8.7	26,476	6.9
Non-interchange, ramp	2,461	0.6	1,533	0.4
Non-interchange, rail crossing	1,895	0.5	1,732	0.4
Non-interchange, bridge	2,425	0.6	2,065	0.5
Non-interchange, cross-over related	1,154	0.3	804	0.2
Non-interchange, other	636	0.2	2,115	0.5
Non-interchange, unknown	2,332	0.6	2,217	0.6
Interchange, non-junction	3,662	0.9	3,090	0.8
Interchange, intersection	2,798	0.7	2,473	0.6
Interchange, intersection related	1,180	0.3	1,120	0.3
Interchange, ramp	14,129	3.5	16,006	4.1
Interchange, bridge	170	0.0	75	0.0
Interchange, cross-over related	52	0.0	0	0.0
Interchange, other	155	0.0	1,016	0.3
Interchange, unknown	289	0.1	49	0.0
Unknown	315	0.1	409	0.1
Total	**402,935**	**100.0**	**385,819**	**99.9***

*Sum not equal to 100% due to rounding.

CRASH CONFIGURATIONS

The crash configuration distribution for large trucks was analyzed by examining the Manner of Collision Variable within the GES. The Manner of Collision Variable (GES Variable A7) indicates the orientation of the vehicles in a collision. Table 8 illustrates this distribution for large trucks for in 2000 and 2001.

The Manner of Collision distribution for large trucks was dominated by four configurations; “no collision,” “rear-end” (which includes the truck being hit from behind and the truck striking the rear of other vehicle), “angle,” and “sideswipe, same direction.” These four crash configurations accounted for over 94% of large truck crashes in 2000 and 2001.

Table 8
Crash Manner of Collision

Manner of Collision	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
No collision	104,710	26.0	90,045	23.3
Rear-end	103,346	25.6	102,945	26.7
Head-on	6,182	1.5	5,612	1.5
Rear-to-rear	0	0.0	644	0.2
Angle	103,168	25.6	106,148	27.5
Sideswipe, same direction	73,198	18.2	64,799	16.8
Sideswipe, opposite direction	11,977	3.0	14,290	3.7
Unknown	336	0.1	1,335	0.3
Total	**402,917**	**100.0**	**385,818**	**100.0**

ROADWAY CONDITIONS

The roadway and environmental conditions data provided useful information for the development of EDR requirements. These statistics revealed that large truck crashes primarily occurred on straight and level roadways. Table 9 and Table 10 show the distribution of large truck crashes by roadway alignment and roadway profile.

Table 9
Crash Roadway Alignment

Roadway Alignment	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Straight	318,668	79.1	297,758	77.2
Curve	45,607	11.3	42,823	11.1
Unknown	38,642	9.6	45,238	11.7
Total	**402,917**	**100.0**	**385,819**	**100.0**

Table 10
Crash Roadway Profile

Roadway Profile	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Level	231,346	57.4	211,521	54.8
Grade	72,815	18.1	67,596	17.5
Hillcrest	5,345	1.3	6,964	1.8
Other	394	0.1	364	0.1
Unknown	93,017	23.1	99,373	25.8
Total	**402,917**	**100.0**	**385,818**	**100.0**

ENVIRONMENTAL CONDITIONS

As shown in Table 11, the GES data revealed that large truck crashes primarily occurred in daylight hours with no adverse weather conditions. A smaller proportion of the crashes occurred in the rain.

Table 11
Crash Atmospheric Conditions

Atmospheric Conditions	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
No Adverse	340,959	84.6	339,860	88.1
Rain	32,028	7.9	32,981	8.5
Sleet	1,199	0.3	511	0.1
Snow	17,894	4.4	7,136	1.8
Fog	2,156	0.5	1,630	0.4
Rain & fog	345	0.1	0	0.0
Sleet & fog	357	0.1	9	0.0
Other	3,257	0.8	1,666	0.4
Unknown	4,721	1.2	2,027	0.5
Total	**402,916**	**100.0**	**385,820**	**100.0**

As shown in Table 12, the roadway surface conditions data mirrored the data from atmospheric conditions. Crashes for large trucks occurred predominantly on dry roads.

Table 12
Crash Surface Conditions

Surface Conditions	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Dry	316,666	78.6	320,882	83.2
Wet	53,348	13.2	48,197	12.5
Snow or slush	15,624	3.9	5,171	1.3
Ice	11,689	2.9	7,435	1.9
Sand, dirt, oil	190	0.0	585	0.2
Other	487	0.1	344	0.1
Unknown	4,913	1.2	3,204	0.8
Total	**402,917**	**100.0**	**385,818**	**100.0**

The lighting conditions under which these crashes occurred are shown in Table 13. The predominant lighting condition for large truck crashes was daylight.

Table 13
Crash Lighting Conditions

Light Conditions	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Daylight	320,490	79.5	314,861	81.6
Dark	32,602	8.1	27,898	7.2
Dark, but lighted	33,452	8.3	28,987	7.5
Dawn	9,500	2.4	7,656	2.0
Dusk	4,245	1.1	4,745	1.2
Unknown	2,628	0.7	1,673	0.4
Total	**402,917**	**100.0**	**385,820**	**100.0**

CRASH CHARACTERISTICS

The GES crash data file provided information about the characteristics of each large truck crash. While not as detailed as the data retrieved from the LTCCS, this data provided useful information about the kinematic environment where crashes occur and the severity of the crashes.

The GES Variable “First Harmful Event” describes the first property damaging or injury producing event in the crash. This variable identifies the type of crash such as, vehicle-to-vehicle, single-vehicle crash, or other type. Table 14 provides data on the first harmful event for large trucks crashes as listed in the 2001 and 2002 GES data file. The most harmful event in a large percentage of crashes was collision with a “Vehicle in Transport.” This value described vehicle-to-vehicle crashes between moving vehicles. The percentages of crashes involving large trucks within this category in 2000 and 2001 were 74.0% and 76.7%, respectively.

Table 14
First Harmful Event

First Harmful Event	2000 GES Frequency	2000 GES Percent	2001 GES Frequency	2001 GES Percent
Non-collision				
Rollover/overturn	12,644	3.1	11,292	2.9
Fire/explosion	2,568	0.6	1,507	0.4
Jackknife	4,251	1.1	3,121	0.8
Non-collision injury	69	0.0	41	0.0
Road surface irregularity	10	0.0	56	0.0
Other non-collision	13,603	3.4	19,815	5.1
Thrown/falling object	291	0.1	297	0.1
Collision with object not fixed				
Pedestrian	1,672	0.4	910	0.2
Cycle/cyclist	681	0.2	641	0.2
Train	685	0.2	292	0.1
Animal	4,419	1.1	4,482	1.2
Vehicle in transport	298,207	74.0	295,774	76.7
Parked vehicle	18,501	4.6	15,905	4.1
Other non-motorist	16	0.0	246	0.1
Other object not fixed	4,273	1.1	2,275	0.6
Object not fixed – no description	425	0.1	36	0.0
Collision with fixed object				
Ground	1,209	0.3	45	0.0
Building	592	0.1	649	0.2
Impact attenuator	388	0.1	50	0.0
Bridge structure	2,436	0.6	511	0.1
Guard rail	4,651	1.2	4,551	1.2
Traffic barrier	2,070	0.5	2,314	0.6
Post/pole/support	11,365	2.8	6,333	1.6
Culvert/ditch	1,995	0.5	2,768	0.7
Curb	803	0.2	587	0.2
Embankment	1,521	0.4	1,716	0.4
Fence	2,083	0.5	676	0.2
Wall	885	0.2	384	0.1
Fire hydrant	1,876	0.5	875	0.2
Shrubbery/bush	97	0.0	268	0.1
Tree	2,953	0.7	1,524	0.4
Boulder	92	0.0	119	0.0
Other/Unknown				
Other fixed object	5,524	1.4	5,383	1.4
Unknown	62	0.0	378	0.1
Total	**402,917**	**100.0**	**385,821**	**100.0**

LTCCS CASE SELECTION

To support the development of distinct tiers of the most critical data elements, “real world” crash data from the LTCCS were analyzed to facilitate determining the most beneficial types of recorded data to reconstruct crashes involving large trucks. The profile of large truck crashes established through the use of NASS GES data was used to select crashes from the NHTSA/FMCSA LTCCS. The LTCCS is the first national study to determine the reasons and associated factors contributing to serious large truck crashes. Using this information, agencies within the US Department of

Transportation (USDOT) and others could gain an understanding of crashes and work to implement effective countermeasures to reduce the occurrence and severity of these crashes.

In the LTCCS, researchers and State truck inspectors collected information on a sample of large truck crashes. The NASS-trained researchers worked in unison with state inspectors at a crash scene to investigate the facts and causes of the truck-involved crash. The NASS-trained researchers worked with state inspectors at a crash scene to investigate the facts and causes of the truck-involved crash. NASS researchers depended on the voluntary participation and cooperation of law enforcement agencies, hospitals, physicians, medical examiners, coroners, tow yard operators, garages, vehicle storage facilities, and the individuals involved in crashes. Cooperation was established with police agencies and hospitals to provide copies or transcripts of official records. Tow yards, police impound yards, and crash involved parties were contacted to obtain permission to inspect vehicles. Personal or telephone contact was made with interviewees to obtain information about occupant characteristics and crash circumstances.

A specific set of data was retrieved from each LTCCS case. Data acquired in each case included, but was not limited to:

- First Harmful Event
- Case Summary by Investigator
- Critical Pre-Crash Event
- Violations Charged
- Critical Reason for Critical Event
- Attempted Avoidance Maneuver
- Scene Diagram
- Relation to Roadway
- Police Reported Travel Speed
- Relation to Junction

The selection of crash cases from the LTCCS was a critical step in the development tiers of data elements for an EDR. The GES profile of large truck crashes previously developed was used to select a similar profile of cases from the LTCCS. The ideal situation would be for the LTCCS case profile to match the GES crash profile previously established. Since the processing of all LTCCS data was not complete at the time of this effort, the cases used for this analysis were those that successfully passed all quality assurance steps within the LTCCS as of March 2003.

The case assessment involved filtering the available cases by crash type. The crash type variable and configuration codes in the LTCCS and NASS GES files are identical, which allowed a comparison of crash populations in both files. Only 213 crash cases were initially available for use in this assessment. An initial review of these cases reduced the number of cases to 180. Cases were dropped due to incomplete quality assurance checks, or the truck was not an active participant in the crash, such as when a truck is parked on the side of the road with the engine off and no driver present. A second round of case reviews eliminated further cases. Since the LTCCS had not completed the release of all data, a number of cases were withdrawn for further quality assurance procedures.

The final number of LTCCS cases for the EDR assessment was 133. The description of the crash compiled by the investigator and the scene diagram were critical in the identification of data elements for an EDR. Each individual case provided input for a list of data elements that would assist in the reconstruction of that case. The summing of the data elements for the various cases would show which elements would have the most utility in the various crash categories and which elements would be the least useful.

The distribution of the crash types and configurations included in the sample was examined to determine the fit with the previously developed GES profile. Table 15 illustrates the final distribution of the crash types in the LTCCS cases.

In the profile established from the GES data, the four most numerous crash categories were:

- Same Trafficway, Same Direction
- Changing Trafficway, Vehicle Turning
- Single Driver
- Miscellaneous (Backing)

In the population of LTCCS cases, these rash categories were the same. Yet, the remaining three categories (Same Trafficway, Opposite Direction; No Impact; and Intersecting Paths (Vehicle Damage)) were not in the same order in both crash profiles. As a result, they were represented in the final LTCCS cases, but not in the same order.

