Vehicle Data Recorders

Task Order 7 of the Commercial Motor Vehicle Technology Diagnostics and Performance Enhancement Program

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

December 2005

Foreword

This project is one of several performed under the provisions of Section 5117 of the Transportation Equity Act of the 21st Century (TEA-21). The primary objective of this project was to explore the potential for the development of cost-effective vehicle data recorder (VDR) solutions tailored to varied applications or market segments. Through a combination of technical research and analysis, including business-related cost-benefit assessment, potential VDR configurations ranging from fundamental to comprehensive were explored.

The work performed under the project included:

- Capturing the available results of this research and synthesizing information from the commercial vehicle user, original equipment manufacturer (OEM), equipment supplier, and recorder manufacturer communities.
- Profiling high-level functional requirements of VDRs, which were extracted from industry and government findings (NHTSA, FHWA, TRB, ATA/TMC), as well as surveying and interviewing key industry stakeholders, and assessing end-user needs and expectations regarding VDR capabilities and required data parameters.
- Developing several VDR concepts with different levels of VDR sophistication. VDR concepts were formulated and targeted for the following end-use applications:
  - Accident reconstruction and crash causation
  - Operational efficiency
  - Driver monitoring
- Profiling and analyzing advanced VDR technologies that could be added to any of the concepts developed.
- Identifying and estimating the costs and benefits for each of the VDR concepts developed.

The results from this project can be used by motor carriers in helping evaluate vehicle data recorder applications, costs, and potential benefit scenarios.

Notice

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16. Abstract

The primary objective of this project was to explore the potential for the development of cost-effective vehicle data recorder (VDR) solutions tailored to varied applications or market segments. Many of the technologies currently in the marketplace or emerging in the industry can or will be able to perform both data logging to improve operational efficiency and traditional event data recorder (EDR) functions—providing benefits in a wide array of applications. Early in this project, the aim was to explore both of these potential benefit scenarios. Through consultation with the FMCSA and NHTSA, the term "vehicle data recorder" (VDR) was selected as a way to streamline the discussion of technologies that perform one or both of these functions. Through a combination of technical research and analysis, including business-related cost-benefit assessment, potential VDR configurations ranging from fundamental to comprehensive were explored.

The following VDR concepts were developed:

- Concept 1. A low-cost event-triggered data recorder for recording baseline accident data
- Concept 2. A more advanced event-triggered data recorder incorporating advanced sensor technologies
- Concept 3. A baseline continuous data recorder that records maintenance and operational data meant to improve fleet operations
- Concept 4. An advanced continuous data recorder that includes additional driver-monitoring parameters
- Concept 5. A "full-featured" VDR that might include accident data and operational-efficiency data.

In general, both VDR and event data recorder (EDR) devices will benefit the commercial vehicle industry and society as a whole, but these benefits will likely be spread across three primary stakeholder groups: (1) benefits to fleets, (2) benefits to OEMs, and (3) benefits to the public sector.

Benefits for fleets will primarily focus on improving operational efficiency and reducing operational costs. Benefits for OEMs will likely come from reducing liability costs and improving vehicle designs and safety. Benefits for public-sector stakeholders—such as transportation agencies, law enforcement, and the general public—will likely include improved vehicle safety; fewer crashes, injuries, and fatalities; and improved inspection capabilities.

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Commercial motor vehicles, event data recorders, onboard recorders, vehicle data loggers	No restrictions

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Unclassified	Unclassified	132	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

*** SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.**

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EXECUTIVE SUMMARY

Project Funding

Under the provisions of Section 5117 of the Transportation Equity Act for the 21st Century of 1998 (TEA-21), Congress authorized the U.S. Department of Transportation (USDOT) to:

> …conduct research on the deployment of a system of advanced sensors and signal processors in trucks and tractor trailers to determine axle and wheel alignment, monitor collision alarm, check tire pressure and tire balance conditions, measure and detect load distribution in the vehicle, and adjust automatic braking systems.

As a result of a comprehensive technology scan—as well as numerous interviews with key industry stakeholders such as truck manufacturers, fleet operators, suppliers, and regulators—a variety of research areas were identified including an assessment of the potential for developing cost-effective VDR solutions for various applications.

Background

By observing and analyzing vehicle performance parameters, driver inputs, and vehicle responses, manufacturers and operators of commercial motor vehicles can extract the maximum utility, achieve new levels of safety and security, and have at their disposal a wealth of new information to help them learn from vehicle events. Coupled with recent innovations in telematics that provide dramatic increases in bandwidth and data transmission rates, these technologies offer new opportunities for improving vehicle safety, reliability, and profitability. Such real-time monitoring and data-logging opportunities include improved vehicle interaction, driver training and oversight, occupant-protection systems, and collision-avoidance systems.

Systems that record specific vehicle inputs, component conditions, and dynamic responses from the period immediately preceding a crash, through the actual event, offer safety agencies and vehicle manufacturers additional opportunities to gain knowledge that can be used to reduce the likelihood of future crashes.

Early in this project, it was decided to explore both of these potential benefit scenarios. In consultation with the FMCSA and the National Highway Traffic Safety Administration (NHTSA), "vehicle data recorder" (VDR) was settled on as a collective term for technologies that perform one or both of these functions.

The primary objective of the project was to explore the potential for the development of cost-effective VDR solutions tailored to varied applications or market segments. Through a combination of technical research and analysis, including business-related cost-benefit assessment, potential VDR configurations ranging from fundamental to comprehensive were explored.

Overview of Approach

Work on this project consisted of the following subtasks:

- Capture the available results of this research and synthesize information from the commercial vehicle user, OEM, equipment supplier, and recorder manufacturer communities. The results of this formed the foundation for the development of VDR alternative concepts, and the evaluation of potential benefits and costs. The focus was not to serve as a liaison for sharing of information among third parties, but rather as a means of gathering information necessary to complete the project.

- Conduct a comprehensive literature search and review of documents published by public, quasi-public (e.g., Associations, Committees, Coalitions, Institute, etc.), and private companies that have conducted VDR-related research and development. These institutions and companies included the various public-private partnerships and consortia that have formed under the provisions of the Intermodal Surface Transportation Efficiency Act and TEA-21 legislation.
- Identify specific VDR features and capabilities available and incorporated in commercially available VDRs, estimate the costs associated with those features, and develop an understanding of the cost drivers for VDR design.
- Profile high-level VDR functional requirements extracted from industry and government findings (NHTSA, FHWA, TRB, ATA/TMC), survey and interview key industry stakeholders, and assess end-user needs and expectations regarding VDR capabilities and required data parameters.
- Develop several VDR concepts with different levels of VDR sophistication. VDR concepts were formulated and targeted in the following end-use applications:
  - Accident reconstruction and crash causation
  - Operational efficiency
  - Driver monitoring
- Develop technical and performance descriptions for each VDR concept to assist in the analysis of the costs associated with their development and manufacture.
- Profile and analyze advanced VDR technologies that could be added to any of the concepts developed.
- Identify and estimate the costs and benefits for each of the VDR concepts developed. Costs (including those for engineering development, application programming, and hardware) were developed for each concept based on the technical and performance requirements developed. An overview of the business-case justification that typical fleets use in purchasing VDRs and the likely benefits of these systems was also developed.

Alternative VDR Concepts

Using industry and government findings from NHTSA, FHWA, and the American Trucking Associations' Technology & Maintenance Council (ATA/TMC), along with surveys and interviews with key industry stakeholders, the contractor team profiled end-user needs and expectations regarding VDR capabilities and required data parameters. Several industry and government organizations have released findings related to the specific data parameters that VDRs should record. These data parameters were then categorized into five data sets based on qualitative rankings and applicability to the three main VDR functions as follows:

1. **Accident Reconstruction and Crash Causation Core Data Set** – Core data parameters necessary for performing accident reconstruction and crash causation analysis. These parameters are typified by the data recorded in an EDR.

2. **Accident Reconstruction and Crash Causation Advanced Data Set** – Data parameters that would complement the core data parameters in group 1, but some of which would likely require the installation of sensors at various locations around the vehicle. This dataset includes all of the core accident reconstruction and crash causation data parameters in group 1.
3. **Operational Efficiency Core Data Set** – Core data parameters that could be used to improve a fleet's operational efficiency. These parameters are typical of the kinds of information recorded by vehicle data loggers. The information collected is used to improve maintenance efficiency, detect and prevent possible on-road breakdowns, monitor driver performance, track goods movement, and manage fleet logistics. The parameters identified as the "core" operational data set would be commonly available on new model tractors and would generally not require installation of additional equipment or sensors. It should be noted that to maximize operational efficiency benefits, a VDR would most likely be equipped to record geographic position using global positioning system (GPS) or similar technology. However, as GPS and similar technologies could benefit all of the five concepts but are not necessarily required, it has been included in the discussion of advanced VDR technologies in Chapter 3.
4. **Operational Efficiency Advanced Data Set –** Other data parameters that a fleet could use to further improve and monitor the efficiency of a fleet. Some of these parameters may require installation of additional sensors. This dataset includes all of the core operational efficiency data parameters in group 3.
5. **Driver Monitoring Data Set** – Data parameters that could be used to monitor driver behavior for regulation enforcement, fleet safe-driver incentives, or insurance policy changes.

Unique (distinct) concepts were developed to represent practical combinations of features and capabilities that would address requirements for differing market segments. Specifically, the following VDR and event data recorder (EDR) concepts were developed:

Concept 1. A low-cost event-triggered data recorder for recording baseline accident data

Concept 2. A more advanced event-triggered data recorder that incorporates advanced sensor technologies

Concept 3. A baseline continuous vehicle data recorder that records maintenance and operational data meant to improve fleet operations

Concept 4. An advanced continuous data recorder that includes additional driver monitoring parameters

Concept 5. A "full-featured" VDR that might include both accident data and operational efficiency data.

Each of these five concepts was mapped to the data sets developed from industry and government findings, as shown in Exhibit ES.1.

Exhibit ES.1 – Capabilities of Concept Vehicle Data Recorders

Capabilities	Vehicle Data Recorders				
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Crash Pulse Recording (high data rate before/after crash event trigger)	✓	✓			✓
Continuous and Histogram Operational Data Recording (low data rate)			✓	✓	✓
Accident Reconstruction Core Data Set	✓	✓			✓
Accident Reconstruction/Causation Advanced Data Set		✓			✓
Operational Efficiency Core Data Set			✓	✓	✓
Operational Efficiency Advanced Data Set			✓	✓	✓
Driver Monitoring Data Set				✓	✓

Advanced VDR Technologies

In addition to the VDR "baseline" concepts, a listing of advanced VDR technologies that could be added to any of the five concepts was developed. These include:

- Additional internal memory storage (i.e., a storage upgrade to record more event data)
- Removable storage media (e.g., magnetic, optical, solid-state memory)
- Onboard vehicle network communication and downloading (e.g., CAN, IDB, serial)
- Vehicle location, direction of travel, and absolute time (e.g., GPS)
- Digital imaging (e.g., video)
- Sensor for determining the relative location of nearby vehicles (e.g., radar, ultrasonic)
- Short-range wireless communications (e.g., infrared, Bluetooth, WiFi 802.11)
- Long-range wireless communications (e.g., satellite, cellular)
- Driver performance (e.g., attentive driver monitoring, drowsy driver warning)
- Tractor-to-trailer communications

The following questions were addressed in detail for each technology or feature:

- Technology Overview
  - How does the system function?
  - What components are required?
  - Are there different levels of implementation for this technology? (Is there an advanced or full-featured version? Is there a basic version?)

  - Where is this technology currently used?
  - What information will it provide to the VDR? How could this information be used for accident reconstruction, operational management, driver training, or emergency personnel?
  - What are the current and near-term commercially available systems?
  - Are any long-term development projects underway that might impact the integration of the technology with a VDR?
- VDR Implementation Issues
  - How might this technology be implemented into an event data record (EDR) on a heavy-duty vehicle?
  - What additional hardware will be required on the vehicle or VDR to use this technology (e.g., additional sensors, receiving and/or transmitting antennas, or databuses required)?
  - What are some of the disadvantages of using this technology over other similar technologies (e.g., removable media versus short-range wireless versus long-range wireless)?
- Infrastructure Requirements (if applicable)
  - What kind of infrastructure is necessary for this technology to operate (e.g., cellular service, satellites, road markings, WiFi "hot spots")?
  - Is this infrastructure currently available? What is the timeframe for development?
  - Who is likely to develop this infrastructure?
- Technology Implementation Cost
  - What is the range of costs, per vehicle, for the hardware required to implement the technology?
  - How might these costs decrease as the technology becomes more popular?

Chapter 3 presents a detailed discussion of the nature and extent of the data compiled on each of these advanced VDR technologies.

Cost-Benefit Analysis

To better understand the benefits associated with various configurations and concepts, benefits were addressed for devices that: (1) could be used to record event data, and (2) could be used to record operational data. To understand the costs and benefits associated with single-purpose accident EDR, Concept 1 was analyzed. To understand the costs and benefits of VDRs targeted at improving operational efficiency (including driver and vehicle monitoring, vehicle tracking, and maintenance management), Concept 3 was analyzed. Concept 5 was also profiled in order to develop a cost-benefit analysis for a "full-featured" VDR that would record both accident event as well as provide more traditional operational data used by fleets.