In the profile of LTCCS cases, there was an under-representation of “Same Trafficway, Same Direction” cases. These cases are typically rear-end or sideswipe/angle crashes. Although these types were underrepresented, they comprised a sufficient number for use in the assessment. Also, the “No Impact” crash types were not present in the LTCCS cases. These crashes typically included jack-knife crashes, comprising a small but significant population of the large truck crash population. Given these constraints, the match of the LTCCS cases to the GES Crash profile was adequate for a clinical analysis that would be used to determine tiers of data element for an EDR, in addition to other information sources.

Table 15
Sample of Cases from the LTCCS

Cat. No.	Code	Category	Configuration	GES Percentage 2000/2001	Frequency	Percent
-	0	No Impact	N/A		0	
			Total: No Impact	**4.9/6.8**	**0**	**0.0**
I	1	Single Driver	A: Right Roadside Departure		12	
	6		B: Left Roadside Departure		8	
	11		C: Forward Impact		7	
			Total: Single Driver	**15.9/11.6**	**27**	**20.3**
II	20	Same Trafficway, Same Direction	D: Rear End		24	
	34		E: Forward Impact		1	
	44		F: Sideswipe/Angle		11	
			Total: Same Trafficway, Same Direction	**41.9/43.2**	**36**	**27.1**
III	50	Same Trafficway, Opposite Direction	G: Head on		4	
	54		H: Forward Impact		1	
	64		I: Sideswipe/Angle		2	
			Total: Same Trafficway, Opposite Direction	**3.8/5.1**	**7**	**5.3**
IV	68	Changing Trafficway, Vehicle Turning	J: Turn Across Path		17	
	76		K: Turn Into Path		11	
			Total: Changing Trafficway, Vehicle Turning	**17.4/16.7**	**28**	**21.0**
V	86	Intersecting Paths (Vehicle damage)	L: Straight Paths		12	
			Total: Intersecting Paths	**3.1/2.5**	**12**	**9.0**
VI	92	Miscellaneous	M: Backing		23	
			Total: Miscellaneous	**12.9/14.0**	**23**	**17.3**
			Total	**99.9*/99.9***	**133**	**100.0**

*Sum not equal to 100% due to rounding.

LTCCS CASE ANALYSIS

The goal of the analysis of LTCCS cases was to develop a set of data elements for an EDR that would permit the reconstruction crashes involving large trucks. The elements recorded from the LTCCS cases are shown in Table 16.

Table 16
Data from LTCCS Cases

Form Type	Variable Number
General Vehicle	7 – Body Type 11 – Police Reported Travel Speed 17 – Violations Charged 20 – Relation to Roadway 21 – Relation to Junction 25 – Number of Travel Lanes 30 – Roadway Alignment 31 – Roadway Profile 32 – Roadway Surface Type 33 – Roadway Surface Condition 40 – Light Condition 41 – Atmospheric Condition 44 – Manner of Collision 45 – First Harmful Event 48 – Rollover 49 – Rollover Initiation Type 50 – Location of Rollover Initiation 54 – Fire Occurrence 55 – Origin of Fire
Crash Event Assessment	4 – Precrash Movement 5 – Critical Precrash Event 6 – Critical Reason for Critical Event 7 – Attempted Avoidance Maneuver 10 – Crash Type
Investigator's Description of Crash	
Driver/Surrogate Description of Crash Event	
Crash Diagram	

In order to support the development of EDR data element tiers, individual LTCCS cases were examined to determine what data would provide information that could lead to the reconstruction of each crash with a high degree of confidence. The cases included information on the environment, driver actions, and vehicle kinematics that may have caused or contributed to the crashes. While many of the data elements included on the list are readily available on existing vehicles and may be acquired by a number of different means, some data elements are not readily available on all large trucks. For example, vehicle speed may be acquired through a number of different means depending on the equipment on the vehicle, which may include:

- Read-out of vehicle speed sensor
- Acquisition of speed from Global Positioning System (GPS) data
- Calculation of speed from vehicle engine speed, gear engaged, and vehicle weight

Other situations exist where the technology is well established and referenced directly. Each manufacturer may use different means of acquiring the specific data elements. Also, the accuracy of the data from data sources may be questionable depending on its use. For instance, GPS provides information as it pertains to the receiver's antenna as it moves under the GPS satellites. Concerning GPS-received heading data, it may be erroneously equated to vehicle heading. The GPS provides the heading of the antenna, which may not be the direction of the vehicle. This situation is most prevalent when there are big slip angles, as found in a sliding turn or spin-out.

The summation of the data from the analysis of the entire population of cases provided a listing of the frequency that a specific data element occurred in the accident reports for the reconstruction of the 133 crash cases. A total of 45 data elements were identified in this analysis. The occurrence in the summed data ranged from 100% to 0.8%. Table 17 lists the data elements in decreasing order of their occurrence in the cases.

There was a drop-off in the data element frequency after the first nine data elements. The remaining data elements have lower frequency of occurrence values, since this information would be needed to define specific crashes. The initial set of nine data elements would primarily be used to describe the initial conditions of the vehicle before the crash (vehicle speed, path, heading), the actions of the driver (throttle, brake, steering position history) and the vehicle kinematics during the crash (lateral, longitudinal tractor accelerations). The tenth data element in the list was video imaging in front of the truck cab, which may be useful for the detection of by the other vehicles involved in a crash.

Important information about the assessment of the data elements is summarized below:

- A time standard by which all data can be linked is critically important in an EDR. The established time standard allows the construction of a crash timeline during the crash reconstruction effort.
- Two data elements that could be provided by onboard safety systems include vehicle headway from Forward Collision Warning Systems (FCWS) and lane position from Lane Departure Warning Systems (LDWS). These technologies would not be available on all large trucks.
- While video imaging from the front of the vehicle was high on the listing of data elements, the imaging of other aspects did not appear high in the listing.
- Many of the elements that are easily accessible on the vehicle data bus were not high on the priority listing developed in this task. Also, "conventional" data such as headlight status, engine speed, and transmission gear engaged could be easily obtained.
- While tractor acceleration appears on a high percentage of cases, trailer acceleration does not. This is primarily due to the dynamics of combination vehicles and the crash types; the acceleration of the trailer is primarily important in cases where the driver loses control, or the vehicle jackknifes. In other situations, the dynamics and acceleration of the combined tractor and trailer are essentially the same.
- The data elements listed in Table 17 were based on engineering judgment in analyzing the LTCCS data to determine which data elements would have been useful in reconstructing each crash in the set of 133 crashes.

Table 17
Data Elements and Frequency of Occurrence in LTCCS Case Analysis

Rank	Data Element	Frequency (%)	Possible Data Source
1	Time Standard	100.0	Real time clock chip in EDR
2	Vehicle Speed	99.2	Speed Sensor/Vehicle Network
3	Vehicle Path	99.2	GPS
4	Throttle Position History	96.8	Engine ECU/Pedal Sensor/Vehicle Network
5	Brake Position History	96.8	Brake position sensor/ABS ECU/Vehicle Network
6	Steering Position History	96.8	Steering wheel position sensor
7	Vehicle Heading	96.0	GPS
8	Acceleration – Tractor Longitudinal	96.0	Accelerometer/ECU – tractor
9	Acceleration – Tractor Lateral	95.2	Accelerometer/ECU – tractor
10	Video Imaging – Vehicle Front	49.6	Video camera
11	Vehicle Lane Position	16.8	Lane tracking system
12	Vehicle Headway	11.2	Automatic Cruise Control - Collision Warning System
13	Brake System Pressure	10.4	Pressure Sensor/ABS ECU/Vehicle Network
14	Acceleration – Tractor Vertical	10.4	Accelerometer/ECU- tractor
15	Yaw Angle/Rate	8.8	Yaw sensor – gyro chip
16	Brake Stroke	4.8	Brake stroke sensor
17	Roll Angle/Rate	4.8	Roll/Tilt sensor – gyro chip
18	Video Imaging – Vehicle Rear	4.8	Video camera
19	Video Imaging – Vehicle Right	4.8	Video camera
20	Video Imaging – Vehicle Left	4.8	Video camera
21	Turn Signal Status	4.0	Switch Sensor/Engine ECU
22	Transmission Gear Engaged	3.2	Gear Sensor /Transmission ECU/Vehicle Network
23	Warning Light Status	3.2	Switch Sensor/Engine ECU
24	Brake System Status	2.4	ABS ECU/Brake Pedal Sensor/Vehicle Network
25	Engine Speed	2.4	Engine ECU/Vehicle Network
26	Driver Fatigue Status	2.4	Driver fatigue sensor/PERCLOS
27	Acceleration – Trailer Vertical	2.4	Accelerometer/ECU – trailer
28	Acceleration – Trailer Longitudinal	2.4	Accelerometer/ECU – trailer
29	Side Object Detection	1.6	Collision Warning System
30	Video Imaging – Vehicle Left Rear	1.6	Video camera

Rank	Data Element	Frequency (%)	Possible Data Source
31	Video Imaging – Vehicle Left Front	1.6	Video camera
32	Video Imaging – Driver	1.6	Video camera
33	Headlight Status	0.8	Switch Sensor/Dash ECU
34	Four-Way Flasher Status	0.8	Switch Sensor/Dash ECU
35	Horn Use/Status	0.8	Switch Sensor/Dash ECU
36	Running Light Status	0.8	Switch Sensor/Dash ECU
37	Tire Pressure Status	0.8	Central Tire Inflation System
38	Trailer Speed	0.8	GPS
39	Trailer Path	0.8	GPS
40	Trailer Heading	0.8	GPS
41	Driver Eye Position	0.8	Eye Tracking System
42	Vehicle Distance to Intersection	0.8	GPS
43	Roadway Surface Friction	0.8	Surface Friction Sensor
44	Acceleration – Trailer Lateral	0.8	Accelerometer/ECU – trailer
45	Video Imaging – Vehicle Right Rear	0.8	Video camera

SUMMARY

In order to develop a rationale for the inclusion of specific data elements in an EDR, the basis of their use in crash reconstruction was investigated. Large truck crashes were analyzed in the time frame from 2000 to 2001. GES data was reviewed to develop a profile of crashes by vehicle body type. The profile indicated that crashes conforming to the "Same Trafficway, Same Direction" crash category was the most common for large trucks. Other major crash categories included "Changing Trafficway, Vehicle Turning," and "Single Driver".

The profile of crashes from the GES data was used to select similar crash cases from the LTCCS. The analysis of the LTCCS cases focused on the identification of data on vehicle, driver, and environmental conditions along with the actions of other drivers that could be recorded on an EDR to facilitate the reconstruction of the crash. The analysis of the LTCCS data produced a list of 45 candidate data elements for an EDR.

TASK 2 – REVIEW LITERATURE

INTRODUCTION

The purpose of Task 2 was to review past and ongoing efforts in EDR development. While Task 1 provided a list of useful data elements for crash reconstruction, the review of past and ongoing EDR development efforts provided additional, valuable information on the data elements recommended by various government agencies, researchers, and other organizations. In order to compile a complete set of all data crash elements to thoroughly analyze crashes involving CMVs, several sources with information on EDR data elements and criteria were examined, which included publications, projects, standards, and other criteria.