In general, both VDR and EDR devices will benefit the commercial vehicle industry and society as a whole, but these benefits will likely be spread across three primary stakeholder groups: (1) benefits to fleets, (2) benefits to OEMs, and (3) benefits to the public sector.

Benefits for fleets will primarily focus on improving operational efficiency and reducing operational costs. Benefits for OEMs will likely come from reducing liability costs and improving vehicle designs and safety. Benefits for public-sector stakeholders—such as transportation agencies, law enforcement, and the general public—will likely include improved vehicle safety; fewer crashes, injuries, and fatalities; and improved inspection capabilities. Exhibit ES.2 shows the possible benefits to each of these stakeholder groups along with whether or not Concept 1, 3, or 5 will likely lead to a realization of that benefit.

Exhibit ES.2 – Vehicle Data Recorder Benefits

		Concept #1 EDR	Concept #3 VDR	Concept #5 EDR+VDR
FLEETS	**Efficiency**			
	- Improved Equipment Utilization (asset management)	0	4	4
	- Improved Fuel Economy Through Incentive Programs	0	3	3
	- Better Route Planning and Adherence Through Location Tracking	0	3	3
	- Enhanced Dispatching and Reduced Backhauls	0	3	3
	- Enhanced Customer Service (shipment tracking, records of P/U & delivery, etc.)	0	4	4
	Maintenance			
	- Reduced Maintenance Costs Through Need-Based Maintenance Planning	0	4	4
	- Fewer OOS Violations Through Early Failure Detection/Preventative Maint.	0	4	4
	- Reduced Diagnostic Time Through Fault and Freeze-Frame Recording	0	4	4
	Administrative			
	- Reduced Fuel Tax Administrative Costs Though Location and Mileage Tracking	0	4	4
	- Improved Monitoring of Driver Hours/Miles (payroll functions)	0	3	3
	- Automated Driver Log (HOS) Capabilities	0	3	3
	Safety			
	- Positive Influence on Driver Behavior	2	3	4
	- Reduce Overall Litigation Costs	3	3	4
	- Lower Insurance Premiums	2	3	3
	- Customized "Alerts" Based On Speed, Braking, and Drowsiness Measures, etc.	0	4	4
	Security			
	- Geo-Fencing (if equipped)	0	4	4
	- Stolen Vehicle Recovery	0	4	4
	- Mandated Periodic Reporting	0	4	4
OEM	**Reduced Product Liability Costs** Though More Accurate "Who's At Fault" Analysis	4	1	4
	Improved Vehicle Design (Safety Systems) by Utilizing Crash Field Data	3	1	4
	Potential For Value-Added Services Related to Maintenance and Diagnostics	0	3	3
	Reduced Warranty Costs Through Availability of Vehicle Use Data	1	3	3
PUBLIC SECTOR	**Transportation Agencies**			
	- Accurate Roadway Usage and Crash Statistics	3	3	4
	- Improved Safety Analysis and Regulatory Support Data Availability	3	3	4
	- Improved Infrastructure Design	3	3	4
	General Public			
	- Fewer Crashes, Fatalities, and Injuries	2	2	4
	Law Enforcement & Security			
	- Reduced Inspection Costs Through Access to Stored Driving Data	0	3	3
	- Improved Hazardous Materials Security Through Location Tracking	0	3	3

0	If implemented, the concept would have no impact/correlation on stated benefit
4	If implemented, the concept would fully support the stated benefit

To better understand the likely development and production costs for the concepts, technical and performance descriptions of each concept were shared with a leading suppler of high-volume custom vehicle electronics for commercial heavy-duty vehicles. The supplier went through the standard development and estimation process, working with their engineering team and their sales and pricing team to gain a detailed understanding of the concepts. This supplier then developed an estimated cost analysis for each concept. The team felt that this approach provided a more accurate estimate of the costs broken down into three parts: engineering development costs, application programming costs, and hardware piece costs. In addition, a combined per-unit cost was totaled based upon order quantities of 10,000+ units per year supplied to OEMs for installation as part of new vehicle builds. In developing a cost estimate for this concept, a cost precision of ±15 percent was used.

It should be noted that estimate is from just one vendor and is only intended to provide a preliminary, rough cost estimate for each generalized concept. It is entirely possible that should an OEM choose to source and install such a concept in its vehicles, the costs would vary—perhaps significantly—depending upon quantities, vendor incentives, and manufacturing and component technologies used. In addition, these costs are intended to represent manufacturing and assembly costs, not necessarily retail costs to a customer or fleet. Exhibit ES.3 shows a summary of these costs.

Exhibit ES.3 – VDR Concept Cost Estimate Summary

	Estimated Piece Cost (±15 %)	One-Time Tooling and Layout Cost	Software Development Cost	Amortized Per Unit Cost (based on 10,000 units)
Concept #1 – Core Event Data Recorder	$260	$20,000	$15,000 to $30,000	$265 (assuming $25,000 for SW)
Concept #3 – Core Vehicle Data Recorder	$140	$20,000	$15,000 to $30,000	$145 (assuming $25,000 for SW)
Concept #5 – Comprehensive EDR and VDR	$450	$20,000	$20,000 to $40,000	$460 (assuming $25,000 for SW)

Of course, these costs would be cost per unit as sold by a vendor to a vehicle OEM. It is anticipated that there would be additional costs associated with integrating the unit into the vehicle (e.g., mounting, wire harnesses, service and repair manuals) and adding the product to the line card and assembly line. It is likely that an OEM would add a 30 to 50 percent markup to a fleet to cover these costs and secure a profit.

In conducting this study, it became clear that return-on-investment calculations for VDRs (from the fleet operator's perspective) are challenging for two main reasons. First, benefits are often defined in terms of increased productivity, efficiency, competitiveness and/or improved safety. All of these measures will vary depending on a particular fleet's situation—and even for a specific fleet's situation, they are very difficult to quantify. Second, costs are difficult to obtain from commercial suppliers of VDR equipment and services. The costs are often embedded (or bundled) within a vehicle price, and/or within a larger telematics service offering. More importantly, the market price of some of the products and services reviewed in earlier chapters is not necessarily indicative of cost. The commercial vehicle telematics, communications, and vehicle data recorder industry is in many ways in its infancy. As such, suppliers with innovative ideas that improve a fleet's competitiveness may well be able to command premium prices that are not cost-based.

Although costs and benefits are difficult to quantify, VDRs and related products and services are nevertheless enjoying market success. Although market penetration data is generally not available (or is closely guarded by suppliers), nearly all vendors contacted report consistent increases in annual sales volumes. This includes various satellite- and terrestrial-based tracking services, and upgraded or enhanced recording functionality embedded within the engine control modules. Stand-alone VDRs and/or EDRs, however, do not appear to be enjoying the same level of success. It would appear, at least anecdotally, that the functionality that might typically be available with a VDR is being incorporated directly into satellite and/or terrestrial tracking systems. Alternatively, if a fleet does not wish to use (or cannot afford) such systems (which require a monthly fee), but they still desire some vehicle monitoring capability, then they opt for the functionality that can be provided by the engine OEMs within the engine Electronic Control Unit (ECU) (see Appendix B). The stand-alone VDR/EDR market therefore seems to be waning.

Generally, however the fleet manager's need for information related to the driver, vehicle health, location, and load status continues to grow. Interviews with industry stakeholders suggest that the information provided by "conventional" fleet tracking and management services is now just part of the cost of doing business and staying competitive. As a simple example, some truckload companies cannot calculate a straightforward return-on-investment in their onboard tracking and communications systems, but shippers (their customers) may have become accustomed to knowing the exact status of their shipments—and therefore a trucking company simply needs this capability to be competitive.

CHAPTER 1. INTRODUCTION AND BACKGROUND

This chapter is organized as follows:

- Background on the Commercial Vehicle Safety Technology Diagnostics and Performance Enhancement Program
- Rationale for the research study
- Overview of the process approach

1.1 BACKGROUND ON THE COMMERCIAL VEHICLE SAFETY TECHNOLOGY DIAGNOSTICS AND PERFORMANCE ENHANCEMENT PROGRAM

The purpose of the Commercial Vehicle Safety Technology Diagnostics and Performance Enhancement Program (i.e., "CV Sensor Study") was to define performance requirements, assess benefits, and accelerate deployment of driver and vehicle assistance products and systems and, in particular, advanced sensor and signal processors in trucks and tractor trailers with an emphasis on onboard diagnostic and improved safety-related products.

The project solicited input from key industry stakeholders (e.g., fleet operators, manufacturers, and suppliers) regarding the selection of research areas, test and demonstration procedures, equipment specifications, and data collection and reporting methodologies. The project focused on conducting research that compliments (rather than duplicates) efforts by the private industry. Objectives of the research included evaluating the probable impact of selected vehicle technologies on improving overall commercial motor vehicle (CMV) safety, and assessing the cost savings potential and operational benefits that help to create market demand and encourage commercialization.

The following tasks were completed to help identify possible research areas:

- Extensive literature search of relevant technical journals and databases
- Individual interviews and discussions with representatives from truck and trailer manufacturers, fleet operators, owner operators, and industry suppliers, as well as staff at NHTSA, FMCSA, and FHWA who are involved in commercial vehicle safety research
- Meeting of key industry stakeholders to review candidate research areas and make suggestions regarding future work under the CV Sensor Study

As a result of this background research and interview process, the following candidate areas of research were identified:

1. Brakes and related controls
2. Tire inflation and condition monitoring systems
3. Truck and tractor alignment ("dynamic alignment")
4. Testing and analysis of high-speed databus networks (J1939)
5. Cost, benefits, and implementation issues associated with Vehicle Data Recorders (VDRs)
6. "Active Suspensions" and related suspension research
7. Advanced vehicle diagnostic and prognostic tools
8. Issues related to implementation of "Smart Copilot" onboard systems

1.2 RATIONALE FOR THE STUDY

The information revolution (and the technologies it has spawned) has made possible a wide variety of innovative vehicle performance and safety enhancement systems. Technology applications (e.g., anti-lock braking systems, traction control, vehicle stability control, collision warning systems, and airbag systems) have brought about major improvements in vehicle and occupant safety. Computerized powertrain control systems—electronic fuel injection, variable valve timing, and electronic transmissions—have provided similar improvements in vehicle performance. The proliferation of these technologies, and other similar systems, offers vehicle manufacturers, aftermarket suppliers, and end users significant opportunities to leverage the information they provide.

The real-time monitoring of vehicle system performance holds significant potential. By observing and analyzing vehicle performance parameters, driver inputs, and vehicle responses, manufacturers and operators of CMVs can extract the maximum utility, achieve new levels of safety and security, and have at their disposal a wealth of new information to help them learn from vehicle events. Coupled with recent innovations in telematics that provide dramatic increases in bandwidth and data transmission rates, these technologies offer new opportunities for improving vehicle safety, reliability, and profitability. Such real-time monitoring and data logging opportunities include improved vehicle interaction, driver training and oversight, occupant protection systems, and collision avoidance systems.

These technologies also open opportunities for public safety agencies to better understand and measure the factors that contribute to commercial vehicle crashes. Systems that record specific vehicle inputs, component conditions, and dynamic responses from the period immediately preceding a crash through the actual event offer safety agencies and vehicle manufacturers the opportunity to gain knowledge that can be used to reduce the likelihood of future crashes. These functions can be viewed as traditional EDR types.

Many of the technologies currently in the marketplace or emerging in the industry can or will be able to perform both data logging to improve operational efficiency and traditional EDR functions—providing benefits in a wide array of applications. Early in this project, the aim was to explore both of these potential benefit scenarios. Through consultation with the FMCSA and NHTSA, the term "vehicle data recorder" was selected as a way to streamline the discussion of technologies that perform one or both of these functions.

The primary objective of this project was to explore the potential for the development of cost-effective VDR solutions tailored to varied applications or market segments. Through a combination of technical research and analysis, including business-related cost-benefit assessment, potential VDR configurations ranging from fundamental to comprehensive were explored.

The specific activities completed are described in the following section.

1.3 OVERVIEW OF THE PROCESS APPROACH

The project team's approach was centered on four tasks:

Task 1: Coordinate Efforts with Other USDOT and Industry Initiatives
Task 2: Profile Capabilities and Cost of VDR Product Offerings
Task 3: Develop Alternative VDR Concepts
Task 4: Identify and Estimate Benefits of VDR Concepts

1.3.1 Task 1 – Coordinate Efforts with Other USDOT and Industry Initiatives

Vehicle OEMs and component suppliers (as well as a few fleet operators) have been engaged in VDR research and testing for many years. Additionally, there has been and continues to be considerable private and government-funded research focused on identifying the capabilities and limitations of VDR-related components and systems, including:

- NHTSA Event Data Recorder Working Group (EDR Working Group)
- NHTSA Truck and Bus Event Data Recorder Working Group (T&B EDR Working Group)
- FHWA-sponsored development of functional requirements for event data recorders
- The American Trucking Associations Technology and Maintenance Council's development of recommended practices

This research has yielded valuable insights. Task 1 focused on capturing the available results of the research and synthesizing information from the commercial vehicle user, OEM, equipment supplier, and recorder manufacturer communities. The results of this task formed the foundation for the development of VDR alternative concepts and the evaluation of potential benefits and costs. The focus was not to be a liaison for sharing of information among third parties, but rather to gather information necessary to perform the assessments required for this project.