LITERATURE REVIEW

A literature review was conducted to research past and ongoing EDR efforts. The following types of documents were reviewed:

- EDR WG Findings
- Government documents
- Technical papers
- Articles from periodicals
- Industry standards and recommended practices
- Manufacturers specifications

EDRs have been used in the aviation industry for several years; therefore, the majority of information collected from these sources was based on aviation practices, aviation experiences, or attempts to transfer aviation EDR knowledge to highway vehicle applications. Other sources focused on work that is currently underway with both light vehicles and large trucks. Several references discussed the survivability, electrical, and mechanical issues involved with automotive EDRs. Other references presented a broader discussion of EDRs and related non-technical issues. Some provided historical information on EDRs and views on data ownership, privacy, and proper use of collected data.

Existing recommendations and other government-backed research were compiled and compared to categorize what data elements have been recommended or used in research.

- NHTSA EDR WG Vol. 1 – General Data Element List
- NHTSA EDR WG Vol. 1 – Top 10 Data Element List
- NHTSA EDR WG Report: Vol. 2 – Supplemental Findings for Trucks, Motorcoaches, and School Buses)
- NTSB Recommendations (NTSB Document H-99-53)
- TRB Recommendations (listed in NHTSA EDR WG Report)
- FHWA Recommendations
- National Aeronautical and Space Administration (NASA) – Jet Propulsion Laboratories (JPL) “Advanced Airbag Technology Assessment”
- ATA – TMC Recommended Practice 1214
- NHTSA Experimental Safety Vehicle Data Elements

- NHTSA Light Vehicle “Naturalistic” Type Driving Study Data Elements
- Data Elements from Intelligent Vehicle Initiative (IVI) Field Operational Tests – Volvo
- Data Elements from IVI Field Operational Tests – Freightliner
- Data Elements from IVI Field Operational Tests – Mack
- Data Elements from IVI Field Operational Tests – Drowsy Driver Study
- NHSTA Automatic Collision Notification (ACN) Field Operational Test (FOT) Data Elements
- ComCARE Alliance ACN Recommendations

Throughout these documents, several of the same data elements may be referred to by different names. Data elements with slightly different names, but the same physical meaning, were combined. In addition, data elements with similar names were combined when possible.

During the timeframe of this project, the Institute of Electrical and Electronic Engineers (IEEE) and SAE were working on EDR standards. The IEEE P1616 WG was working on developing a standard, “Motor Vehicle Event Data Recorders (MVEDRs),” that will contain data element and interface definitions. It will define a standard for various EDR manufacturers to produce data in the same format. The SAE Vehicle Event Data Interface Committee (J1698-1) has working to establish a common format for the display and presentation of the data recorded by an EDR. It is also considering common data definitions for specific data elements, as well as other aspects of EDR standardization. The initial version of this standard documented current industry practices. Data standardization would aid in the process of easily identifying, interpreting, and comparing data retrieved from vehicles.

NHTSA RECOMMENDATIONS

The findings of the NHTSA T&B EDR WG provided the most comprehensive examination of EDR functionality, which served as the foundation for this project. The NHTSA report, *EDR Volume II – Supplemental Findings for Trucks, Motorcoaches, and School Buses (May 2002)* presented the output of collaboration between many government and industry stakeholders. The EDR WG’s objective was to facilitate the collection and utilization of collision avoidance and crashworthiness data from on-board EDRs. The T&B EDR WG consisted of NTSB experts, EDR manufacturers, academia, and other government organizations that assessed the need to obtain EDR data for describing crashes involving CMVs. This group of experts prioritized data elements that should be included in EDRs for CMVs into three lists: Priority 1, 2, and 3 (optional).

The T&B EDR WG determined that twenty-eight data elements should be included in EDRs for CMVs. These data elements were subdivided into the following lists:

- The Priority 1 data elements included:
    1. Acceleration, X (Longitudinal)
    2. Acceleration, Y (Lateral)
    3. Acceleration, Z (Vertical)
    4. Accelerator Pedal Position
    5. Antilock Brake System Status (ABS)
    6. Automatic Transmission Gear Selection
    7. Belt Status (driver)

8. Brake Position History and Status (Service Pedal, Emergency, Trailer)
9. Engine RPM
10. Identification
11. Time/Date
12. Vehicle Speed
13. Wheel Speeds

- The Priority 2 data elements included:
  1. Air Bag Deploy Time
  2. Air Bag Lamp Status
  3. Air Bag Status
  4. Battery Voltage
  5. Cruise Control (and Auto Distance)
  6. Heading
  7. Lamp Status
  8. Retarder System Status
  9. School Bus Warning Lamp Status
  10. Steering Wheel Angle
  11. Traction Control
  12. Turn Signal/Hazard Operation
  13. Windshield Wiper Status

- The optional data elements included:
  1. Digital Imaging
  2. Vehicle Load

These lists of data elements formed the basis for the Tier 1 and Tier 2 lists of data elements for this project. This information served as the foundation for further research and analysis of crash data.

The following summary presents an overview of the overall T&B EDR WG findings in their report:

- In the current fleet of large vehicles, very few employ EDR technology.
- Manufacturers of aftermarket EDRs have had limited success in deploying EDR technology into large vehicle fleets.
- Many manufacturers of engines for use in large vehicles have included memory modules in the engine's electronic control unit (ECU). To date, the data recorded are primarily for fleet management use.
- The NTSB has used engine control module (ECM) data to support crash investigations.
- The Working Group defined 28 data variables for inclusion in large vehicle EDRs.
- Thirteen data variables were defined as Priority 1.
- The Working Group established a set of survivability guidelines specifically tailored for large vehicle application.
- The Working Group established some guidelines for defining when data should be recorded in a crash event.

- The Working Group identified several areas that require additional research. Funding for research and development of emerging EDR technologies is required.
- EDRs have the potential to greatly improve truck, motorcoach, and school bus vehicle safety.

MODEL MINIMUM UNIFORM CRASH CRITERIA DATA ELEMENTS REVIEW

Another way of determining data elements for crash reconstruction was to examine the data elements specified by the Model Minimum Uniform Crash Criteria (MMUCC). The MMUC is a minimum set of crash data elements established by some of America's most prominent traffic safety experts. The MMUCC defines crash data elements relevant to injury control and highway and traffic safety, and it sets voluntary guidelines to help states collect consistent reliable crash information.

The MMUCC was used to determine how many of these data elements could be obtained from an EDR. Specifically, each data element was examined to determine the possibility recording that data element from an EDR and how the data would be obtained.

Of the 113 MMUCC data elements, 57 data elements have the potential of being recorded by an EDR. Although only approximately 50% of the MMUCC could be recorded, an EDR would assist the crash researcher and compliment the data collected at crash scenes. Several data elements would require cooperative data sharing with responsible jurisdictions and municipalities to determine geographical information system (GIS) data. Some jurisdictions would not have this geo-coded information.

IN-VEHICLE NETWORK DATA ELEMENTS REVIEW

Many data elements are available on the truck data buses or in-vehicle data networks. Two in-vehicle network specifications were examined:

1. SAE J1587 – Electronic Data Interchange Between Microcomputer Systems in Heavy-Duty Vehicle Applications (Low-Speed Network)
2. SAE J1939 – Recommended Practice for Control and Communications Network for On-Highway Equipment (High-Speed Network)

These specifications listed the data elements potentially available in an in-vehicle data network.

Of the 982 data elements reserved in SAE J1587 and J1939, 82 elements are currently available or will be available within five years. Of the 436 data elements having potential merit in an EDR, 71 are currently available on newly produced vehicle networks.

ON-BOARD LAND-VEHICLE MAYDAY REPORTING INTERFACE REVIEW

SAE Document J2313, "On-Board Land-Vehicle Mayday Reporting Interface" was reviewed to determine which data elements defined in the standard are also useful in crash reconstruction. This document defined the messages and data elements used for Mayday ACN systems. The majority of the data elements would be useful for crash reconstruction, since most of this data conveys crash and vehicle occupant data.

COMPLETE SET OF DATA ELEMENTS

The review of the aforementioned projects, publications, specifications, and criteria provided important information regarding the feasibility and usefulness of the data elements to fully describe the crash characteristics. This review resulted in a complete list of 571 EDR data elements.

TASK 3 – DEVELOP FUNCTIONAL SPECIFICATIONS

INTRODUCTION

Task 3 was based on the output of Task 1 (Develop Requirements for an EDR through Crash Analysis) and Task 2 (Review Previous and Ongoing Efforts with Respect to EDRs and VDRs). This task involves establishing the tiers of useful data elements for the reconstruction of crashes involving large trucks and specifying physical and operational aspects of EDRs for large trucks.

DATA ELEMENT TIERS

Using the complete list of 571 potential data elements that could be recorded by an EDR, crash analyses results, and previous and ongoing EDR information, EDR data elements were defined in detail that would comprise a list of Tier 1, 2, and 3 data elements for thoroughly analyzing crashes involving CMVs. These data elements would facilitate crash reconstruction and enhance the understanding of crashes involving large trucks.

Tier 1 – The minimum required elements for an EDR on CMVs:

- Acceleration (Longitudinal, Lateral, and Vertical)
- Accelerator Pedal Position/Time History
- Brake Status/Pressure/Time History (includes Antilock Brake System)
- Engine Speed
- Seat Belt Status
- Steering Wheel Angle/Time History
- Time/Date Standard
- Transmission Gear Selection
- Vehicle Identification
- Vehicle Path (GPS)
- Vehicle Speed
- Wheel Speeds

Tier 2 – Additional data elements to those in Tier 1 that would permit further analysis of crashes involving CMVs:

- Airbag Status/Deployment
- Angular Rate Yaw, Pitch, and Roll (Stability Control)
- Battery Voltage
- Cruise Control Status
- Engine Retarder System Status
- Headlight Status/Running Light Status
- Traction Control Status
- Vehicle Load
- Warning Light/Turn Signal Status
- Windshield Wiper Status

Tier 3 included data elements in addition to Tier 1 and 2 data elements, as well as:

- Brake Stroke
- Brake System Pressure
- Distance to Intersection
- Driver – Eye Glance Position
- Driver – Fatigue Status
- Horn Use / Status
- Roadway Surface Friction
- Running Light Status
- Side Object Detector
- Tire Pressure
- Truck Headway
- Truck Lane Position
- Video Imaging – Driver
- Video Imaging – Roadside Environment

These tiers were established by reviewing the complete list of 571 data elements along with recommended data elements from the T&B EDR WG and other experts. Furthermore, the frequency of occurrence information associated with each data element from the analysis of crash cases from the LTCCS was used to develop these tiers. The three tiers of priority crash data elements were established to provide valuable information for future designs of crash EDRs for large trucks.

DATA ELEMENT COST-EFFECTIVENESS ANALYSIS

Determining the availability and cost of data sources for each data element in the three tiers was complex due to the many different options and cost ranges of data sources available on trucks. Many data elements are available on truck data buses or in-vehicle data networks. In-vehicle data networks are used to report vehicle-operating conditions from ECUs gathering data from sensors already on the trucks. Therefore, the recording of information from the in-vehicle data networks, SAE J1708/J1587 and SAE J1939, would be low or no cost. Other data elements are basic “on/off” or “discrete” types of signals from switches, which can be cost-effectively recorded in an EDR.

Several data elements require costly data sources, such as GPS receivers, on-board “intelligent vehicle” safety systems, and video cameras. Although GPS units and many onboard safety systems are becoming more common on commercial vehicles, the use of these systems is not widespread throughout the trucking industry. If available on large trucks, these systems are often directly connected to the in-vehicle network; therefore, an EDR could be programmed to record data from these systems without incurring additional recurrent costs.

A cost effectiveness analysis revealed that the majority of Tier 1 data elements could be collected by the EDR at a low to moderate cost. The vehicle path data element would require a GPS receiver, and the steering wheel angle and transmission gear selection data elements would require advance sensors which are more costly data sources. In Tier 2, the vehicle load data element would require a high cost onboard system.

An EDR with the Tier 1 and 2 data elements would be able to record the major vehicle dynamics and operational conditions of a large truck at the time surrounding a crash. Many of these data elements may have the “dual-functionality” for both crash reconstruction and fleet management applications.

FUNCTIONAL SPECIFICATIONS

An EDR can only provide useful crash information if it functions properly and survives crashes. As a result, an analysis of common industry practices for in-vehicle electronics and for embedded data acquisition systems was conducted relating to the function and survivability of an EDR on large trucks. Yet, further research, system design, and testing would be required to confirm and validate the following information on large truck EDR functional specifications.

Crash Event Triggers

Crash event triggers initiate the recording of vehicle data to an EDR’s memory when an unusual event, incident, or operational situation occurs. The vehicle data surrounding that event should be saved for possible future analysis. EDR data is constantly read and temporarily stored in a circular buffer, which allows data to be captured before and after the event trigger. These data are often referred to as “pre-trigger” and “post-trigger” data for the reconstruction of an entire crash.

Algorithms

Algorithms refer to the method and procedure used when an EDR detects an event trigger. Developing a detailed algorithm for event trigger detection depends on the electronic hardware, sensors, microprocessor speed and type, and software design of an EDR.

Crash events involving a large change in velocity or a large acceleration/deceleration pulse over a short period of time would be relatively easy to detect and trigger EDR data storage on large trucks. However, many crashes involving large trucks may not be easily detected due to weight differences between light and heavy vehicles. Also, vehicle dynamics are important when articulated vehicles are involved in crashes. For example, if a light vehicle hits a truck’s trailer perpendicular to the long axis of the trailer at the trailer’s rear axle, an EDR on the tractor may not detect the impact. In order to detect trailer impacts, a second EDR could be mounted in the trailer. As a result, additional crashes may be detected with two EDRs that could record the acceleration and angular rotation of both the tractor and trailer. An EDR on the trailer could be set up to only record trailer dynamics and communicate with the primary EDR.

A false alarm may occur when an event is incorrectly recorded as a crash if the crash detection parameters are not adjusted properly. Also, crash-like events that occur during normal truck operations may be difficult to filter out. For example, coupling a tractor to a fully loaded trailer may be recorded as a rear-impact to the tractor. In order to minimize the number of false alarms, reliable data pertaining to large truck vehicle dynamics and operating parameters in various types of crashes, such as magnitude, duration, and frequency, should be used for the development of crash detection algorithms.

A manual feature could also be used to trigger an EDR recording. A driver-initiated event could be recorded when a driver presses a manual record button. An EDR would record the time that the button was pressed and store all vehicle dynamics and operational data in its memory for the time surrounding the event. Since EDR data are stored in a circular buffer, the recorded “pre-trigger” data would most likely capture the event.

Several types of vehicle sensor/system failures could trigger a vehicle-initiated event on an EDR. For example, a sudden loss of brake system air pressure could trigger an EDR recording event. These failures could potentially indicate a crash causation factor if the system failure event occurs relatively close to the time an actual crash event occurs. Since many different types of system failure event triggers could overcomplicate the overall EDR system, this type of event is recommended to be recorded only when "key" system failures occur that affect the safe operation of the vehicle.

A summary of the different event algorithms is shown in Table 18.

Table 18
Summary of EDR Event Algorithms

Event Type	Examples	Advantages	Disadvantages
Crash Events	Head-on, side-impact, rear-impact, offset, rollovers, jackknives, etc.	"Main" use of EDR –Many types of crash event data can be recorded, which could be used in Automatic Collision Notification (ACN) systems.	Some crash types may be difficult to detect due to the difference in mass between passengers cars and large trucks.
Driver-Initiated Events	Panic button for pedestrian impacts, abnormal vehicle operation, minor vehicle-to-vehicle crashes, etc.	"Supplemental" use of EDR – Drivers can initiate the recording of the vehicle state during an abnormal event, and can record events when witnesses are not present at scene.	Other EDR events may be overwritten. Drivers may not remember to use an EDR recording button due to infrequent use. Drivers may be unwilling to admit fault when an event has occurred and not use the button. Drivers may not have time to search for the button due to driving demands.
Vehicle-Initiated Events	Vehicle-operation based: Failures in brake system air pressure, fuel pressure, ABS, engine operation, or the charging/starting system, etc.	"Supplemental" use of EDR – Fleet management may be enhanced by early diagnosis of vehicle problems.	Other EDR events may be overwritten, and it adds complexity to overall event determination software.

EDR OPERATIONAL ENVIRONMENT

Several design standards have been developed for electronic device operation in vehicles. SAE J1455 ("Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks)") and SAE J1211 ("Recommended Environmental Practices for Electronic Equipment Design") are two comprehensive standards that cover both environmental and electrical conditions that an EDR may encounter in a vehicle. For EDR system designs, these SAE standards are recommended for operational parameters and test methods. An optimum location of an EDR is inside a truck's cab; as a result, the details presented in this section focus on standards for an interior mounted EDR.

Temperature – SAE J1455

A summary of the operational temperature data from SAE J1455 is shown in Table 19. Based on the operating temperature ranges for automotive grade electronics and crash survivability, the interior of the vehicle is recommended as an optimum location for an EDR in a large truck. Therefore, the

EDR should survive the normal operating temperature range in a vehicle cab of -40°C (-40°F) to 85°C (185°F).

Table 19
SAE J1455 Temperature Extremes for Heavy-Duty Truck/Tractor

Location	Temperatures Minimum	Temperatures Operating	Temperatures Maximum
Engine compartment – under hood, lower	-40°C	- - -	56°C over ambient
Engine compartment – under hood, upper	-40°C	- - -	222°C over ambient
Engine compartment – under hood, bulkhead	-40°C	- - -	56°C over ambient
Interior – floor*	**-40°C (-40°F)**	**27°C (81°F)**	**75°C (167°F)**
Interior – instrument panel	**-40°C (-40°F)**	**24°C (75°F)**	**85°C (185°F)**
Interior – headliner	-40°C	24°C	79°C
Interior – bunk area	-40°C	24°C	93°C
Interior – storage area	-40°C	24°C	74°C
Chassis – forward	-40°C	- - -	121°C
Chassis – rear	-40°C	- - -	93°C

* Shaded rows represent ideal EDR mounting locations (interior-floor and interior-instrument panel).

Humidity – SAE J1211

SAE J1211 states that the most extreme humidity occurs at 98% RH at 38°C (100°F) and references the following three methods of humidity testing:

1. Active temperature/humidity cycling under accelerated conditions (most common)
2. 10-day soak at 95% RH and 38°C (100°F) temperature
3. 8 to 24 hour exposure at 103.4 kPa (15 psi) in a pressure vessel

Salt Atmosphere – SAE J1455

Electronic equipment mounted on a vehicle chassis, exterior, and underhood may be exposed to a salt spray environment from sea breezes and road salt. If an EDR is mounted inside the truck cab, salt exposure would be limited. If an EDR is mounted on the exterior of the truck, then the SAE J1455 Salt Atmosphere Standard would be recommended for EDR testing.

Immersion and Splash (Water, Chemicals, and Oils) – SAE J1455

Immersion and splash by other fluids is a common problem on the exterior of the vehicle. During normal operation, an exterior mounted EDR would come in contact with any fluid used by the tractor such as diesel fuel, coolant, oil, power steering fluid, hydraulic brake fluid, and windshield washer fluid. An externally mounted EDR should also withstand exposure to road spray and the contaminants that are transported in the spray.

If an EDR is mounted inside the cab, exposure to these fluids is less likely, yet possible. Many truck drivers carry beverages and spare quantities of tractor fluids inside the cab, increasing the potential of leaks or spills in the area around an EDR. SAE Standards J1455 and J1211 specify a similar test method for immersion and spray.

Steam Cleaning/Pressure Washing – SAE J1455

The intense heat from cleaning sprays and the caustic nature of chemical agents used in washing solutions create a severe environment for devices and associated wiring and connectors mounted in the engine compartment, on the chassis, and on exterior areas. Exterior mounted EDRs should be tested in accordance with SAE J1455.

Fungus – SAE J1455

Fungi may affect a system's performance by degrading the material and causing physical/chemical changes or electrical failures. Two keys to avoiding susceptibility to fungus are to minimize the nutritive value of EDR materials, particularly, the case, paint, connectors, and seals, and to ensure that an EDR is properly sealed.

Dust, Sand, and Gravel Bombardment – SAE J1455

Dust creates a harsh environment for chassis, underhood, and exterior-mounted devices, and it can be a long-term problem in interior locations, such as under the dash and seats. Sand is an important environmental consideration for components mounted in the chassis, exterior, and underhood areas. Bombardment by gravel is significant for chassis, lower engine, and exterior-mounted electronic components.

Two recommended dust test methods for an interior mounted EDR are:

1. The EDR is placed in a dust chamber where dust is moved to maintain a concentration of 0.88 grams per cubic meter (g/m^3) for a period of 24 hours, or
2. 4.54 kg of powered cement is placed in a 91.4 cm cubical box. At intervals of 15 minutes, the dust is agitated by compressed air for 2 seconds, and blown in a downward direction. The cycle is repeated for 5 hours.

Altitude – SAE J1455

The effects of altitude on electronic systems include:

1. Reduction in convection heat transfer efficiency
2. Change in mechanical stress on parts with internal cavities
3. Reduction in the high voltage breakdown characteristics of systems with electrically stressed insulators, conductors, or air surfaces

In accordance with the SAE J1455 Standard, an EDR should operate in altitudes up to 3.6 km (12,000 ft), and survive non-operating up to 12.2 km (40,000 ft). These conditions correspond to absolute pressures of 62.0 kPa (9 psi) and 18.6 kPa (2.7 psi), respectively.

Mechanical Vibration – SAE J1455

Mechanical vibration is another key factor for vehicle electronic component design in a large truck environment. The amount of vibration varies significantly depending on the EDR mounting location and method, vehicle suspension, and types of roads traversed. SAE Standard J1455 provides examples of vibration environments in commercial vehicles. Section 4.9 of that standard explains how to test a device for mechanical vibration.

Three recommended mechanical vibration test methods are:

1. Swept Sine Vibration Tests – An EDR is placed on a shaker and ramped from low frequency to high frequency with an amplitude seen at the mounting location of the vehicle. The frequency ramp should be slow enough to allow for mechanical resonances to occur. This test should be performed in all three orthogonal axes.
2. Random Vibration Tests – If the power spectral density (PSD) of the mounting area is known, then a random vibration test can be performed. An EDR is mounted to a shaker, and a test excitation frequency containing the PSD of the mounting location is applied to the EDR.
3. Vehicle Tests – With the EDR mounted in the correct location on the vehicle, the vehicle is driven over several different test tracks to simulate real-world conditions. While this is a good final test, it is not an effective test during initial shakedown, because intermittent failures often go away when the vibration excitation is removed.