The contractor team performed a comprehensive literature search and review of documents published by the public, quasi-public (e.g., associations, committees, coalitions, institutes, etc.), and private companies that have conducted VDR-related research and development. These institutions and companies include the various public-private partnerships. Exhibit 1.1 outlines the various agencies whose VDR research and activities were reviewed.

Exhibit 1.1 – Organizations Supporting/Conducting VDR Research/Development

Public Sector		
Transportation Research Board (TRB)	Federal Highway Administration (FHWA)	Federal Motor Carrier Safety Administration (FMCSA)
National Transportation Safety Board (NTSB)	National Highway Traffic Safety Administration (NHTSA)	American Association of State Highway and Transportation Officials (AASHTO)
Private Sector		
Motor Equipment Manufacturers Association	Individual vehicle manufacturers (OEMs)	Vehicle Original Equipment Suppliers
ATA Technology and Maintenance Council	Truck Manufacturers Association	Alliance of American Insurers
Alliance of Automobile Manufacturers	American Automobile Association	Automotive Aftermarket Industry Association
Automotive Coalition for Traffic Safety	Highway Loss Data Institute	Japan Automobile Manufacturers Association
Society of Automotive Analysts	Commercial Vehicle Safety Alliance	

Other Organizations		
Institute of Electronic and Electrical Engineers (IEEE)	Intermodal Freight Technology Working Group (IFTWG)	Society of Automotive Engineers (SAE)
ITS America		

Several initiatives in VDR- and EDR-related research currently underway were reviewed and the results used, where appropriate, to develop the VDR concepts in Task 3 (see Chapter 2.2), including the following (source document references are in Appendix A):

NHTSA Light-Duty and Heavy-Duty Vehicle EDR Working Groups
In 1998, NHTSA's Office of Research and Development formed a working group (i.e., the EDR Working Group) comprised of industry, academia, and other government organizations to study the state-of-the-art of EDRs. The group concentrated on the following areas:
- Status of EDR technology
- Data elements
- Data retrieval
- Data collection and storage
- Permanent records
- Privacy and legal issues
- Consumers and users of EDR data
- EDR technology demonstrations

The working group's results and findings were published in August 2001.[1]

In 2000, NHTSA sponsored a second working group (i.e., the T&B EDR Working Group) to research EDRs specifically associated with trucks, school buses, and motorcoaches. The objectives of this working group focused on the data elements, survivability, and event definitions related to trucks, school buses, and motorcoaches. The group's results and findings were published in May 2002.[2]

SAE J1698 Standards Committee
The scope of the SAE J1698 standards development effort is to develop common data output formats and definitions for a variety of data elements that may be used for analyzing vehicle "events," most notably crashes. The standards are intended to govern data element definitions and data extraction methodology as applicable for light-duty (less than 8,500 lbs GVW) original equipment applications. Further, the standard will specify common connectors and network communications protocols to facilitate the extraction of such data.

The first standard developed by this committee, J1698-1, establishes a common format for displaying and presenting crash-related data recorded and stored within certain electronic components currently installed in many light-duty vehicles. This recommended practice pertains only to the post-download format of such data and is not intended to standardize the format of the data stored within any onboard storage unit, or to standardize the method of data recording,

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[1] *National Highway Transportation Safety Administration, Event Data Recorders – Summary of Findings, NHTSA EDR Working Group. NHTSA-99-5218-9, Washington, DC, 2001.*

[2] *National Highway Transportation Safety Administration, Event Data Recorders – Summary of Findings: Volume II Supplemental Findings for Trucks, Motorcoaches, and School Buses, NHTSA EDR Working Group. DOT HS 809 432, Washington, DC, 2002.*

storing, or extraction. J1698-1 does not standardize or mandate the recording of any specific data element, or specify a minimum data set. It is intended to be a compilation of data elements and parameters that various manufacturers are currently recording, as well as those elements reasonably predicted to be recorded in the foreseeable future, and to establish a common format for display and presentation of that recorded data. This version of the recommended practice is limited in application to vehicular data recorded in single frontal impact events. Provisions for multiple-impact or side-impact events may be included in the next version of this standard or in later standards efforts. The SAE J1698-1 standard "Vehicle Event Data Interface – Vehicular Output Data Definition" was published in December 2003.[3]

SAE J2728 Commercial Vehicle Event Data Recorder (CVEDR) Standards Committee
A second SAE committee (in addition to the J1698 committee), SAE J2728, was recently formed to develop a standard for EDRs for commercial vehicles. The CVEDR subcommittee's stated purpose is to "Establish common data elements and data element definitions for heavy commercial vehicle event data recording." The subcommittee is focusing on medium-duty (Class[4] 3-7) and heavy-duty (Class 8) trucks, and will deal specifically with crash event data recording—as opposed to including vehicle data logging/recording. The subcommittee will develop a standard specifying event triggers, threshold levels, and survivability aspects, and will recommend data extraction methods. It is anticipated that the standard will closely resemble that of SAE J1698.[5]

IEEE P1616 Standards Committee
The IEEE P1616 standards development effort is aimed at defining a protocol for motor vehicle event data recorder (MVEDR) output data compatibility and export protocols for MVEDR data elements. The standard does not prescribe the specific data elements to be recorded, or the collection, recording, and storage of data. It is applicable to EDRs for both light- and heavy-duty vehicles, whether offered as original or aftermarket equipment. The IEEE P1616 standard "Motor Vehicle Event Data Recorders" was published in February 2005.[6]

FHWA IVI Program 134 – Development of Requirements and Functional Specifications for Event Data Recorders
The purpose of this project was to use the work products of the NHTSA EDR Working Group and additional EDR reference materials to define specific EDR requirements and functional specifications for the reconstruction of crashes involving large trucks (>10,000 lbs gross vehicle weight). The project's goal was to provide accident analysis data-driven rationale for inclusion of new sensors and measurements into commercial vehicles. The project involved developing EDR requirements for thorough accident analysis of data from the FMCSA's Large Truck Crash Causation Study, and then developing EDR functional specifications for both complete crash reconstruction and less detailed analyses of crashes. Requirements were developed for the EDR

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3 *Society of Automotive Engineers, SAE J1698-1 "Vehicular Event Data Interface – Vehicular Output Data Definition" Detroit, MI, 2003.*

4 *Weights Classes (GVWR in lbs.) - Class 3: 10,001-14,000, Class 4: 14,001-16,000, Class 5: 16,001-19,500, Class 6: 19,501-26,000, Class 7: 26,001-33,000, Class 8: 33,001 and over.*

5 *Society of Automotive Engineers, www.sae.org.*

6 *Institute of Electrical and Electronics Engineers, IEEE P1616 "IEEE Standard for Motor Vehicle Event Data Recorder (MVEDR)", New York, NY, 2005.*

components, hardware, software, sensors, and databases. A cost-effectiveness analysis was also completed for this project.

The analysis of crash data from the Large Truck Crash Causation Study involved an extensive review of 133 crash cases to identify the EDR data elements that will likely be required to reconstruct a variety of large truck crash configurations. A taxonomy, or categorization, of crash configurations that will be helpful in identifying data elements was completed as well. The following three tiers of data elements were developed:

- 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.

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.

The Final Report for FHWA IVI Program 134, Development of Requirements and Functional Specifications for Event Data Recorders, has been published and is available at http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14146.htm.

American Trucking Associations' Technology and Maintenance Council Recommended Practice 1214 – Guidelines for Event Data Collection, Storage, and Retrieval
The Technology and Maintenance Council published a recommended practice (RP) to define the collection of event-related data onboard commercial vehicles. The RP outlines the data elements, storage methodology, and the retrieval approach for event data recording on commercial vehicles. The RP lists several data parameters based upon message ID and parameter ID specifications in the SAE J1587 recommended practice. It also defines the recording interval as a period 30 seconds before and 15 seconds after an event trigger (defined by an unspecified deceleration rate between 0 and 10 mph/sec).[7]

National Cooperative Highway Research Program (NCHRP) Project 17-24 – Use of Event Data Recorder Technology for Roadside Crash Data Analysis
The TRB is administering an NCHRP project under Area 17, Safety. The objectives of this project are to recommend a minimum set of EDR data elements for roadside safety analysis and to recommend procedures for the retrieval, storage, and use of EDR data from vehicle crashes. This project, conducted by Rowan University, includes the following tasks:

1. Synthesizing the current U.S. and international literature on collection, storage, and use of EDR data for roadside and vehicle safety, and meeting with a data collection agency to assess current EDR data collection techniques.

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[7] *American Trucking Associations' Technology and Maintenance Council, Recommended Practices 1214 - Guidelines for Event Recording – Collection, Storage, and Retrieval, Alexandria, VA.*

2. Identifying existing and potential EDR data elements that could be used to improve vehicle and roadside safety. The EDR data elements will be prioritized based on roadside safety analysis needs.
3. Reviewing the data elements that are currently recommended for collection in "Model Minimum Uniform Crash Criteria" (MMUCC) and identifying those that can be more accurately and effectively collected using EDRs, and identifying and prioritizing, based on roadside safety needs, data elements not included in MMUCC that could be provided accurately and effectively using EDRs.
4. Investigating current methods for initial retrieval and storage of, as well as subsequent use of, EDR crash data for roadside safety analysis, and identifying key issues, problems, and costs associated with these methods.
5. Preparing an interim report documenting the findings of Tasks 2 through 4 and meeting in Washington, DC, with the project panel approximately one month after submittal of the interim report.
6. Recommending procedures for improved retrieval, storage, and use of EDR crash data, and identifying possible obstacles to implementation of the recommended procedures. The recommendations will consider, at a minimum, resource requirements, cost effectiveness, legal acceptability, and public acceptance.
7. Submitting a final report that documents the entire research effort.

The report for NCHRP Project 17-24 was published as Web Document 75 in June 2005.

NHTSA Notice of Proposed Rule Making – Event Data Recorders
On June 14, 2004, NHTSA published a Notice of Proposed Rule Making with requirements for voluntarily installed EDRs in light-duty vehicles. This proposal **would not** require the installation of EDRs in any motor vehicles, but would:

1. Require that the EDRs voluntarily installed in light vehicles record a minimum set of specified data elements useful for crash investigations and analysis of the performance of safety equipment (e.g., advanced restraint systems and automatic collision notification systems).
2. Specify requirements for data format.
3. Increase the survivability of the EDRs and their data by requiring that the EDRs function during and after the front, side, and rear vehicle crash tests specified in several Federal motor vehicle safety standards.
4. Require vehicle manufacturers to make publicly available information that would enable crash investigators to retrieve data from the EDR.
5. Require vehicle manufacturers to include a brief standardized statement in the owner's manual indicating that the vehicle is equipped with an EDR and describing the purposes of EDRs.

The proposed regulations require 18 basic event data elements with specific attributes to be recorded for up to 3 crash events if the manufacturers choose to install an EDR in their vehicles. In addition to the basic elements, the proposal requires 24 additional data elements to be recorded if the EDR-equipped vehicles already have onboard technologies to acquire these data elements.

As a basic survivability requirement, the proposed regulations require that an EDR must function after the full-scale front, side, and rear vehicle crash tests specified in FMVSS 208, 214, and 301.

According to the May 16, 2006 Regulatory Agenda (70 FR 27218, at 27295) the NHTSA EDR Final Rule is projected to be published in 2006.[8]

1.3.2 Task 2 – Profile Capabilities and Cost of VDR Product Offerings

This task focused on the identification of specific features and capabilities available and incorporated in commercially available VDRs, and the estimation of the costs associated with those features. The objective was to develop an understanding of the cost drivers for VDR design. A review of the existing literature suggested that there was a considerable amount of information available regarding recommended data elements, sampling rates, and measurement accuracy needed to support various levels of crash causation and safety analyses (e.g., NHTSA's Summary of Findings of the EDR Working Group, Volume 2, Supplemental Findings for Trucks, Motorcoaches, and Buses). However, there was virtually no information available related to the costs associated with incorporating various data gathering capabilities into a particular VDR design. As importantly, there is little available research or quantitative analysis related to the benefits of VDRs. The results of this task are shown in Appendix B.

1.3.3 Task 3 – Develop Alternative VDR Concepts

In order to understand the costs and benefits associated with different implementations of a VDR, the team developed several concepts with different levels of functional sophistication. As a first step, the contractor team identified the high-level functional requirements, capabilities, and performance expectations for VDRs as articulated by different end-user groups (or stakeholders). Such stakeholder groups included government researchers, vehicle manufacturers, fleet operators, and the law enforcement/litigation communities. Each alternative (or concept) could then be examined to evaluate VDRs relative to their ability to meet the goals of the various stakeholder groups.