Mechanical Shock – SAE J1455

The automotive shock environment can be divided into four classes:

1. Shipping and Handling Shocks – These shocks are similar to those encountered in non-vehicle applications. Two tests are recommended for this type of shock: 1) Handling Drop Test, which impacts the device on three orthogonally different faces, and 2) Shipping Drop Test, which tests the device packed in its shipping container on various corners and faces.
2. Installation Harness Shock – A common production line practice is lifting and carrying components by their harness. Therefore, the harness design should incorporate secure fastening and suitable strain relief. The test would repeatedly swing the EDR by its wiring harness and check the harness and its strain relief area for damage.
3. Operational Shock – The shocks encountered during a vehicle's life caused by curbs, potholes, etc., can be severe. These shocks vary widely in amplitude, duration, and number, and test conditions can only be generally simulated. Trailer coupling or low speed loading dock collision provides a severe horizontal shock in truck operation. The complex profile used to derive an operational shock test consists of a rise in the roadway followed by a depression or dip. Upon leaving the dip at 48 km/hr (30 mph), the vehicle can become airborne. Severe shock may be experienced when the vehicle returns to the roadway. Another severe vertical shock is encountered in dump body trucks when loaded with rock and soil.
4. Crash Shock – This shock is included as an operating environment for safety systems. The operational requirements for these systems are limited to longitudinal shock at the present time. Only limited and preliminary data on the effects of crash shock on the vehicle electronic component environment are available. However, a representative deceleration

profile for a 48 km/hr (30 mph) barrier crash is shown in Figure 13 of SAE J1455. The following factors vary with each installation and should be considered in a pretest analysis:

a. Vehicle electronic component
b. Mounting system
c. Structure of the associated vehicle (crash distance, rate of collapse, etc.)
d. Particular engine package
e. Direction of crash

Full details for these operating specifications and related tests are given in SAE Standard J1455.

Steady-State Electrical Characteristics – SAE J1455

A normal operating vehicle will maintain supply voltages ranging from +11 to +16 VDC. However, under certain conditions, the voltage may fall to approximately 9 VDC. This voltage drop might occur in an idling vehicle with a large electrical load and a fully discharged battery. Therefore, depending upon the application, the designer/user may specify the +9 to +16 VDC range. For specific vehicle electronic components, such as those components that must function during engine start, voltage may be specified as appropriate.

Cold cranking of an engine with a partially depleted battery at -40°C (-40°F) can reduce the nominal 12 V to 6.5 V minimum at the battery terminals. At the starter motor terminals, because of the voltage drop on the battery cabling, the voltage typically varies sinusoidally from 5.2 to 7.8 V at a low frequency about 4 Hz (56 rpm, 8 cylinder engine) due to the engine compression load variation during the crank cycle.

Another condition affecting the DC voltage supply occurs when the voltage regulator fails, causing the alternator to drive the system at 18 V or higher. Extended 18 V operation will eventually cause boil-off of the battery electrolyte, resulting in voltages as high as 75 to 130 V. Other charging system failures can result in lower than normal battery voltages. General steady-state voltage regulation characteristics for 12 V and 24 V systems are shown in Table 20.

Garages and emergency road services have been known to utilize 24 V sources for emergency starts, and there are reports of 36 V being used for this purpose. High voltages such as these are applied for up to 5 minutes and sometimes with reverse polarity. The use of voltages that exceed the vehicle system voltage can damage electrical components, and the higher the voltage, the greater the likelihood of damage.

These specifications should be used for testing an EDR. In addition, combinations of temperatures and supply voltages that are designed to represent the worst case stresses on control components are recommended. See SAE Standard J1455, Section 4.11.1 for more details.

Table 20
SAE J1455 12-Volt and 24-Volt Operating Characteristics

Electrical Parameter	12-Volt Systems	24-Volt Systems
Normal operating vehicle	16 V maximum 14.2 V nominal 9 V minimum	32 V maximum 28.4 V nominal 18 V minimum
Cold cranking at -40 °C (-40 °F)	At the starter motor terminals: 5.2 V to 7.8 V At the battery terminals: 6.5 V minimum	At the starter motor terminals: 10.6 V to 16.0 V At the battery terminals: 13.3 V minimum
Jumper starts	+24 V	+48 V
Reverse polarity	-12 V	-24 V
Voltage regulator failure	9 to 18 V	18 to 36 V
Battery electrolyte boil-off	75 to 130 V	75 to 130 V

Voltage Transients – SAE J1455

Three principal types of transients are encountered on truck/tractor wire harnesses: load dump, inductive switching, and mutual coupling, which generally occur simultaneously. Table 21 describes these transient waveforms for both 12- and 24-volt systems.

Load Dump – Load dump occurs when the alternator load is abruptly reduced. This sudden reduction in current causes the alternator to generate a positive voltage spike. The most severe case load dump is caused by disconnecting a discharged battery when the alternator is operated at a rated load. Using the discharged battery load to create the load dump creates the worst situation for two reasons:

1. The battery normally acts like a capacitor and absorbs transient energy when it is in the circuit.
2. The partially discharged battery forms the single greatest load on the alternator. Therefore, disconnecting it creates the greatest possible step load change.

Inductive Switching – Inductive transients are caused by solenoid, motor field, air conditioning clutch, and ignition system switching, which occur during vehicle operation whenever an inductive accessory is turned off. The severity depends on the magnitude of switched inductive load and line impedance.

Mutual Coupling – Coupling is a mechanism that is capable of introducing transients into circuits not directly connected to the transient source. Three general coupling modes are in the vehicle: magnetic, capacitive, and conductive. Coupling problems are caused by long harnesses, non-shielded conductors, and common ground return impedances. When a number of wires are bundled into a harness and a step change in current or voltage occurs, inductive or capacitive coupling between the conductor experiencing the change and the other wires can result. Multiple ground returns with different potentials cause "ground loops" and result in conductive coupling of transients.

Table 21
SAE J1455 Transient Voltage Characteristics

Test Type	Lines	Source (Ohms)	Rise (µS)	Open Circuit Response (12 VDC)	Open Circuit Response (24 VDC)	Repetition	Energy
Load Dump	Power	0.4	100	$14 + 86e^{(-2.5t)}$	$28 + 122e^{(-2.5t)}$	5 pulses @ 10s interval	Note 2 Note 3
Inductive Switching	Input/Output (I/O) (Note1)	20	1	$14 \pm 600e^{(-1000t)}$	$14 \pm 600e^{(-1000t)}$	10 pulses @ 1s interval	Note 1 Note 3
Mutual Coupling	I/O All	50	1	$14 \pm 300e^{(-66666t)}$	$14 \pm 300e^{(-66666t)}$	10 pulses @ 1s interval	Note 3

Note 1: This transient applies to those I/O lines which may be connected to unclamped inductive loads. In addition, the energy available will be $0.5LI^2$, where I is the current through the inductor amps and L is the inductance in henries.

Note 2: The alternator is capable of outputting much more energy than can be absorbed by used electronic clamping devices. Therefore, when clamping devices are used in electronic modules, caution must be used in the design of the vehicle electrical system to insure the energy limitations of each clamping device are observed.

Note 3: The transient waveforms described previously in mathematical form may actually be implemented by diode allowing a DC and transient voltage.

Electrical Noise and Electrostatic/Electromagnetic Compatibility Characteristics

Normal accessory noise and vehicle transceiver feedback are two common interference sources that are covered under SAE Standards J1113 sections on conducted susceptibility, listed in Table 22. Electromagnetic Interference (EMI) is electromagnetic energy which interrupts, obstructs, or otherwise degrades or limits the effective performance of components, subsystems, and systems. EMI may be transient, intermittent, or continuous in nature arising from sources such as transmitters or other equipment located either on-board or adjacent to the vehicle.

Table 22
Various SAE Electrical Noise Test Standards

SAE Standard Number	Standard Title
J1113-1	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) (60 Hz to 18 GHz)
J1113-2	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) – Conducted Immunity, 30 HZ to 250 kHz--All Leads
J1113-3	Conducted Immunity, 250 kHz to 5000 MHz, Direct Injection of Radio Frequency (RF) Power
J1113-4	Immunity to Radiated Electromagnetic Fields– Bulk Current Injection (BCI) Method
J1113-11	Immunity to Conducted Transients on Power Leads
J1113-12	Electrical Interference by Conduction and Coupling – Coupling Clamp and Chattering Relay
J1113-13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 13 – Immunity to Electrostatic Discharge
J1113-21	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 21– Immunity to Electromagnetic Fields, 10 kHz to 18 GHz, Absorber-Lined Chamber
J1113-22	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 22 – Immunity to Radiated Magnetic Fields from Power Lines
J1113-23	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, Strip Line Method
J1113-24	Immunity to Radiated Electromagnetic Fields; 10 kHz to 200 MHz – Crawford TEM Cell and 10 kHz to 5 GHz – Wideband TEM Cell
J1113-25	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to Radiated Electromagnetic Fields, 10 KHz to 500 MHz - Tri-Plate Line Method
J1113-26	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to Alternating Current (AC) Power Line Electric Fields
J1113-27	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 27 – Immunity to Radiated Electromagnetic Fields

SAE Standard Number	Standard Title
J1113-41	Limits and Methods of Measurement of Radio Disturbance Characteristics of Components and Modules for the Protection of Receivers used On-Board Vehicles
J1113-42	Electromagnetic Compatibility– Component Test Procedure – Part 42 – Conducted Transient Emissions

Back-Up Power

A back-up power reserve is important to capture key crash data; however, an external power source may be problematic. If the structural integrity in the area of an EDR was compromised, the wiring connecting an EDR to this external power source could be damaged from an impact. Also, an external power source may be more costly than an internal power source.

With an internal back-up power source, an EDR would only record data from its internal sensors. Using a rechargeable internal battery or internal ultra-capacitor, an EDR could receive power if primary power is interrupted for approximately one minute. These internal back-up power sources solutions are industry-standard, cost-effective, and mature technologies.

Long-Term Data Storage

Using removable data storage media may be problematic, since devices, such as mini floppy drives or hard disk drives, are susceptible to dust, moisture, mechanical shock, and vibration. Using removable solid state media, such as PCMCIA cards or solid state hard disks, are also problematic, since these devices may be jarred loose from vehicle vibration or the impact from a crash event. In addition, the connectors used for these devices may corrode over time.

A non-removable solid state memory, such as Electrically-Erasable Programmable Read-Only Memory (EEPROM) or Flash Read Only Memory (ROM) should ensure data availability for future downloading. Battery-backed EDR memory could be used to store this data; however, the current state-of-the-art in non-volatile solid-state memory eliminates the need for a battery. Memory technologies, such as EEPROM or Flash Memory, will store its data for an indefinite period of time. The data remains in the memory until it is actively changed or erased.

Size, Weight, and Mounting Method

The size and weight of an EDR are subject to limitations. A trade-off between small size and heat dissipation may be necessary to allow an EDR to operate at the desired high-end of the operating temperature range. Light units are advantageous, because they will not add appreciable weight to the vehicle. In addition, a lighter unit will likely be subject to less inertia when the vehicle undergoes severe vibration or deceleration due to a crash. Since an EDR must also be able to survive the large truck environment and a crash, a balance between weight and ruggedness should be considered for EDR survivability.