To profile VDR concept requirements, the contractor team extracted, from industry and government findings (i.e., from NHTSA, FHWA, TRB, ATA/TMC) along with surveys and interviews with key industry stakeholders, the end-user needs and expectations regarding VDR capabilities and required data parameters. VDR concepts were formulated and targeted in the following end-use applications:

- Accident reconstruction and crash causation
- Operational efficiency
- Driver monitoring

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[8] *National Highway Traffic Safety Administration, Notice of Proposed Rulemaking – Event Data Recorders, NHTSA-2004-18029, Washington DC, June 14, 2004.*

1.3.4 Task 4 – Identify and Estimate Benefits of VDR Concepts

This task focused on understanding the benefits of VDRs based on the hypothetical product profiles (operational concepts) developed in Task 3. In addition, estimated costs (e.g., for engineering development, application programming, and hardware) were developed for these same product concepts.

In an effort to better understand likely development and production costs for the concepts outlined in Chapter 2, technical and performance descriptions of each concept from Task 3 were shared with a leading suppler of high-volume custom vehicle electronics for commercial heavy-duty vehicles. The supplier went through the standard development and estimation process, working with both its engineering and sales/pricing team to gain a detailed understanding of the concepts. The supplier then developed an estimated cost analysis for each concept. The team felt that this approach provided a more accurate estimate of the costs broken down into three parts—engineering development costs, application programming costs, and hardware piece costs.

Finally, while return-on-investment calculations are very fleet-specific, and are made difficult due to the "soft" nature of both the benefits and costs, the final part of this task involved developing an overview of the business-case justification that typical fleets use in purchasing VDRs and related products.

CHAPTER 2. ALTERNATIVE VDR CONCEPTS

2.1 APPROACH

Using industry and government findings (i.e., from NHTSA, FHWA, ATA/TMC) along with surveys and interviews with key industry stakeholders, the contractor team profiled end-user needs and expectations regarding VDR capabilities and required data parameters. VDR concepts targeted at the following end-user applications were then developed:

- Accident reconstruction and crash causation
- Operational efficiency
- Driver monitoring

Each concept was intended to typify the design, functionality, and operational performance that would generally be demanded by these three broad user groups. VDR concepts were initially developed in the abstract—without any constraints as to what may be available in the marketplace today. This was to ensure that they represent the team's best judgment as to what a "minimalist" and "full-featured" VDR might be for each end-user application. This is not to imply that the concepts are not practical and/or implementable using current technology—only that it was not a requirement that the concept have a close parallel in the current marketplace.

Unique (distinct) concepts were developed to represent practical combinations of features and capabilities that would address requirements for differing market segments. Specifically, the following VDR concepts were developed:

1. A low-cost event-triggered data recorder for recording baseline accident data
2. A more advanced event-triggered data recorder that incorporates some advanced sensor technologies
3. A baseline continuous VDR that records maintenance and operational data meant to improve fleet operations
4. An advanced continuous data recorder that includes additional driver monitoring parameters
5. A "full-featured" VDR that may include both accident data and operational efficiency data

A profile of each concept was developed that included the source for each data element; necessary network protocols; data collection and transmission rate requirements; and data security, storage, and retrieval needs. Each of these concepts was also defined in terms of an operational scenario—in effect, the conditions under which such a system might be employed, by whom, and for what purposes. This facilitated the accrual of benefit and cost information for subsequent analysis.

Concept descriptions contain, to the extent possible, known and estimated purchase, installation, and operating costs. Because commercial vehicle owners and operators are extremely sensitive to equipment and operating costs, these figures represent important indicators of the commercialization potential of the various concepts.

In addition to the five "core" VDR concepts, which are focused around specific parameters and data sets, a list of advanced VDR features that could be added to any of the five concepts was developed. By separating these advanced VDR features from the five core concepts, and discussing the costs and benefits of these technologies separately, the reader can better understand the costs and implications of adding each feature to a vehicle's data recording system. The five concept data recorders can be thought of as five different "baseline" products that might be appropriate to fulfill the needs of different user-segments. The technologies and features can be thought of as "options" that could be added to any of the baseline products. Using this "base product" and "options" concept allows a reduction of the number of VDR scenarios to be examined while still providing the reader with valuable information needed to effectively construct the reader's own VDR scenarios or configurations.

2.2 RECOMMENDATIONS FOR DATA PARAMETERS TO BE MONITORED

Several industry and government organizations have released findings related to the specific data parameters that VDRs should record. In one case (the NHTSA T&B EDR Working Group), this list included the priority by which these parameters should be recorded.

The NHTSA EDR Working Group presented a summary of findings for light-duty vehicles in August 2001 with an extensive list of data elements that could be considered for EDRs to record along with a Top 10 list of elements based on input from EDR users and manufacturers. In addition, the working group's summary of findings included two lists of EDR parameters important to highway safety research—one from FHWA and one from the TRB.[9]

The NHTSA T&B EDR Working Group developed a detailed list of data elements that were applicable to trucks, motorcoaches, and school buses. The group established two priorities for these data elements. The group deemed Priority 1 parameters to be absolutely necessary to record in order to perform crash causation and accident reconstruction. Priority 2 data elements would improve this ability and should be recorded when available on the vehicle. In addition, the T&B EDR Working Group labeled two parameters (i.e., digital video and vehicle/trailer load present) as optional in that they would greatly assist in performing crash causation analysis and accident reconstruction but currently require the use of advanced onboard sensors (i.e., digital imaging).[10]

In November 1999, the National Transportation Safety Board (NTSB) issued safety recommendations (H-99-45 through H-99-54) to NHTSA to improve school bus and motorcoach safety. One recommendation (H-99-52) required all school buses and motorcoaches manufactured after January 1, 2003 to be equipped with onboard recording systems that record numerous vehicle parameters at a sampling rate suitable to determine vehicle dynamics and are preserved in the event of a vehicle crash or power loss.[11]

The ATA/TMC developed a recommended practice, RP 1214, for VDRs—"Guidelines for Event Recording – Collection, Storage, and Retrieval." This recommended practice defines guidelines

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9 *National Highway Transportation Safety Administration, Event Data Recorders – Summary of Findings, NHTSA EDR Working Group. NHTSA-99-5218-9, Washington, DC, 2001.*

10 *National Highway Transportation Safety Administration, Event Data Recorders – Summary of Findings: Volume II Supplemental Findings for Trucks, Motorcoaches, and School Buses, NHTSA EDR Working Group. DOT HS 809 432, Washington, DC, 2002.*

11 *National Transportation Safety Board, Safety Recommendation H-99-45 through –54, Washington, DC, November 2, 1999.*

for commercial vehicle event data collection (including a list of parameters), storage, and retrieval for post-accident analysis using onboard vehicle ECUs.[12]

The FHWA is conducting an IVI program, Project 134, on the "Development of Requirements and Functional Specifications for Event Data Recorders." One product of the IVI project was a functional specification for a crash EDR that outlined three tiers of data elements:

- 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.

The NHTSA Notice of Proposed Rulemaking, NHTSA-2004-18029, outlined a list of data elements that are required to be recorded on light-duty vehicles equipped with EDRs. It also specified the number of data elements that should be recorded if the vehicle is equipped with the relevant advanced safety system or sensing capability.[13]

Exhibit 2.1 provides a comprehensive list of possible data elements that could be useful for VDRs to record. It summarizes the data parameters that each of the above organizations consider important to record onboard. Entries are listed as follows:

✓: Considered important to record onboard
1x-10x: NHTSA EDR Working Group (WG) "Top Ten" List
P1: NHTSA T&B EDR WG Priority 1 data elements (see footnote #4)
P2: NHTSA T&B EDR WG Priority 2 data elements (see footnote #4)
O: NHTSA T&B EDR WG optional data elements (see footnote #4)
T1: FHWA IVI-134 Project Tier 1 minimum data elements (see footnote #7)
T2: FHWA IVI-134 Project Tier 2 typical data elements (see footnote #7)
T3: FHWA IVI-134 Project Tier 3 complete data elements (see footnote #7)
R: NHTSA NPRM required data elements (see footnote #8)
IE: NHTSA NPRM elements to be recorded if equipped (see footnote #8)

Exhibit 2.1 – Recommendations for Data Parameters to Be Monitored

Parameters	NHTSA EDR WG Top 10[3]	NHTSA EDR WG FHWA[3]	NHTSA EDR WG TRB[3]	NHTSA EDR T&B WG[4]	NTSB H-99-52[5]	ATA TMC RP 1214[6]	FHWA IVI-134[7]	NHTSA NPRM 18029[8]
General Vehicle								
Ignition Status/Cycle	✓							R
Vehicle Speed	5a	✓	✓	P1	✓	✓	T1	R

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[12] *American Trucking Associations Technology and Maintenance Council, Guidelines for Event Recording – Collection, Storage, and Retrieval RP 1214, ATA/TMC, 2001.*

[13] *National Highway Traffic Safety Administration, Notice of Proposed Rulemaking – Event Data Recorders, NHTSA-2004-18029, Washington, DC, June 14, 2004.*

Parameters	NHTSA EDR WG Top 10[3]	NHTSA EDR WG FHWA[3]	NHTSA EDR WG TRB[3]	NHTSA EDR T&B WG[4]	NTSB H-99-52[5]	ATA TMC RP 1214[6]	FHWA IVI-134[7]	NHTSA NPRM 18029[8]
Wheel Speed	✓		✓	P1			T1	
Longitudinal Acceleration	1a	✓		P1	✓		T1	R
Lateral Acceleration	1b			P1	✓		T1	IE
Vertical/Normal Acceleration	✓			P1	✓		T1	IE
Maximum Delta-V	✓							R
Yaw Rate	8		✓				T2	
Tilt/Roll Angle	7		✓				T2	IE
Steering Angle/Wheel Position	5b	✓	✓	P2	✓		T1	IE
Axle/Vehicle Load Status			✓	O			T2	
Tire Pressures/Warning Lamp	✓						T3	
Cruise Control Status	✓			P2		✓	T2	
Odometer/Trip Distance	✓					✓		
VIN			✓	P1			T1	
Subsystem Fault Codes/Lamps	✓							
System Voltage	✓			P2			T2	
Alternator Current								
Turn Signal Status	✓			P2	✓		T2	
Wiper Status	✓			P2			T2	
Headlight Status	✓			P2	✓		T2	
Marker Light Status	✓			P2	✓		T3	
School Bus Stop Lamp Stat.	✓			P2	✓			
Horn Status							T3	
Trailer Status	✓							
Cell Phone/CB Status	✓							
Radio Volume								
Engine and Emissions Control								
Throttle Percentage	✓	✓	✓			✓		R
Accelerator Pedal Pos.			✓	P1			T1	
Intake/Boost Pressure								
Exhaust Temperature								
Engine Temperature								
Engine RPM	✓			P1	✓	✓	T1	R
Engine Load								
Detonation “knock”								
Airflow (MAF, VAF, MAP)*								
Fuel Consumption/Level	✓							
Fuel Pressure								
Engine Retarder Status	✓			P2		✓	T2	
Oil Pressure								
PTO Status								
Engine Idle Time								
Transmission								
Transmission Gear	✓			P1	✓		T1	

Parameters	NHTSA EDR WG Top 10[3]	NHTSA EDR WG FHWA[3]	NHTSA EDR WG TRB[3]	NHTSA EDR T&B WG[4]	NTSB H-99-52[5]	ATA TMC RP 1214[6]	FHWA IVI-134[7]	NHTSA NPRM 18029[8]
Clutch Position	✓							
Input Shaft Speed								
Inertia Brake Status								
Trans. Fluid Temperature								
2/4/All Wheel Drive Status	✓							
Output Shaft Speed								
Brake Systems								
Brake Pedal Position	5c	✓	✓		✓	✓		
Service Brake Status	✓			P1			T1	R
Emergency Brake Status				P1			T1	
Trailer Brake Status				P1			T1	
Air Reservoir Pressure							T3	
Control Pressure								
Application Pressure	✓						T1	
ABS Status	9a			P1			T1	IE
Traction Control Status	9b			P2			T2	
Stability Control Status	9c			P2				IE
Brake Camber Stroke							T3	
Brake Shoe/Pad Force								
Brake Shoe/Pad Temp.								
Brake Light Status	✓				✓			
Brake System Faults					✓			
Safety Systems								
Airbag Lamp Status							T2	
Impact Sensors								
Driver Airbag Deploy. Time	10a			P2	✓		T2	R
Driver Airbag Deploy. Level	10b						T2	R
Driver Airbag Nth Stage Time	10c						T2	IE
Driver Side Airbag Deploy. Time	10d						T2	IE
Pass. Airbag Disabled	10e							IE
Pass. Airbag Deploy. Time	10f							R
Pass. Airbag Deploy. Level	10g							R
Pass. Airbag Nth Stage Time	10h							IE
Pass. Side Airbag Deploy. Time								IE
Driver Seatbelt Latch Status	3a	✓	✓	P1	✓		T1	R
Driver Tensioner Status	✓							IE
Pass. Seatbelt Latch Status	3b							IE
Pass. Tensioner Status	✓							IE
Door Latch/Lock Status	✓							
Seat Occupancy	4	✓	✓					IE
Driver/Pass./Seat Position	✓							IE
Driver/Pass. Size Detection	✓							IE

Parameters	NHTSA EDR WG Top 10[3]	NHTSA EDR WG FHWA[3]	NHTSA EDR WG TRB[3]	NHTSA EDR T&B WG[4]	NTSB H-99-52[5]	ATA TMC RP 1214[6]	FHWA IVI-134[7]	NHTSA NPRM 18029[8]
External Elements								
Time/Date/Event Time	6	✓	✓	P1		✓	T1	R
Geographic Position	2	✓	✓					
Direction of Travel	✓			P2	✓		T1	
Ambient Temperature	✓							
Road Surface Conditions	✓		✓				T3	
Road Surface Temperature	✓							
Other								
Proximity to Objects							T3	
Lane Position							T3	
Distance to Intersections							T3	
Driver ID								
Trailer ID/VIN								
Video	✓			O			T3	
Audio								
Temp. of Wheel Ends								
Suspension Pulse History	✓		✓					
Driver Condition			✓				T3	
Crush Zone History			✓					

* MAF, VAF, MAP stand for Mass Air Flow, Vane Air Flow, and Manifold Absolute Pressure respectively. These are deferent sensor techniques for measuring air flow and composition into a spark-ignition engine.