EDR mounting involves two main concerns:

1. **Accurate recording of data –** If an EDR is mounted in an area prone to vibration or towards the front of the vehicle, it will be subject to a crash pulse different from one felt by vehicle occupants. As a result, an EDR mounted in a rigid area in or near the occupant compartment is recommended for a more accurate crash pulse history to be recorded.

2. **Prevention of EDR damage in crash events –** Since an EDR should be able to withstand a significant crash force, it should be installed in a location that is not prone to extensive crash damage. An EDR must function after the event trigger to record and store post-trigger data until it can be off-loaded. If a severe impact occurs directly in the area where an EDR is installed, an EDR mounting method could be designed to release the EDR from the mounting surface.

EDR SURVIVABILITY

In addition to environmental conditions, EDRs must survive crashes. Table 23 lists survivability parameters for EDRs. For comparison, the table includes the IEEE P1616 WG Preliminary Draft Recommendations, NHTSA Truck & Bus Findings, Federal Motor Vehicle Safety Standards (FMVSS) 208/214 views on data survivability, NTSB specifications for the survivability for aircraft Flight Data/Cockpit Voice Recorders, and recommended survivability requirements for locomotive and rail passenger EDRs. Further research and testing of these survivability parameters would be required prior to advocating a particular survivability parameter.

Table 23
EDR Data Survivability Parameters

Parameter	IEEE P1616 MVEDR Draft Recommendation	NHTSA Truck & Bus Findings	FMVSS 208/214	Flight Data/Cockpit Voice Recorder	Locomotive Event Recorder	Rail Passenger Equipment Recorder
Impact Shock	**150 g, 50 ms, ½ sine wave pulse, applied separately in each of the three principal axes.** Rationale: The NHTSA Pulse (300 g, 50 ms) results in a ΔV of 165 mph and a crush of 75 inches. The FMVSS Pulse (50 g, 150 ms) results in a ΔV of 82 mph and a crush of 110 inches. The recommended pulse of 150 g, 50 ms results in a ΔV of 82 mph and a crush of 38 inches, which may be more reasonable. Applying the pulse in all three axes is necessary because an EDR may be mounted in any orientation.	300 g, 50 ms	50 g, 150 ms	3400 g for 6.5 ms, ½ sine wave pulse	23 g for 250 ms or equivalent energy	55 g peak, 100 ms duration, 2.85 g-sec area under curve energy, ½ sine crash pulse, separately in the direction of each of the three principal axes.

Parameter	IEEE P1616 MVEDR Draft Recommendation	NHTSA Truck & Bus Findings	FMVSS 208/214	Flight Data/Cockpit Voice Recorder	Locomotive Event Recorder	Rail Passenger Equipment Recorder
Penetration	**5 ft. drop of 100 lbs., 0.25 inch diameter point, separately in each of the three principal axes.** Rationale: The FDR drop has a potential energy of 6,783 J. The light rail recorder has a potential energy of 339 J. The NHTSA T&B drop has a potential energy of 814 J. The recommended pulse has a potential energy of 678 J, which is twice the amount of energy as the light rail drop and uses a lighter weight which will make the testing easier. The recommended 0.25 inch diameter point is consistent with an EDRs from other modes. 814 J over a 0.5 inch diameter point results in a 4,145 J/ in^2 impact. 678 J over a 0.25 inch diameter point results in a 13,812 J/ in^2 impact which is 3.33 times higher than the NHTSA recommendation.	3 ft. drop of 200 lbs., 0.5 inch diameter point	Not specified	10 ft. drop of 500 lbs., 0.05 in^2 point (0.25 inch diameter)	Not required	Penetration 50 lbs. (23 kg) weight with a protruding 0.25 inch (6.4 mm) diameter steel pin dropped from a height of 5.0 ft. (1.5 m) separately in the direction of each of the three principle axes.
Static Crush	**1,500 lbf, 5 minutes, each face and diagonals** Rationale: Given that the weight of a large truck is much less than a rail engine or aircraft, a reduction of the applied force makes sense, but 500 lbs. may be low. Adding the force application duration adds consistency to the recommendation. “Diagonals” add completeness, and crush forces may be applied perpendicular to an EDR faces in a crash.	500 lbs.	Possibly some, depending on location of EDR	5,000 lbf, 5 min., faces and diagonals	25,000 lbf for 5 min., each face	25,000 lbs. (110 kN) for 5 minutes separately in the direction of each of the three principle axes.

Parameter	IEEE P1616 MVEDR Draft Recommendation	NHTSA Truck & Bus Findings	FMVSS 208/214	Flight Data/Cockpit Voice Recorder	Locomotive Event Recorder	Rail Passenger Equipment Recorder
Fire Resistance, High	**1,000 °C (1,832°F) for 5 minutes** Rationale: Recordings of crashes with fires may be important because the vehicle and other evidence may be destroyed. 30 minutes was the estimated duration of an intense vehicle fire.	Small percentage of crashes, not specified	Not specified	1,100 °C (2012°F) for 30 min, 100% coverage, 50k BTU/ ft^2hour	1,000 °C (1,832°F) for 60 minutes	1,200°F (650°C) for 30 minutes, followed by 570°F (300°C) for 60 minutes, followed by 212°F (100°C) for 5 hours.
Fire Resistance, Low	**260 °C (500°F) for 30 minutes** Rationale: Recordings of crashes with fires may be important because the vehicle and other evidence may be destroyed. 30 minutes was the estimated duration of an intense vehicle fire.	Small percentage of crashes, not specified	Not specified	260 °C (500°F), 10 hours	260 °C (500°F) for 10 hours	1,200°F (650°C) for 30 minutes, followed by 570°F (300°C) for 60 minutes, followed by 212°F (100°C) for 5 hours.
Immersion, Fuel/Fluids	**Immersion in all of the following individually for 8 hours: gasoline, diesel fuel, lubricating oil, water, fire extinguishing fluids.** Rationale: These fluids are commonly found in or around the vehicle. An 8-hour period was chosen as it is likely that after a crash, the fluids would be removed/flushed/cleaned up. EDR electrical components may be damaged if fluids reach its interior circuitry and the unit is powered up.	Shallow immersion for a short period of time	Not specified	48 hours	48 hours	Immersion in any of the following individually for 48 hours: Grade 1 and 2 diesel fuel, regular and salt water, and lubricating oil.

Parameter	IEEE P1616 MVEDR Draft Recommendation	NHTSA Truck & Bus Findings	FMVSS 208/214	Flight Data/Cockpit Voice Recorder	Locomotive Event Recorder	Rail Passenger Equipment Recorder
Battery/Power	**Enough reserve power to complete all data acquisition after a trigger event has been detected (30-60 seconds)** **Data should remain intact for 1 year** Rationale: Thirty to sixty seconds of reserve power should allow an EDR to record the entire event – including the post-trigger part of the event. In the case of a severe crash, the vehicle's power system can be damaged and the in-vehicle data network will go down, but an EDR's internal sensors will continue to monitor the vehicle's dynamics until the vehicle comes to a complete stop. Non-volatile memory (memory that does not require external power) is typically low-cost and commonly used in all aspects of electronics.	Enough reserve to record for 1 minute Data should remain intact for 30 days	As long as it takes to record it As long as it takes to retrieve it	6 year shelf life 30 day operation	Not specified	Not specified

*Sources: 1) "Summary of Findings by the NHTSA EDR WG – Volume II – Supplemental Findings for Trucks, Motorcoaches, and School Buses," DOT HS 809432, May 2002.

2) "Design of a Crash Survivable Locomotive Event Recorder," Thomas Stevens, Robert E. Onley, and Robert S. Morich, L-3 Communications, Electrodynamics, Inc., Rolling Meadows, IL.

3) NTSB FDR /Cockpit Voice Recorder (CVR) Website: http://www.ntsb.gov/aviation/CVR_FDR.htm.

4) "A New Event Recorder Standard for Passenger Rail Equipment," Christopher J. Holliday, P.E., STV, Incorporated.

5) "EDR Survivability Crosswalk Comparing T&B EDR WG Findings with Proposal to Tie Survivability to FMVSS Crash Tests," J. Hinch (NHTSA), S. McComb (NTSB), IEEE P1616 WG Presentation, April 2003.

SYSTEM CONNECTIVITY

System connectivity involves both the connection of an EDR inside the vehicle and how crash investigators and fleet managers off-load EDR.

Figure 1 shows a simple block that includes the major EDR connections throughout the vehicle.

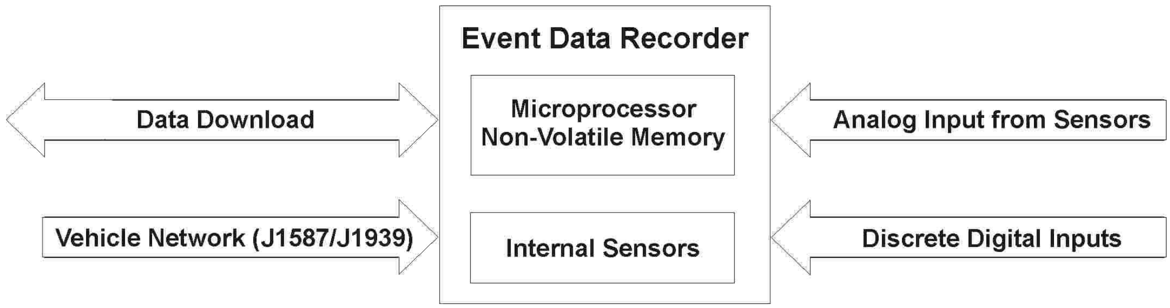

Figure 1
EDR System Connectivity Block Diagram

As shown in Figure 1, five types of data measurement connections or sensors make up the entire EDR measuring chain:

1. **Internal Sensors –** Internal sensors are located inside an EDR when data is not available to be read directly from other sources on the truck. These sensors typically include: longitudinal, lateral, and vertical accelerometers; yaw, pitch, and roll angular sensors; and a GPS receiver, if the vehicle does not have a GPS receiver on its in-vehicle data network.
2. **Analog Input from Sensors –** Analog input from sensors refers to the electrical output of analog (i.e., continuous, 1 to 5 Volts Direct Current (VDC)) sensors that can be located in various locations on the vehicle. An example of an analog sensor is the throttle position sensor.

   Any analog inputs from the vehicle directly into an EDR are undesirable, because the analog signal may degrade due to long wire lengths, which will reduce the signal strength, place an additional load on the sensor which may alter its reading, and increase noise on the line. Most analog sensors used for engine control have data placed on the in-vehicle data network.
3. **Discrete Digital Inputs –** Discrete digital inputs refer to connections throughout the vehicle to on/off devices. Brake lights, turn signals, horn, running lights, and headlights are examples of this type of signal. Determining the state of discrete digital inputs is cost effective and will not effect the operation of the device. The wiring required to tap into the signals is simple, and the physical connection can be made by the use of a simple crimp-style wire splice.
4. **Vehicle Network –** Another cost effective method of obtaining vehicle data is via the vehicle network. Two in-vehicle data networks commonly found in large trucks: 1) a low-speed network (SAE J1708/J1587) and 2) a high-speed network (SAE J1939). When both networks are present, the low-speed network conveys general vehicle operating data, and the high-speed network carries engine control data.

   Obtaining vehicle data via the vehicle networks is cost efficient, because one network interface allows all operating data available on the network to be accessed by an EDR. Since the network protocols are well-defined and standardized, the same network messages will exist across many types of vehicles.

5. **Data Download –** Data download is the process of transferring data stored in an EDR to another device, which serves as the only two-way connection interface. Using a data download connection, an EDR receives commands from a device (e.g., a laptop), and transmits data to it. Checksums are transferred by an EDR and analyzed by the off-loading device to ensure there are no errors in data transmission. In addition, this link can be used to upload new operating software to an EDR. This connection is a type of serial link (e.g., RS-232, USB, Firewire, etc.), which could be a wireless link.

EDR DATA RETRIEVAL

EDR Operational Concerns

An EDR should operate with minimal driver and fleet manager interaction unless an EDR provides additional functionality (e.g., daily maintenance or other operational data). If an EDR detects an internal error, the user should be notified via an EDR status light initiated when the ignition is turned-on, and the light should turn off, if error-free. When the user has to off-load EDR data, then the interaction should be simple and relatively quick.

Interface Configurations and Data Retrieval Process

Three categories of data retrieval interface configurations can be used to transfer EDR data to another device:

1. **Wired Data Download –**This interface configuration requires a direct connection from an EDR to the device that will store EDR data. While a direct connection is required, an EDR may be in a different location than where the download connection is made. For example, an EDR may be mounted under the driver seat, but the interface connection may be in the dash. An EDR may also be removed from the vehicle for a direct connection. Wired data download methods may include: RS-232, Universal Serial Bus (USB), FireWire, or other serial data transfer methods. Wired data download methods may include:

    a. **RS-232 –** The RS-232 is an older serial data communication method, and its ports still exist in laptop and desktop computers. If the EDR contains an RS-232 port, it should be configured so that its connection to the data download device (i.e., laptop computer) requires a standard 9-pin straight-through cable. The EDR should be capable of transferring data at a rate of 115,200 baud, which is the typical maximum of RS-232 ports found on computers.

    b. **USB –** The USB is the successor to RS-232 and comes in two varieties: USB 1.1 and USB 2.0. USB 1.1 supports 12 mega-bits per second (Mbps) data transfer rate, and USB 2.0 supports 480 Mbps. EDRs can support either type, and USB 1.1 is fast enough to transfer an entire EDR event in less than one second. If the EDR contains a USB port, it should have a Type B or Mini Type B connector.

    One implementation of a USB interface would be to make the EDR appear as a USB mass storage device. Windows® supports these devices without the installation of special communication drivers. Using this implementation with the EDR connected to the computer, a folder appears on the computer screen listing the data files available for download, allowing the user to drag the files from the EDR folder to a folder located on the computer.

FireWire – FireWire is also referred to as IEEE 1394. It is the newest serial transfer protocol. There are two types of FireWire: FireWire 400 supports data transfer rates of 400 Mbps, and FireWire 800 supports 800 Mbps. EDRs can support either type, and FireWire is fast enough to transfer an entire EDR event in less than one second. It should be noted that FireWire is common on newer Apple® computers, but is relatively uncommon on Windows- and Linux-type computers.

If the EDR contains a FireWire port, it can be configured with either a 6-pin or a 4-pin FireWire connector. An advantage of a FireWire interface would be to make the EDR appear as a FireWire mass storage device.

2. **Local Wireless Data Download** –EDR data may be transferred to another device via a local wireless communication protocol. The receiving device is in close proximity (less than 200 ft) to an EDR, and cabling between an EDR and uploading device is not necessary for data transfer. However, wireless communication methods cost more than wired methods. Local wireless data download methods may include: Infrared, Bluetooth, IEEE 802.11b, or other local wireless data transfer methods.

   a. **Infrared –** Infrared communication is used by the majority of laptops and personal digital assistants (PDAs). The Infrared Data Association (IrDA) consortium specifies a way to wirelessly transfer data via infrared radiation. IrDA devices communicate using infrared Light-Emitting Diodes (LEDs). The wavelength used is 875 nm ±30 nm (production tolerances). Receivers utilize PIN photodiodes in generation. There are two publicly-available IrDA standards. IrDA devices conforming to standards IrDA 1.0 and 1.1 work over distances up to 1.0 m, but they must "see" each other directly and be within a 30° viewing angle of each other for successful communication to occur.

      Transmission speeds for IrDA 1.0 range from 2400 to 115,200 kbps. IrDA v. 1.1 defines speeds 0.576, 1.152, and 4 Mbps. Because the EDR will have a relatively large amount of data to transfer, a minimum of 115,200 kbps should be supported.

   b. **Bluetooth –** Bluetooth is a new technology using short-range radio links, intended to replace the cables connecting portable and/or fixed electronic devices. Bluetooth radio modules operate in the unlicensed InterStellar Medium (ISM) band at 2.4 GHz, and avoid interference from other signals by hopping to a new frequency after transmitting or receiving a packet. Compared with other systems in the same frequency band, the Bluetooth radio hops faster and uses shorter packets. The transmission range of Bluetooth is 10 m (33 ft).

   c. **IEEE 802.11b –** IEEE 802.11b, "Wi-Fi," uses radio for its communication medium. It is rapidly gaining acceptance with OEMs such as Apple, Dell, IBM, and Symbol. While the newer Bluetooth is suitable for wireless connections within 10 meters, Wi-Fi allows portable devices to be connected to other systems at distances as great as 100 meters. Wi-Fi supported data transfer at speeds up to 11 Mbps.

3. **Remote Wireless Data Download –** Another method of transferring data from an EDR to another device is via a remote wireless data download method. Although cabling is not needed between an EDR and uploading device, wireless communication methods are more costly than wired data downloads.

Since remote wireless data download is relatively expensive and would likely be used in conjunction with a wired or local wireless download method, the remote wireless modem would be a separate device that communicates with an EDR via a direct, wired, serial connection (e.g., an RS-232 port). Remote wireless data download methods may include: radio modems, cellular modems, satellite modems, or other wireless data transfer methods. ACN is one aspect of an EDR with remote wireless data download capability and can be used to notify local authorities almost immediately in the event of a large truck crash. When an EDR detects an event trigger, the event data could automatically be transmitted to a remote receiver.

4. **Remote Wireless Data Download –** A third method of transferring data from the EDR to another device is via a remote wireless data download method where the EDR could be thousands of miles away from a remote receiver. An advantage of using this type of data transfer is that cabling is not required between the EDR and uploading device to complete a data transfer. Another aspect of an EDR with remote wireless data download capability is ACN and can be used to notify local authorities almost immediately after a crash.

   Yet, the ease of remote data transfer is associated with increased system cost, since wireless communication methods cost more than wired methods. Due to the high cost, remote wireless data download would likely be used in conjunction with a wired or local wireless download method. The remote wireless modem would be a separate device that communicates with the EDR via a direct, wired, serial connection (e.g., an RS-232 port).

   There are several types of remote wireless download protocols that can be used in a standard way. Remote wireless data download methods may include:

   a. **Radio Modems –** Radio modems use a local radio network to transfer data between devices. The range of these networks is limited to approximately 10 miles, and a radio modem must be located at both the EDR and receiver locations. One disadvantage is only one device may communicate on the network at a time. Another disadvantage is the radio network communication rate is typically limited to 19.2 kbps, which means that the transfer of data may take several minutes. Since there is no "connect time," a direct cost is not associated with the transmission of data between devices.

      Cellular Modems – Cellular modems are cell phones with data transfer capability. There are several different types of cell modems with different data rate capabilities and operating modes. Some types of cellular communication have connect time and/or byte count charges where each EDR data transfer incurs additional costs. While most of the continental U.S. has cellular coverage, cellular modem communications do not function in some areas.

   b. **Satellite Modems –** Satellite modems communicate directly with satellites that are in orbit around the earth. One satellite system has a data communication rate of 9.6 kbps. However, satellite communication can be costly due to byte count/connect time charges.

Data Retrieval Protocol

The software protocol used to retrieve data from an EDR protocol will vary depending upon the communication interface present in an EDR. Two data retrieval protocols are:

1. **Mass Storage Emulation –** Whenever possible, the transfer of EDR event data files should appear as a file transfer from a mass storage device (e.g., hard disk). For instance, if an EDR

has a USB interface, the computer would be connected to it and a folder would appear on the computer where the user would drag EDR event files onto the computer's hard disk. This approach is possible for USB and FireWire interfaces and would not require any additional software to be loaded on the receiving device. If RS-232, IrDA, IEEE 802.11b, or Bluetooth are used, then this mode would be possible, but the receiving device would need an EDR communication driver when it detects the presence of an EDR.

2. **Interactive Communication –** When remote wireless data download protocols are being used, an EDR can contact the remote site or vice versa.

One method of assuring vehicle owner access only is through use of an EDR system password to extract data, as specified in the TMC RP 1212, *Personal Computer (PC) to User Interface Recommendations for Electronic Engines Data*.

EDR Data File Format

An EDR data file format has the flexibility for EDR manufacturers to include new data elements in their EDRs where the data retrieval software would be able to receive and properly process the new data types. When an EDR data file has been decoded, the actual event data can be examined. The EDR data file consists of a series of data records. Each record represents data for a particular data element and consists of several fields that completely define the data element. EDR data element records should follow the format shown in Table 24.

Table 24
EDR Data Element Record Format

Field Number	Description	Format	Example
1	Data Element Name (abbreviation)	ASCII string	AccPos
2	Sampling Rate (in Hz)	ASCII number	10
3	Sample Size (bytes per sample)	ASCII number	1
4	Resolution (physical unit per bit)	ASCII number	0.4
5	Unit of Measure (e.g., psi, deg-f, on/off)	ASCII string	%
6	Data Unavailable Value (e.g., pre-trigger buffer not full yet)	ASCII number	254
7	Sensor Error/Fault Value (e.g., vehicle network down)	ASCII number	255
8	Sample Number Prior to Event Trigger*	ASCII number	150
9	Estimated Time from Sample to Trigger* (in ms)	ASCII number	5
10	Number of Samples for This Data Element	ASCII number	451
11	Data (a contiguous string of bytes)	Binary	N/A

*EDR Data Record Fields 8 (Sample Number Prior to Event Trigger) and 9 (Estimated Time from Sample to Trigger) are used to align the data record with the event trigger time so all EDR data element records can be time synchronized.

Number of Events Stored in EDR Memory

An EDR can store crash events, driver-initiated events, and vehicle-initiated events. Certain events may be overwritten as newer event triggers occur. These event types include: driver-initiated events and vehicle-initiated events. If crash events occur, they should remain in EDR memory until the event data are off-loaded. Optional “near” crash event triggers may be defined. In this case, this type of event may be overwritten.

An EDR is recommended to store three crash events in a multi-event crash. If three crash events have been recorded, then an EDR could signal the user via an EDR Status Light that its buffer is full and event data should be off-loaded. When the data are off-loaded, the events may be manually cleared. For multi-trigger events, it may require gathering all of the pre-trigger data (up to 15 seconds before the first trigger) and all of the post-trigger data.

Multiple Events and Overlap of Events

An EDR may record several events as illustrated in the following examples:

1. The vehicle is involved in a minor crash, but one large enough to trigger an EDR. It proceeds for a number of seconds and then has another major impact with another vehicle. Afterward, the vehicle careens off the road and down an embankment.
2. The driver detects that the vehicle is operating abnormally and pushes the EDR record button. After several seconds, a major mechanical failure occurs, the driver looses control and the vehicle rolls over.

As a result, for multi-trigger events, gathering pre-trigger data and post-trigger data would be important.