Based on the listings and priorities presented in Exhibit 2.1, each parameter was ranked for its relevance and applicability for commercial vehicles to (1) crash causation and accident reconstruction analysis, (2) improving operational efficiency, and (3) driver monitoring. Each parameter was assigned a qualitative ranking based on the guidelines presented in Exhibit 2.2.

Exhibit 2.2 –Ranking Categories

0	Parameter not directly related to function
1	Optional parameters that would greatly assist in performing the function but require advanced sensor installation
2	Parameters that complement the core parameters and should be recorded when the sensor technology is installed in the vehicle
4	Core parameters necessary for performing each function

Exhibit 2.3 shows the rankings for each parameter's relevance to accident reconstruction and crash causation, operational efficiency, and driver monitoring.

Exhibit 2.3 – Relationship of Data Parameters to VDR Functions

Parameters	Accident Reconstruction/ Crash Causation	Operational Efficiency	Driver Monitoring
General Vehicle			
Ignition Status/Cycle	2	0	0
Vehicle Speed	4	4	4
Wheel Speed	2	2	0
Longitudinal Acceleration	4	0	0
Lateral Acceleration	4	0	0
Vertical/Normal Acceleration	4	0	0
Maximum Delta-V	4	0	0
Yaw Rate	1	0	0
Tilt/Roll Angle	1	0	0
Steering Angle/Wheel Position	1	0	0
Axle/Vehicle Load Status	1	1	0
Tire Pressure/Warning Lamp	1	1	0
Cruise Control Status	2	2	4
Odometer/Trip Distance	2	4	4
VIN	4	4	0
Subsystem Fault Codes	0	4	0
System Voltage	2	2	0
Alternator Current	0	2	0
Turn Signal Status	2	0	0
Wiper Status	2	0	0
Headlight Status	2	0	0
Marker Light Status	2	0	0
School Bus Stop Lamp Stat.	2	0	0
Horn Status	1	0	0
Trailer Status	1	0	0
Cell Phone/CB Status	1	0	1
Radio Volume	1	0	1
Engine and Emissions Control			
Throttle Percentage	0	0	0
Accelerator Pedal Pos.	4	4	2
Intake/Boost Pressure	0	2	0
Exhaust Temperature	0	2	0
Engine Temperature	0	4	0
Engine RPM	4	4	4
Engine Load	0	4	4
Detonation “knock”	0	2	0
Airflow (MAF, VAF, MAP)	0	2	0
Fuel Consumption/Level	0	4	4
Fuel Pressure	0	2	0
Engine Retarder Status	0	2	2
Oil Pressure	0	2	0
PTO Status	0	2	2

Parameters	Accident Reconstruction/ Crash Causation	Operational Efficiency	Driver Monitoring
Engine Idle Time	0	4	4
Transmission			
Transmission Gear	4	4	2
Clutch Position	2	0	0
Input Shaft Speed	0	0	0
Inertia Brake Status	2	2	2
Trans. Fluid Temperature	0	2	0
2/4/All Wheel Drive Status	0	0	0
Output Shaft Speed	0	0	0
Brake Systems			
Brake Pedal Position	4	4	4
Service Brake Status	4	0	4
Emergency Brake Status	4	0	4
Trailer Brake Status	4	0	4
Air Reservoir Pressure	2	2	0
Control Pressure	1	0	0
Application Pressure	2	0	0
ABS Status	4	2	4
Traction Control Status	2	0	2
Stability Control Status	2	0	2
Brake Camber Stroke	1	1	0
Brake Shoe/Pad Force	1	1	0
Brake Shoe/Pad Temp.	1	1	0
Brake Light Status	2	0	0
Brake System Faults	2	4	0
Safety Systems			
Airbag Lamp Status	2	0	0
Impact Sensors	1	0	0
Driver Airbag Deploy. Time	2	0	0
Driver Airbag Deploy. Level	2	0	0
Driver Airbag Nth Stage Time	2	0	0
Driver Side Airbag Deploy. Time	2	0	0
Pass. Airbag Disabled	2	0	0
Pass. Airbag Deploy. Time	2	0	0
Pass. Airbag Deploy. Level	2	0	0
Pass. Airbag Nth Stage Time	2	0	0
Pass. Side Airbag Deploy. Time	2	0	0
Driver Seatbelt Latch Status	4	0	2
Driver Seatbelt Tensioner Status	1	0	0
Pass. Seatbelt Latch Status	4	0	0
Pass. Seatbelt Tensioner Status	1	0	0
Door Latch/Lock Status	2	0	0
Seat Occupancy	2	0	0
Driver/Pass./Seat Position	1	0	0

Parameters	Accident Reconstruction/ Crash Causation	Operational Efficiency	Driver Monitoring
Driver/Pass. Size Detection	1	0	0
External Elements			
Time/Date	2	4	4
Geographic Position	1	1	1
Direction of Travel	1	1	1
Ambient Temperature	1	0	0
Road Surface Conditions	1	0	0
Road Surface Temperature	1	0	0
Other			
Proximity to Objects	1	0	1
Driver ID	2	2	4
Trailer ID/VIN	1	1	1
Video	1	0	1
Audio	1	0	1
Temp. of Wheel Ends	1	0	0
Suspension Pulse History	1	0	0
Driver Condition	1	0	1
Crush Zone History	1	0	0

These data parameters were then categorized into the following five groups (outlined in Exhibit 2.4) based on the qualitative rankings and applicability to the three main VDR functions:

1. **Accident Reconstruction and Crash Causation Core Data Set** – These are the core data parameters necessary for performing accident reconstruction and crash causation analysis. They are typified by the data recorded in an EDR.
2. **Accident Reconstruction and Crash Causation Advanced Data Set** – These are the data parameters that would complement the core data parameters in group 1, but some of which would likely require the installation of sensors at various locations around the vehicle. This data set includes all of the core accident reconstruction and crash causation data parameters in group 1.
3. **Operational Efficiency Core Data Set** – These are the core data parameters that could be used to improve a fleet's operational efficiency. The parameters are typical of the kinds of information recorded by vehicle data loggers. The information collected is used to improve maintenance efficiency, detect and prevent possible on-road breakdowns, monitor driver performance, track goods movement, and manage fleet logistics. The parameters identified as the core operational data set would be commonly available on new model tractors and would generally not require installation of additional equipment/sensors. It should be noted that to maximize operational efficiency benefits, a VDR would most likely be equipped to record geographic position through GPS or similar technology. However, as GPS and similar technologies could be beneficial to all of the five concepts but is not necessarily required, it has been included in the discussion of advanced VDR technologies in Chapter 3.
4. **Operational Efficiency Advanced Data Set** – These are the other data parameters that a fleet could use to further improve and monitor the efficiency of a fleet. Some of these parameters may require installation of additional sensors. This data set includes all of the core operational efficiency data parameters in group 3.

5. **Driver Monitoring Data Set** – These are the data parameters that could be used to monitor driver behavior for regulation enforcement, fleet safe driver incentives, or insurance policy changes.

Exhibit 2.4 – Categorized Data Sets

(1) Accident Reconstruction and Crash Causation Core Data Set		
– Vehicle Speed – Longitudinal Acceleration – Lateral Acceleration – Vertical Acceleration – Maximum Delta-V – VIN	– Accelerator Pedal Pos. – Engine RPM – Transmission Gear – Brake Pedal Position – Service Brake Status – Emergency Brake Status – Trailer Brake Status	– ABS Status – Driver Seatbelt Latch Status – Passenger Seatbelt Latch Status
(2) Accident Reconstruction and Crash Causation Advanced Data Set		
– All Group (1) Parameters – Tractor Wheel Speeds – Yaw Rate – Tilt/Roll Angle – Steering Angle/Wheel Position – Vehicle Load Status – Cruise Control Status – Odometer – System Voltage	– Turn Signal Status – Wiper Status – Headlight Status – Marker Light Status – Engine Retarder Status – Clutch Position – Inertial Brake Status	– Air Reservoir Pressure – Application Pressure – Traction Control Status – Stability Control Status – Brake Light Status – Brake System Faults – Door Latch/Lock Status – Seat Occupancy
(3) Operational Efficiency Core Data Set		
– Vehicle Speed – Odometer/Trip Distance – VIN – Subsystem Fault Codes – Accelerator Pedal Pos.	– Engine Temperature – Engine RPM – Engine Load – Fuel Consumption – Driver ID	– Engine Idle Time – Transmission Gear – Brake Pedal Position – Brake System Faults – Time/Date
(4) Operational Efficiency Advanced Data Set		
– All Group (3) Parameters – Vehicle Load (GVW) – Tractor Tire Pressures – Cruise Control Status – System Voltage – Alternator Current – Intake/Boost Pressure	– Exhaust Temperature – Detonation “knock” – Fuel Pressure – Engine Retarder Status – Oil Pressure – PTO Status	– Inertia Brake Status – Transmission Fluid Temperature – Air Reservoir Pressure – ABS Status
(5) Driver Monitoring Data Set		
– Vehicle Speed – Cruise Control Status – Odometer/Trip Distance – Accelerator Pedal Pos. – Engine RPM – Engine Load – Fuel Consumption/Level	– Engine Retarder Status – PTO Status – Engine Idle Time – Transmission Gear – Inertia Brake Status – Brake Pedal Position – Service Brake Status – Emergency Brake Status – Trailer Brake Status	– ABS Status – Traction Control Status – Stability Control Status – Seatbelt Latch Status – Time/Date – Driver ID

2.3 VDR CONCEPTS

Using the government and industry findings on data parameters for VDRs along with the summary rankings presented in the previous section, the following VDR concepts were developed:

1. A low-cost event-triggered data recorder for recording baseline crash and severe incident data
2. A more advanced event-triggered data recorder that incorporates some advanced sensor technologies
3. A baseline continuous VDR that records maintenance and operational data meant to improve fleet operations
4. An advanced continuous data recorder that includes additional driver monitoring parameters
5. A "full-featured" VDR that may include both accident data and operational efficiency data

Each of these five concepts was mapped to the data sets developed in the previous section, as shown in Exhibit 2.5.

Exhibit 2.5 – Concept VDR Overview

Capabilities	Concept Vehicle Data Recorders				
	Concept #1	Concept #2	Concept #3	Concept #4	Concept #5
Crash Pulse Recording (high data rate before/after crash event trigger)	✓	✓			✓
Continuous and Histogram Operational Data Recording (low data rate)			✓	✓	✓
Accident Reconstruction Core Data Set	✓	✓			✓
Accident Reconstruction/Causation Advanced Data Set		✓			✓
Operational Efficiency Core Data Set			✓	✓	✓
Operational Efficiency Advanced Data Set			✓	✓	✓
Driver Monitoring Data Set				✓	✓

In order to develop cost estimates for each concept (see Chapter 4), a high-level set of specifications was developed, which included the following requirements:

- Data elements to be recorded

- Estimated memory requirements[14]
- Input and output requirements[15]
- Internal sensor components
- Data extraction requirements
- Power backup requirements
- Display requirements
- Programming capabilities
- Physical vehicle environment requirements

A requirement was placed on all five concepts that they be standalone electronic modules, separate from other electronic modules or ECUs on the vehicle. It is anticipated that for some of the concepts, it may be possible to combine their functionality within other current or future vehicle ECUs (e.g., the engine or airbag modules). This would likely yield cost reductions over a standalone system as they could potentially utilize the same I/O, microprocessor, and storage hardware. However, certain concept architectures may not be compatible with the architecture of other vehicle ECUs (i.e., it may not be cost effective to pair crash pulse recording functionality with engine control functionality within the same electronic module). Therefore, an in-depth proprietary knowledge of the different ECU designs would be necessary to understand the exact cost impacts of pairing different concept functionalities with current/future vehicle ECUs. While it is recognized that this might impact the actual cost to manufacture each concept, in order to adequately compare the relative costs between concepts, all concepts were specified as a separate electronic modules.

As noted earlier, in addition to the VDR "baseline" concepts, a listing of advanced VDR technologies that could be added to any of the five concepts was developed. These include:

- Additional internal memory storage (i.e., a storage upgrade to record more data surrounding an event)
- Removable storage media (i.e., magnetic, optical, solid-state memory)
- Onboard vehicle network communication and downloading (e.g., CAN, IDB, serial)
- Vehicle location, direction of travel, and absolute time (e.g., GPS)

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[14] *It should be noted, that to estimate the memory requirements for each data element estimates where necessary for the field size, frequency, and recording duration for each. Raw field size for time series data elements with high accuracy data (i.e., acceleration) was estimated at 8 bytes, low accuracy data (i.e., accelerator pedal position) was estimated at 4 bytes, digital data (i.e., on/off signals) was estimated at 1 byte, and histogram data was estimated at 40 bytes per histogram. For high frequency data elements (i.e., acceleration) a frequency of 1,000 Hz was used as an estimate, and for low frequency data elements, a frequency of 10 Hz was used as an estimate. For high frequency data, a recording duration of 5 seconds was estimated, for low frequency data, a recording duration of 20 seconds was estimated. These estimates were intended for use in estimating the total raw record size for each data element, which, in turn, was used to estimate the total memory requirements for each concept. These were only intended for estimation purposes and it is entirely probable that the actual field size, frequency, and recording duration would be different if these concepts were manufactured – during the development and testing of the concepts more appropriate values for these would likely be refined and tested.*

[15] *It should be noted that, for several channels, analog sensor inputs were selected based upon an assessment of the state-of-the-practice. New developments in digital sensors and digital pulse width modulation signaling are enabling many vehicle and electronic manufacturers to move away from analog sensors. As these systems become increasingly more prevalent in the commercial vehicle market, it is likely that many of the sensors in these concepts will utilize digital or digital pulse width modulation input instead of analog sensors.*

- Digital imaging (e.g., video)
- Sensor for determining the relative location of nearby vehicles (e.g., radar, ultrasonic)
- Short-range wireless communications (e.g., infrared, Bluetooth, WiFi 802.11)
- Long-range wireless communications (e.g., satellite, cellular)
- Driver performance (e.g., attentive driver monitoring, drowsy driver warning)
- Tractor-to-trailer communications

The following subsections describe in detail each concept. The advanced VDR technologies and features are described in Chapter 3.

2.3.1 Concept 1 – Core Accident Event VDR

Concept 1 is a low-cost event-triggered data recorder for recording various types of onboard data that might be used to assist with accident reconstruction. It would include provisions for recording vehicle dynamics before, during, and after an event.

Most of the data would come from existing subsystem ECUs and would be available over one or more of the vehicle's communications networks (e.g., J1587 and J1939). The EDR would need to contain a three-axis accelerometer (i.e., longitudinal, lateral, vertical). It will also be necessary to have four digital inputs (on/off) to record emergency brake, trailer brake, driver seatbelt latch, and passenger seatbelt latch status. Two analog sensor inputs will be required for accelerator and brake pedal position sensors. Because Concept 1 would be designed to record data both before and after an accident event, it will require an internal backup power supply that would enable the EDR to record data for the short period immediately following an accident should the vehicle main battery be disabled. Exhibit 2.6 details the data elements which would be included in Concept 1, along with the storage algorithm (e.g., time triggered history, histogram, single value, etc.), units, possible data sources, and possible input sources (e.g., J1939, J1708, analog input, digital input, etc.).

Exhibit 2.6 – Concept 1 Standard Data Elements

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Accident Reconstruction and Crash Causation Core Data Set				
ABS Status	Triggered Time History	On/Off/Active	ABS ECU	J1939/J1708
Acceleration – Lateral	Triggered Time History	ft/sec/sec	Accelerometer	Internal Analog Accelerometer
Acceleration – Longitudinal	Triggered Time History	ft/sec/sec	Accelerometer	Internal Analog Accelerometer
Acceleration – Vertical	Triggered Time History	ft/sec/sec	Accelerometer	Internal Analog Accelerometer
Accelerator Pedal Position	Triggered Time History	%	Pedal Position Sensor	Analog Sensor Input
Brake Pedal Position	Triggered Time History	%	Pedal Position Sensor	Analog Sensor Input
Driver Seatbelt Latch Status	Triggered Time History	On/Off	Latch Sensor	Digital Sensor Input
Emergency Brake Status	Triggered Time History	On/Off	Switch Sensor	Digital Sensor Input
Engine RPM	Triggered Time History	rpm	Engine ECU	J1939/J1708

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Maximum Delta-V	Single Triggered Value	ft/sec/sec	Accelerometer	Internal Analog Accelerometer
Passenger Seatbelt Latch Status	Triggered Time History	On/Off	Latch Sensor	Digital Sensor Input
Service Brake Status	Triggered Time History	On/Off	ABS ECU	J1939/J1708
Trailer Brake Status	Triggered Time History	On/Off	Switch Sensor	Digital Sensor Input
Transmission Gear	Triggered Time History	Numeric	Transmission ECU	J1939/J1708
Vehicle Speed	Triggered Time History	ft/sec	Transmission ECU, ABS ECU	J1939/J1708
VIN	Single Most Recent Value	Alphanumeric	Engine/Vehicle ECU	J1939/J1708

Exhibit 2.7 shows an estimate of the memory requirements for storing the data elements in Exhibit 2.6. This estimate was developed to provide a rough basis for determining the cost associated with each concept. It is a raw memory size estimate, and does not include the anticipated overhead needed to store the programming, file structures, or other needed information in the VDR.

Exhibit 2.7 – Concept 1 Estimated Memory Requirements

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Accident Reconstruction and Crash Causation Core Data Set					
ABS Status	On/Off	1	10	20	1600
Acceleration – Lateral	High	8	1,000	5	320,000
Acceleration – Longitudinal	High	8	1,000	5	320,000
Acceleration – Vertical	High	8	1,000	5	320,000
Accelerator Pedal Position	Low	4	10	20	6,400
Brake Pedal Position	Low	4	10	20	6,400
Driver Seatbelt Latch Status	On/Off	1	10	20	1,600
Emergency Brake Status	On/Off	1	10	20	1,600
Engine RPM	Low	4	10	20	6,400
Maximum Delta V	High	8			64
Passenger Seatbelt Latch Status	On/Off	1	10	20	1,600
Service Brake Status	On/Off	1	10	20	1,600
Trailer Brake Status	On/Off	1	10	20	1,600
Transmission Gear	Low	4	10	20	6,400
Vehicle Speed	Low	4	10	20	6,400
VIN	String	17			136
Total Raw Record Size (bits)					**1,001,800**

Input/Output (I/O) Requirements

The following inputs will be required:

- Four digital sensor inputs
- Two analog sensor inputs

No outputs will be required.

The following vehicle network I/O transceivers will be required:

- J1939
- J1708
- RS-232 (for downloading of data and programming of EDR)[16]

Internal Sensor Components
The following sensor components will be required to be internal to the recorder:

- Three-axis (i.e., longitudinal, lateral, vertical) high-resolution, high-frequency accelerometer (similar to those used in light-duty airbag modules)

Data Extraction requirements
Data would be formatted and downloadable via RS-232.

Power Backup Requirements
Power should be maintained for a minimum of 10 seconds after an event to continue to record data, and for the additional time necessary to properly store this data permanently to prevent data loss or corruption.

Displays
None.

Programming Capabilities
The EDR should have basic programming capabilities to allow OEMs to program specific event triggers (based upon available inputs) and recording durations (before/after trigger). This could be performed over the RS-232 port or J1939/J1708. This capability would not be available to the operator/purchaser of the vehicle.

Other Requirements

- The system would be contained within a separate electronic module. The module should have impact, heat, and other mechanical design specs similar to other electronic modules that would be mounted within the driver compartment (i.e., SAE J1455 for driver compartment mounted components).
- All processing of data would be done post-downloading during accident reconstruction (data would need to be simply recorded in a pre-defined location).
- Should be able to record up to two (2) events.
- Recording trigger would be based on exceeding preset deceleration rate or delta-V.

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[16] *RS-232 was selected as the serial communications standard for these concepts, largely due to its proven durability, simplicity, and low cost. Other communications protocols are available RS-485, RS-422, USB, etc. but these are typically less common, and/or new to the automotive environment. Universal Serial Bus (USB), has become the standard in personal computer serial communications with many accessories and hardware now using it exclusively. It would have been an expectable alternative to RS-232 for these concepts, but the limited data transmission size and rate requirements for these concepts does not necessitate the performance of USB over RS-232. It is recognized; however, that should one of these concepts be implemented in the future, USB may be substituted for the RS-232 connection. This would likely not result in a significant cost difference.*

- All components will be selected to meet heavy-duty vehicle Class 6, 7, and 8 NVH standards (i.e., SAE J1455 for driver compartment-mounted components).

2.3.2 Concept 2 – Advanced Accident Event VDR with Advanced Vehicle Sensors

In addition to including all of the capabilities of Concept 1, Concept 2 would incorporate some advanced sensor technology and additional data elements for accident reconstruction and crash causation. Concept 2 is primarily intended to provide all of the necessary data for determining vehicle dynamics and driver inputs during an accident event, and would therefore likely require several additional sensors not normally found on a commercial vehicle, including yaw rate, tilt, steering wheel position, and vehicle/axle load sensors. Additionally, Concept 2 would record the status of most vehicle subsystems (e.g., lights, retarder, inertia brake[17], traction control, stability control, and airbag). Like Concept 1, Concept 2 would mostly record high-resolution data shortly before and after an event, along with some key information stamped at the time of the trigger (e.g., odometer, vehicle load).

Concept 2 will not only require fast data-processing capabilities, it will also require a larger storage capacity to accommodate both the core and advanced accident reconstruction data sets. Like Concept 1, Concept 2 would have an internal backup power supply to allow recording of data after an accident event should the main battery power be disabled.

Exhibit 2.8 details Concept 2 individual data elements along with each element's storage algorithm, units, data source, and input source.

Exhibit 2.8 – Concept 2 Standard Data Elements

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Accident Reconstruction and Crash Causation Core Data Set (Concept 1 Data Elements)				
See Concept 1				1,001,800
Accident Reconstruction and Crash Causation Advanced Data Set				
Air Reservoir Pressure	Triggered Time History	PSI	Pressure Sensor, ABS ECU	Analog Sensor Input
Application Pressure	Triggered Time History	PSI	Pressure Sensor, ABS ECU	Analog Sensor Input
Brake Light Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Brake System Faults	Single Triggered Value	Alphanumeric	ABS ECU	J1939/J1708
Clutch Position	Triggered Time History	On/Off	Transmission ECU, Clutch Sensor	J1939/J1708
Cruise Control Status	Triggered Time History	On/Off	Engine/Vehicle ECU, Switch Sensor	J1939/J1708
Door Latch/Lock Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	Digital Sensor Input
Engine Retarder Status	Triggered Time History	On/Off	Engine ECU	J1939/J1708
Headlight Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708

[17] *Inertia brakes use electromechanical forces and a clutch pack to convert electrical current into a large amount of torque in the transmission. The inertia brake assists in reducing engine speeds quickly. It usually is connected to the power take off (PTO) opening on the transmission.*

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Inertia Brake Status	Triggered Time History	On/Off	Transmission ECU	J1939/J1708
Marker Light Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Odometer	Single Triggered Value	Numeric	Engine/Vehicle ECU	J1939/J1708
Seat Occupancy	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU, ABS ECU	Digital Sensor Input
Stability Control System Status	Triggered Time History	On/Off/Active	ABS ECU	J1939/J1708
Steering Angle/Wheel Position	Triggered Time History	deg	Steering Wheel Position Sensor	Analog Sensor Input
System Voltage	Triggered Time History	volts	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Tilt/Roll Angle	Triggered Time History	deg	Tilt Sensor	Internal Tilt Sensor
Traction Control System Status	Triggered Time History	On/Off/Active	ABS ECU	J1939/J1708
Tractor Wheel Speeds	Triggered Time History	ft/sec	ABS ECU	J1939
Turn Signal Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Vehicle Load (GVW)	Single Triggered Value	lbs	Axle Load Sensors	Analog Sensor Input
Wiper Status	Triggered Time History	On/Off	Vehicle/Dash ECU, Switch Sensor	J1939/J1708
Yaw Rate	Triggered Time History	deg/sec	Yaw Sensor	Internal Yaw Sensor

Exhibit 2.9 shows an estimate of the memory requirements for storing the data elements in Exhibit 2.8. As with the memory estimates for Concept 1, this estimate was developed to provide a rough basis for determining the cost associated with each concept. It is a raw memory size estimate, and does not include the anticipated overhead needed to store the programming, file structures, or other needed information in the VDR.