Overall Accuracy

Two main areas concerning accuracy issues involve numerical data and timing accuracy. For data obtained from the vehicle network, the accuracy of the data may be difficult to determine, since the vehicle sensors and signal conditioning are supplied by the vehicle manufacturer or an aftermarket system supplier. Accuracy determination can be made only by examining the functional specifications of the vehicle and its systems.

The accuracy of an EDR’s internal sensors is more easily controlled, since the sensors can be calibrated during manufacturing. In addition, accelerometers and angular rotation sensors include integrated temperature sensors to minimize the effect of changes in temperature. With factory calibration and temperature compensation, the internal sensors should have an accuracy of 2% full scale.

Timing accuracy is also important. The timing of the data received from the in-vehicle network is somewhat uncontrolled, since the network data’s value cannot be correlated to an exact moment in time. The timing can be roughly estimated between two successive readings. Internal EDR timing is more clearly defined and controlled, yet the actual timing of the data will vary slightly from manufacturer to manufacturer. An EDR manufacturer should publish the sample timing for their EDR for events to be accurately reconstructed from the data.

System and Data Repeatability

Overall, EDR data should be repeatable. The event timing, event trigger detection, and data from the internal sensors should be repeatable, since the sensors should produce the same values given the same input, and the software event trigger detection algorithms should remain constant over time.

An EDR should be manufactured using components that remain stable over time and the expected operating temperature range. The crystals used to regulate data sampling should be high quality to maintain accurate timing.

Data obtained from the vehicle network should be repeatable, but since there is no direct control over the performance of vehicle sensors and other aftermarket equipment which may provide vehicle network data, this may not necessarily be the case.

System Calibration and Maintenance

An EDR is typically calibrated at the factory, and all calibration parameters should be stored in an EDR's non-volatile memory. An EDR's internal sensor electronics (and all other analog signal conditioning circuitry) should be designed to remain stable over the expected operating life of a large truck from 5 to 10 years.

An EDR is a sealed unit that would not typically require regular maintenance, since it would not require internal or external adjustments. If an EDR fails, the entire unit would likely be replaced and programmed with the vehicle's VIN.

Incorporation with Fleet Management Tools

Fleet management applications that would likely benefit from EDR data include: fuel tax calculation, vehicle malfunction identification, driver training, road toll verification, maintenance planning, automatic vehicle location, fuel usage, route planning, and automatic crash notification.

On-board fleet management tools include:

- Vehicle operating data
- Driver logs
- Driver and fleet manager links

These tools are primarily available in three forms:

1. Data recorders that record basic vehicle operating data
2. Electronic records of duty status for hours-of-service regulations
3. Driver data terminals for fleet operations and logistics applications

Some of these systems are integrated, yet the majority of these systems are highly customized, closed systems which are not designed to interact with another manufacturer's system. They do not provide standardized methods to exchange information. Table 25 lists some examples of dual-functionality EDR data elements.

Table 25
Examples of Dual-Use EDR Technologies

Technology Type	Use in Crash Reconstruction	Use in Fleet Management & Administration	Stakeholder Beneficiary
GPS	Vehicle Path	Fuel Tax Determination	Fleet Manager
		Route Planning	Fleet Manager
		Proof of Location	Driver
		Accurate Time	Fleet Manager, Driver
Longitudinal	Crash Pulse	Braking Analysis	Maintenance Manager

Technology Type	Use in Crash Reconstruction	Use in Fleet Management & Administration	Stakeholder Beneficiary
Acceleration	Vehicle Dynamics	Panic Stop Analysis	Fleet Manager
Lateral Acceleration	Crash Pulse	Roll-Over Alarm	Fleet Manager, Driver
	Vehicle Dynamics	Drowsy Driver Alarm	Fleet Manager, Driver
Vehicle Databus Communication	Vehicle Indicated Speed, VIN	Various Operating Parameters (pressures, temperatures)	Maintenance Manager

Some fleet management systems contain data that would be useful to EDRs, such as vehicle location, speed, and heading data from a GPS data source. One standardized way to transfer GPS data from a fleet management system to an EDR is by placing the GPS data on the in-vehicle data network. SAE standards J1587 and J1939-71 specify how GPS data should be transmitted over the network, and an EDR could be programmed to receive this data. As a result, one GPS receiver could provide data to the fleet management system and an EDR. The SAE Standards include messages for other fleet management functions, including trip data, vehicle maintenance data, and driver logs.

An EDR may also contain data that could be useful for fleet management systems. Internal EDR data could be transmitted to other in-vehicle systems over the in-vehicle data network, SAE Standards J1587 and J1939-71. Also, the fleet management system's communication link could be used to transfer EDR data from the vehicle to the fleet manager's home base. For example, if the vehicle was involved in a crash, the event data could automatically be transmitted to the fleet manager via ACN functionality. Establishing a link between these two systems could relay crucial data when an EDR records an event.

Expandability

Adding new types of data elements into an EDR's event memory can expand an EDR's functionality; however, the following expandability aspects could also be addressed:

- **Signal Type –** Is the signal analog, digital (discrete), variable frequency, or pulse-wide modulated? Is it available on the in-vehicle data network?
- **Electrical Interface –** If the new data is coming from a wired connection, is it in a voltage range an EDR can accept? Does the signal require any special conditioning before it can be run into an EDR? Can the signal be tapped into without affecting the integrity of the signal?
- **Storage Requirements –** Does an EDR have the ability to read the data at the desired sampling rate? Does an EDR have sufficient memory to store it?

To accommodate additions and changes to an EDR's functionality, its internal program should be modifiable. In addition, errors may exist in EDR software, which may be corrected by uploading a new EDR program by using the same communication interface (wired or local wireless) used to obtain EDR event data.

An EDR has both program and data memory. Program memory holds an EDR's internal program of the commands that gives an EDR its specific functionality. Data memory holds all of an EDR's event data. When event data is transferred from an EDR to another device, the event data is read from data memory.

Both the program and data memory may be the same type or technology, because both memories need to be non-volatile, i.e., they should be able to retain their values in the event of a power failure. Battery-backed memory could be used; however, low cost, flash memory would be beneficial for both program and data memory.

The amount of memory available in a chip is increasing, and the cost per byte of flash memory is decreasing. To accommodate memory expandability after an EDR is developed, only two-thirds of the memory space is recommended to be used with one-third of the memory available for future use.

Despite planning for future requirements, obsolescence may occur when an EDR's components are no longer available from the manufacturer. One way of avoiding this risk is to use relatively new technologies. Another type of obsolescence may occur when new technology is installed in the vehicle. For example, existing EDRs may not be able to read data from a new in-vehicle network protocol without the correct electrical connection or appropriate electronic drivers.

CONCLUSION

Of the hundreds of potential data elements that could be used in an EDR, the following data elements collected by an EDR can enhance the crash reconstruction process, along with offering useful data to aid in injury prediction, vehicle defect analysis, crash causation, and other uses.

Tier 1 – The minimum required elements for an EDR on CMVs:

- Acceleration (Longitudinal, Lateral, and Vertical)
- Accelerator Pedal Position/Time History
- Brake Status/Pressure/Time History (includes Antilock Brake System)
- Engine Speed
- Seat Belt Status
- Steering Wheel Angle/Time History
- Time/Date Standard
- Transmission Gear Selection
- Vehicle Identification
- Vehicle Path (GPS)
- Vehicle Speed
- Wheel Speeds

Tier 2 – Additional data elements to those in Tier 1 that would permit further analysis of crashes involving CMVs:

- Air bag Status/Deployment
- Angular Rate Yaw, Pitch, and Roll (Stability Control)
- Battery voltage
- Cruise Control Status
- Engine Retarder System Status
- Headlight Status/Running Light Status
- Traction Control Status
- Vehicle Load
- Warning Light/Turn Signal Status
- Windshield Wiper Status

Tier 3 additional data elements to those in Tier 1 and Tier 2:

- Brake Stroke
- Brake System Pressure
- Distance to Intersection
- Driver – Eye Glance Position
- Driver – Fatigue Status
- Horn Use / Status
- Roadway Surface Friction
- Running Light Status
- Side Object Detector

- Tire Pressure
- Truck Headway
- Truck Lane Position
- Video Imaging – Driver
- Video Imaging – Roadside Environment

Two key subsystems, the GPS receiver and vehicle network connection, allow many data elements to be collected from the same data source. A connection to the vehicle network gives an EDR access to a wealth of data elements that are used to report vehicle operating conditions. As a result, any data on the vehicle network could easily be added to this list. Several of the other data elements are basic on/off or discrete types of signals. This type of data can be cost-effectively recorded in an EDR. An EDR would also contain several internal sensors, such as accelerometers and rotational motion sensors.

Conceptually, a block diagram for an EDR as described in this report would look like Figure 2 below.

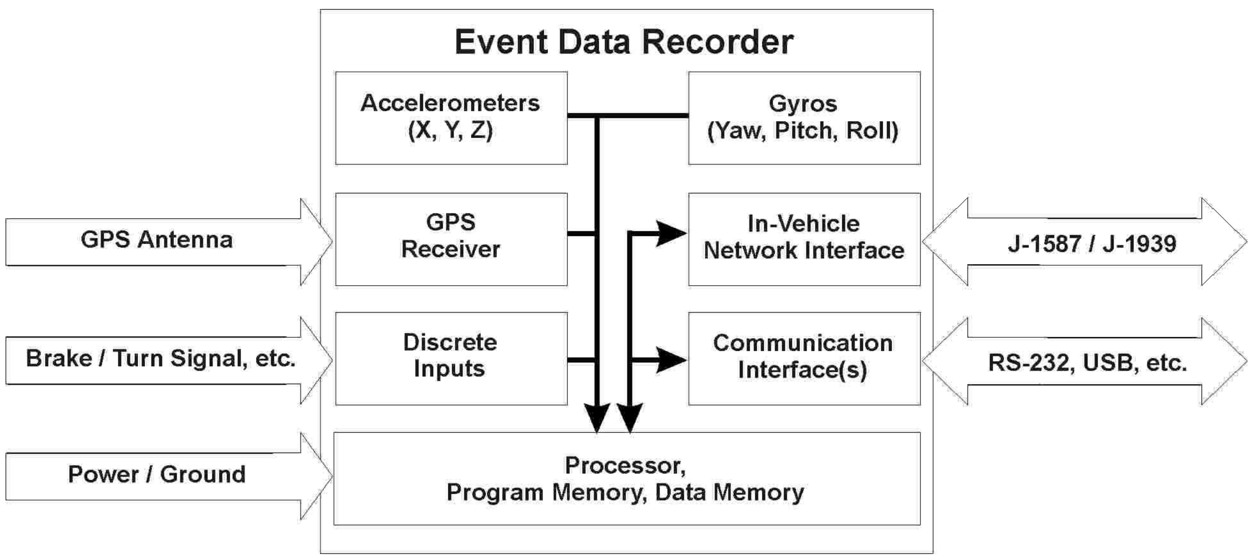

Figure 2
Simplified EDR Block Diagram

The development of an EDR for large trucks would encompass a wide-range of survivability and operational parameters. For the environmental and electrical operational parameters, SAE standards illustrate industry's best practices, yet further design and testing of a technically accurate and feasible EDR on large trucks would be necessary to validate the analysis in this report.

The actual development of a technically accurate and economically feasible EDR may be a challenge. However, EDR data has the potential to improve highway safety by aiding research related to driver, passenger, vehicle, and highway safety; improving occupant-protection systems; and enhancing the accuracy of crash reconstructions.