Exhibit 2.9 – Concept 2 Estimated Memory Requirements

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Accident Reconstruction and Crash Causation Core Data Set (Concept 1 Data Elements)					
See Concept 1					
Accident Reconstruction and Crash Causation Advanced Data Set					
Air Reservoir Pressure	Low	4	10	20	6,400
Application Pressure	Low	4	10	20	6,400
Brake Light Status	On/Off	1	10	20	1,600
Brake System Faults	String	100			800
Clutch Position	Low	4	10	20	6,400
Cruise Control Status	On/Off	1	10	20	1,600
Door Latch/Lock Status	On/Off	1	10	20	1,600
Engine Retarder Status	On/Off	1	10	20	1,600
Headlight Status	On/Off	1	10	20	1,600
Inertia Brake Status	On/Off	1	10	20	1,600
Marker Light Status	On/Off	1	10	20	1,600

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Odometer	Low	4			32
Seat Occupancy	On/Off	1	10	20	1,600
Stability Control System Status	On/Off	1	10	20	1,600
Steering Angle/Wheel Position	Low	4	10	20	6,400
System Voltage	Low	4	10	20	6,400
Tilt/Roll Angle	High	8	1,000	5	320,000
Traction Control System Status	On/Off	1	10	20	1,600
Tractor Wheel Speeds (6)	Low	24	10	20	4,800
Turn Signal Status	On/Off	1	10	20	1,600
Vehicle Load (GVW)	Low	4			32
Wiper Status	On/Off	1	10	20	1,600
Yaw Rate	High	8	1,000	5	320,000
Total Raw Record Size (bits)					**1,693,864**

I/O Requirements
The following inputs will be required:

- Six digital sensor inputs
- Six analog sensor inputs

No outputs will be required.

The following vehicle network I/O transceivers will be required:

- J1939
- J1708
- RS-232 (for downloading of data and programming of EDR)

Internal Sensor Components
The following sensor components will be required to be internal to the recorder:

- Three-axis (i.e., longitudinal, lateral, vertical) high-resolution, high-frequency accelerometer (similar to those used in light-duty airbag modules)
- Yaw rate sensor – high resolution, high frequency
- Tilt/roll angle sensor – high resolution, high frequency

Data Extraction requirements
Data would be formatted and downloadable via RS-232.

Power Backup Requirements
Power should be maintained for a minimum of 10 seconds after an event to continue to record data, and for the additional time necessary to properly store this data permanently to prevent data loss or corruption.

Displays
None.

Programming Capabilities
The EDR should have basic programming capabilities to allow OEMs to program specific event triggers (based upon available inputs) and recording durations (before/after trigger). This could be performed over the RS-232 port or J1939/J1708. This capability would not be available to the operator/purchaser of the vehicle.

Other Requirements

- The system would be contained within a separate electronic module. The module should have impact, heat, and other mechanical design specs similar to other electronic modules that would be mounted within the driver compartment (i.e., SAE J1455 for driver compartment mounted components).
- All processing of data would be done post-downloading during accident reconstruction (data would need to be simply recorded in a pre-defined location).
- Should be able to record up to two (2) events.
- Recording trigger would be based on exceeding preset deceleration rate or delta-V.
- All components will be selected to meet heavy-duty vehicle Class 6, 7, and 8 NVH standards (i.e., SAE J1455 for driver compartment mounted components).

2.3.3 Concept 3 – Core Operational Efficiency VDR

Concept 3 is a “continuous” VDR that records a variety of operating data that can be used for improving maintenance planning (predictive maintenance) and for monitoring driver performance and operations. It would include only a core operational efficiency data set to provide basic measures of vehicle/fleet efficiency. To this end, both summary data (minimums, maximums, averages, cumulative totals) and histogram data (segmented data categorized in various “bins”) would be recorded for a variety of channels.

The modest parameter set and storage algorithm requirements result in a VDR with a small storage capacity, and would likely not require a fast processing capability as only summary-type data are recorded at a much slower frequency than that of Concept 1 (EDR). Additionally, all of the data elements should be available over one of the vehicle networks (J1587/J1939) from either the engine, transmission, or ABS ECUs. It may be necessary, however, for Concept 3 to have two analog inputs for the accelerator pedal position and brake pedal position if these data are not available over either databus. In practice, this type of VDR functionality is made available as an option by engine manufacturers using the engine ECU as the recording and processing device.

Concept 3 would also require a methodology for recording driver identification. This would require either manual driver inputs of driver ID or an automated system that can keep track of driver IDs. Exhibit 2.10 details Concept 3 individual data elements.

Exhibit 2.10 – Concept 3 Standard Data Elements

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Operational Efficiency Core Data Set				
Accelerator Pedal Position	Histogram, Max, Min, Average	%	Pedal Position Sensor	Analog Sensor Input
Brake Pedal Position	Histogram, Max, Min, Average	%	Pedal Position Sensor	Analog Sensor Input
Brake System Faults	Single Most Recent Value	Alphanumeric	ABS ECU	J1939/J1708
Driver ID	Time History of Driver ID	Alphanumeric Driver ID	SmartCard Reader, TWIC Reader, Driver ID Keyboard	RS-232
Engine Idle Time	Cumulative	h-m-s	Engine ECU	J1939/J1708
Engine Load	Histogram, Max, Min, Average	%	Engine ECU	J1939/J1708
Engine RPM	Histogram, Max, Min, Average	rpm	Engine ECU	J1939/J1708
Engine Temperature	Histogram, Max, Min, Average	degrees F	Engine ECU	J1939/J1708
Fuel Consumption	Average	mpg	Engine ECU	J1939/J1708
Odometer/Trip Distance	Single Most Recent Value	Numeric	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Subsystem Fault Codes	Single Most Recent Value	Alphanumeric	All ECUs	J1939/J1708
Time/Date	Single Most Recent Value	mm/dd/yyyy h-m-s	VDR Internal Clock	Internal Clock
Transmission Gear	Histogram	Numeric	Transmission ECU	J1939/J1708
Vehicle Speed	Histogram, Max, Min, Average	ft/sec	Transmission ECU, ABS ECU	J1939/J1708
VIN	Single Most Recent Value	Alphanumeric	Engine ECU, Vehicle/Dash ECU	J1939/J1708

Exhibit 2.11 shows an estimate of the memory requirements for storing the data elements in Exhibit 2.10.

Exhibit 2.11 – Concept 3 Estimated Memory Requirements

Data Element	Record Type/ Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Operational Efficiency Core Data Set					
Accelerator Pedal Position	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Brake Pedal Position	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Brake System Faults	Alphanumeric String	100			800
Driver ID	Time History of Driver ID (1/60 Hz, 1 Week Duration) – Low	4			322,560
Engine Idle Time	Cumulative	4			32
Engine Load	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Engine RPM	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Engine Temperature	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Fuel Consumption/Level	Low	4			32
Odometer/Trip Distance	Low	4			32
Subsystem Fault Codes	Alphanumeric String	100			800
Time/Date	Low	4			32
Transmission Gear	Histogram – Low	40			320
Vehicle Speed	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
VIN	Alphanumeric String	17			136
				Total Raw Record Size (bits)	**327,904**

I/O Requirements

The following inputs will be required:

- Two analog sensor inputs
- RS-232 (for interfacing with driver ID recording device)

No outputs will be required.

The following vehicle network I/O transceivers will be required:

- J1939
- J1708
- RS-232 (for downloading of data and programming of VDR)

Internal Sensor Components
The following sensor components will be required to be internal to the recorder:

- Internal clock to record mm/dd/yyyy h-m-s.sss

Driver ID Recording
The VDR will record a driver's ID if and when a driver ID is entered by means of a variety of devices (e.g., SmartCard reader, TWIC card reader, and keyboard) that connect to the VDR via the RS-232 input. The VDR will then keep a time history record of the driver ID when the vehicle is running and in motion (i.e., in service).

Data Extraction requirements
Data would be formatted and downloadable via RS-232.

Power Backup Requirements
No specific power backup is required. The system should maintain enough power or be designed so that data is not corrupted in the event of a loss of power or voltage spike.

Displays
None.

Programming Capabilities
The VDR should have basic programming capabilities to allow fleets, OEMs, and operators to program the type of summary trip activity information recorded (e.g., averages, minimum and maximum thresholds). This could be performed over the RS-232 port or J1939/J1708. This capability would be available to the operator of the vehicle.

Other Requirements

- The system would be contained within a separate electronic module. The module should have impact, heat, and other mechanical design specs similar to other electronic modules that would be mounted within the driver compartment (i.e., SAE J1455 for driver compartment mounted components).
- All components will be selected to meet heavy-duty vehicle Class 6, 7, and 8 NVH standards (i.e., SAE J1455 for driver compartment mounted components).

2.3.4 Concept 4 – Advanced Operational Efficiency and Driver Monitoring VDR

Concept 4 would be a comprehensive VDR for improving driver, vehicle, and fleet operational efficiency and for driver monitoring. The concept would include provisions for recording data elements needed to provide fleet managers and maintenance personnel with a detailed picture of both the driver's and vehicle's performance. Concept 4 would record both summary and histogram data on almost every critical vehicle subsystem along with driver behavioral sensors (e.g., seatbelt latch, maximum vehicle speeds, maximum engine RPM). Most of these parameters are available over one of the vehicle networks (J1587, J1939), so a limited number of additional sensors would be required, including:

- Axle or vehicle load sensors
- Tire pressure monitoring sensors
- Emergency brake status switch sensor (if not already installed)

- Trailer brake status switch sensor (if not already installed)
- Seatbelt latch sensor (if not already installed)

Concept 4, like Concept 3, would require a methodology for recording driver identification, either through manual driver inputs of driver ID or an automated system that can keep track of driver IDs. Concept 4 also includes tractor tire pressure data elements, and the sensors and systems needed to accomplish this.

Exhibit 2.12 details the Concept 4 individual data elements along with each element's storage algorithm, units, record type, and possible sources.

Exhibit 2.12 – Concept 4 Standard Data Elements

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Operational Efficiency Core Data Set (Concept 3 Data Elements)				
See Concept 3				327,904
Operational Efficiency Advanced Data Set and Driver Monitoring Data Set				
ABS Status	Histogram	On/Off/Active	ABS ECU	J1939/J1708
Air Reservoir Pressure	Histogram, Max, Min, Average	PSI	ABS ECU, Pressure Transducer	Analog Sensor Input
Alternator Current	Histogram, Max, Min, Average	amps	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Cruise Control Status	Histogram	On/Off	Engine ECU, Vehicle/Dash ECU, Switch Sensor	J1939/J1708
Detonation "knock"	Histogram	On/Off	Engine ECU	J1939/J1708
Driver Seatbelt Latch Status	Histogram	On/Off	Latch Sensor	J1939/J1708
Emergency Brake Status	Histogram	On/Off	Switch Sensor	Digital Sensor Input
Engine Retarder Status	Histogram	On/Off	Engine ECU	J1939/J1708
Exhaust Temperature	Histogram, Max, Min, Average	degrees F	Engine ECU	J1939/J1708
Fuel Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
Inertia Brake Status	Histogram, Cumulative	On/Off	Transmission ECU	J1939/J1708
Intake/Boost Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
Oil Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
PTO Status	Histogram	h-m-s	Engine ECU, Transmission ECU	J1939/J1708
Service Brake Status	Histogram	On/Off	ABS ECU	J1939/J1708
Stability Control System Status	Histogram	On/Off/Active	ABS ECU	J1939/J1708
System Voltage	Histogram, Max, Min, Average	volts	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Traction Control System Status	Histogram	On/Off/Active	ABS ECU	J1939/J1708
Tractor Tire Pressures (10)	Histogram, Max, Min, Average	PSI	Tire Pressure Monitoring System	J1939
Trailer Brake Status	Histogram	On/Off	Switch Sensor	Digital Sensor Status
Transmission Fluid Temperature	Histogram, Max, Min, Average	degrees F	Transmission ECU	J1939/J1708
Vehicle Load (GVW)	Histogram, Max, Min, Average	lbs	Axle Load Sensors	Analog Sensor Input

Exhibit 2.13 shows an estimate of the memory requirements for storing the data elements in Exhibit 2.12.

Exhibit 2.13 – Concept 4 Estimated Memory Requirements

Data Element	Record Type/ Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Operational Efficiency Core Data Set (Concept 3 Data Elements)					
See Concept 3					
Operational Efficiency Advanced Data Set and Driver Monitoring Data Set					
ABS Status	Histogram - Low	40			320
Air Reservoir Pressure	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Alternator Current	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Cruise Control Status	Histogram – On/Off	10			320
Detonation “knock”	Histogram – Low	40			320
Driver Seatbelt Latch Status	Histogram – On/Off	10			320
Emergency Brake Status	Histogram – On/Off	10			320
Engine Retarder Status	Histogram – On/Off	10			320
Exhaust Temperature	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Fuel Pressure	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Inertia Brake Status	Histogram – On/Off	10			320
Intake/Boost Pressure	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Oil Pressure	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
PTO Status	Cumulative – Low	4			32
Service Brake Status	Histogram – On/Off	10			320
Stability Control System Status	Histogram – On/Off	10			320
System Voltage	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Traction Control System Status	Histogram – On/Off	10			320
Tractor Tire Pressures (10 tires)	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	400 40 40 40			3,200 320 320 320
Trailer Brake Status	Histogram – On/Off	10			320

Data Element	Record Type/ Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Transmission Fluid Temperature	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
Vehicle Load (GVW)	Histogram – Low Min Value – Low Max Value – Low Ave Value – Low	40 4 4 4			320 32 32 32
				Total Raw Record Size (bits)	**339,360**

I/O Requirements
The following inputs will be required:

- Four analog sensor inputs
- Two digital sensor inputs
- RS-232 (for interfacing with driver ID recording device)

No outputs will be required.

The following vehicle network I/O transceivers will be required:

- J1939
- J1708
- RS-232 (for downloading of data and programming of VDR)

Internal Sensor Components
The following sensor components will be required to be internal to the recorder:

- Internal clock to record mm/dd/yyyy h-m-s.sss

Driver ID Recording
The VDR will record a driver's ID if/when a driver ID is entered by means of a variety of devices (e.g., SmartCard reader, TWIC card reader, keyboard) that connect to the VDR via the RS-232 input. The VDR will then keep a time history record of the driver ID when the vehicle is running and in motion (i.e., in service).

Data Extraction requirements
Data would be formatted and downloadable via RS-232.

Power Backup Requirements
No specific power backup will be required. The system should maintain enough power or be designed so that data is not corrupted in the event of a loss of power or voltage spike.

Displays
None.

Programming Capabilities
The VDR should have basic programming capabilities to allow fleets, OEMs, and operators to program the type of summary trip activity information recorded (e.g., averages, minimum and

maximum thresholds). This could be performed over the RS-232 port or J1939/J1708. This capability would be available to the operator of the vehicle.

Other Requirements

- The system would be contained within a separate electronic module. The module should have impact, heat, and other mechanical design specs similar to other electronic modules that would be mounted within the driver compartment (i.e., SAE J1455 for driver compartment mounted components).
- All components will be selected to meet heavy-duty vehicle Class 6, 7, and 8 NVH standards (i.e., SAE J1455 for driver compartment mounted components).

2.3.5 Concept 5 – "Full-Featured" Accident Event, Operational Efficiency, and Driver Monitoring VDR

Concept 5 is a "full-featured" VDR/EDR and combines advanced accident reconstruction data set with advanced operational efficiency and driver monitoring data set. It is not only designed to record high-resolution data before, during, and after an accident event, but also to continuously record histogram and summary data to improve fleet efficiency, fleet maintenance, and monitor driver performance. This recorder would therefore require several added internal sensors (three-axis accelerometer, yaw rate, tile/roll angle) and several inputs for additional sensors not normally found on a commercial vehicle (steering wheel position, tire pressure monitoring, and vehicle/axle load). Additionally, this recorder would record the status of most vehicle subsystems (e.g., lights, retarder, inertia brake, traction control, stability control, airbag).

This recorder would record an extensive amount of data and, therefore, would require significant storage capacity. Additionally, because it would be recording data at a high frequency before and after an event trigger, it will require a fast data-processing capability and an internal backup power supply. The extensive list of data elements means that Concept 5 would require six analog and five digital inputs to record data that is not available on the vehicle's databuses (J1587/J1939). Exhibit 2.14 details the data elements for Concept 5.

Exhibit 2.14 – Concept 5 Standard Data Elements

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Accident Reconstruction and Crash Causation Core Data Set Accident Reconstruction and Crash Causation Advanced Data Set Operational Efficiency Core Data Set Operational Efficiency Advanced Data Set Driver Monitoring Data Set				
ABS Status	Triggered Time History, Histogram	On/Off/Active	ABS ECU	J1939/J1708
Acceleration – Lateral	Triggered Time History	ft/sec/sec	Accelerometer, Airbag ECU	Internal Analog Accelerometer
Acceleration – Longitudinal	Triggered Time History	ft/sec/sec	Accelerometer, Airbag ECU	Internal Analog Accelerometer
Acceleration – Vertical	Triggered Time History	ft/sec/sec	Accelerometer, Airbag ECU	Internal Analog Accelerometer
Accelerator Pedal Position	Triggered Time History, Histogram, Max, Min, Average	%	Pedal Position Sensor	Analog Sensor Input
Air Reservoir Pressure	Triggered Time History, Histogram, Max, Min, Average	PSI	Pressure Sensor, ABS ECU	Analog Sensor Input

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Alternator Current	Histogram, Max, Min, Average	amps	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Application Pressure	Triggered Time History	PSI	Pressure Sensor, ABS ECU	Analog Sensor Input
Brake Light Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Brake Pedal Position	Triggered Time History, Histogram, Max, Min, Average	%	Pedal Position Sensor	Analog Sensor Input
Brake System Faults	Single Triggered Value, Single Most Recent Value,	Alphanumeric	ABS ECU	J1939/J1708
Clutch Position	Triggered Time History	On/Off	Transmission ECU, Clutch Sensor	J1939/J1708
Cruise Control Status	Triggered Time History, Histogram	On/Off	Engine/Vehicle ECU, Switch Sensor	J1939/J1708
Detonation “knock”	Histogram	On/Off	Engine ECU	J1939/J1708
Door Latch/Lock Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	Digital Sensor Input
Driver ID	Time History of Driver ID	Alphanumeric Driver ID	SmartCard Reader, TWIC Reader, Driver ID Keyboard	RS-232
Driver Seatbelt Latch Status	Triggered Time History, Histogram	On/Off	Latch Sensor	J1939/J1708
Emergency Brake Status	Triggered Time History, Histogram	On/Off	Switch Sensor	Digital Sensor Input
Engine Idle Time	Cumulative	h-m-s	Engine ECU	J1939/J1708
Engine Load	Histogram, Max, Min, Average	%	Engine ECU	J1939/J1708
Engine Retarder Status	Triggered Time History, Histogram, Cumulative	On/Off	Engine ECU	J1939/J1708
Engine RPM	Triggered Time History, Triggered Time History, Histogram, Max, Min, Average	rpm	Engine ECU	J1939/J1708
Engine Temperature	Histogram, Max, Min, Average	degrees F	Engine ECU	J1939/J1708
Exhaust Temperature	Histogram, Max, Min, Average	degrees F	Engine ECU	J1939/J1708
Fuel Consumption/ Level	Histogram, Max, Min, Average	mpg	Engine ECU	J1939/J1708
Fuel Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
Headlight Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Inertia Brake Status	Triggered Time History, Histogram	On/Off	Transmission ECU	J1939/J1708
Intake/Boost Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
Marker Light Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Maximum Delta-V	Single Triggered Value	ft/sec/sec	Accelerometer, Airbag ECU	Internal Analog Accelerometer
Odometer	Single Triggered Value Single Current Value	Numeric	Engine/Vehicle ECU	J1939/J1708
Oil Pressure	Histogram, Max, Min, Average	PSI	Engine ECU	J1939/J1708
Passenger Seatbelt Latch Status	Triggered Time History	On/Off	Latch Sensor	J1939/J1708
PTO Status	Cumulative	h-m-s	Engine ECU, Transmission ECU	J1939/J1708

Data Element	Storage Algorithm	Unit	Data Sources	Input Source
Seat Occupancy	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU, ABS ECU	Digital Sensor Input
Service Brake Status	Triggered Time History, Histogram	On/Off	ABS ECU,	J1939/J1708
Stability Control System Status	Triggered Time History, Histogram	On/Off/Active	ABS ECU	J1939/J1708
Steering Angle / Wheel Position	Triggered Time History	deg	Steering Wheel Position Sensor	Analog Sensor Input
Subsystem Fault Codes	Single Current Value	Alphanumeric	All ECUs	J1939/J1708
System Voltage	Triggered Time History, Histogram, Max, Min, Average	volts	Engine ECU, Vehicle/Dash ECU	J1939/J1708
Tilt/Roll Angle	Triggered Time History	deg	Tilt Sensor	Internal Tilt Sensor
Time/Date	Single Triggered Value Single Current Value	mm/dd/yyyy h-m-s	VDR Internal Clock	Internal Clock
Traction Control System Status	Triggered Time History, Histogram	On/Off/Active	ABS ECU	J1939/J1708
Tractor Tire Pressures (10)	Histogram, Max, Min, Average	PSI	Tire Pressure Monitoring System	J1939
Tractor Wheel Speeds (6)	Triggered Time History	ft/sec	ABS ECU	J1939
Trailer Brake Status	Triggered Time History, Histogram	On/Off	Switch Sensor	Digital Sensor Input
Transmission Fluid Temperature	Histogram, Max, Min, Average	degrees F	Transmission ECU	J1939/J1708
Transmission Gear	Triggered Time History, Histogram	Numeric	Transmission ECU	J1939/J1708
Turn Signal Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Vehicle Load (GVW)	Single Triggered Value, Histogram, Max, Min, Average	lbs	Axle Load Sensors	Analog Sensor Input
Vehicle Speed	Triggered Time History, Histogram, Max, Min, Average	ft/sec	Transmission ECU, ABS ECU	J1939/J1708
VIN	Single Most Recent Value	Alphanumeric	Engine/Vehicle ECU	J1939/J1708
Wiper Status	Triggered Time History	On/Off	Switch Sensor, Vehicle/Dash ECU	J1939/J1708
Yaw Rate	Triggered Time History	deg/sec	Yaw Sensor	Internal Yaw Sensor

Exhibit 2.15 shows an estimate of the memory requirements for storing the data elements in Exhibit 2.14.

Exhibit 2.15 – Concept 5 Estimated Memory Requirements

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
ABS Status	Triggered Time History – Low Histogram – Low	4 40	10	20	6,400 320
Acceleration – Lateral	Triggered Time History – High	8	1,000	5	320,000
Acceleration – Longitudinal	Triggered Time History – High	8	1,000	5	320,000
Acceleration - Vertical	Triggered Time History – High	8	1,000	5	320,000

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Accelerator Pedal Position	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
Air Reservoir Pressure	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
Alternator Current	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Application Pressure	Triggered Time History – Low	4	10	20	6,400
Brake Light Status	Triggered Time History – On/Off	1	10	20	1,600
Brake Pedal Position	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
Brake System Faults	Single Triggered Value – String Single Most Recent Value – String	100 100			800 800
Clutch Position	Triggered Time History – Low	4	10	20	6,400
Cruise Control Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Detonation "knock"	Histogram – Low	40			320
Door Latch/Lock Status	Triggered Time History – On/Off	1	10	20	1,600
Driver ID	Time History of Driver ID- Low	4	1/60	604,800	322,560
Driver Seatbelt Latch Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Emergency Brake Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Engine Idle Time	Cumulative – Low	4			32
Engine Load	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Engine Retarder Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Engine RPM	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
Engine Temperature	Histogram – Low Max – Low Min – Low Average - Low	40 4 4 4			320 32 32 32
Exhaust Temperature	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Fuel Consumption/ Level	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Fuel Pressure	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Headlight Status	Triggered Time History – On/Off	1	10	20	1,600
Inertia Brake Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Intake/Boost Pressure	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Marker Light Status	Triggered Time History – On/Off	1	10	20	1,600
Maximum Delta-V	Single Triggered Value – High	8			64
Odometer	Single Triggered Value – Low Single Current Value – Low	4 4			32 32
Oil Pressure	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Passenger Seatbelt Latch Status	Triggered Time History – On/Off	1	10	20	1,600
PTO Status	Cumulative – Low	4			32
Seat Occupancy	Triggered Time History – On/Off	1	10	20	1,600
Service Brake Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Stability Control System Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Steering Angle/Wheel Position	Triggered Time History – Low	4	10	20	6,400
Subsystem Fault Codes	Single Current Value – String	100			800
System Voltage	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
Tilt/Roll Angle	Triggered Time History – High	8	1000	5	320,000
Time/Date	Single Triggered Value – Low Single Current Value – Low	4 4			32 32
Traction Control System Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80
Tractor Tire Pressures (10)	Histogram – Low Max – Low Min – Low Average – Low	400 40 40 40			3,200 320 320 320
Tractor Wheel Speeds (6)	Triggered Time History – Low	24	10	20	4,800
Trailer Brake Status	Triggered Time History – On/Off Histogram – On/Off	1 10	10	20	1,600 80

Data Element	Resolution	Field Size (bytes)	Frequency (Hz)	Recording Duration (sec)	Raw Record Size (bits)
Transmission Fluid Temperature	Histogram – Low Max – Low Min – Low Average – Low	40 4 4 4			320 32 32 32
Transmission Gear	Triggered Time History – Low Histogram – Low	4 40	10	20	6,400 320
Turn Signal Status	Triggered Time History – On/Off	1	10	20	1,600
Vehicle Load (GVW)	Single Triggered Value – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4			32 320 32 32 32
Vehicle Speed	Triggered Time History – Low Histogram – Low Max – Low Min – Low Average – Low	4 40 4 4 4	10	20	6,400 320 32 32 32
VIN	Single Most Recent Value – String	17			136
Wiper Status	Triggered Time History – On/Off	1	10	20	1,600
Yaw Rate	Triggered Time History – High	8	1000	5	320,000
				Total Raw Record Size (bits)	2,040,280

I/O Requirements
The following inputs will be required:

- Six analog sensor inputs
- Five digital sensor inputs
- RS-232 (for interfacing with driver ID recording device)

No outputs will be required.

The following vehicle network I/O transceivers will be required:

- J1939
- J1708
- RS-232 (for downloading of data and programming of VDR)

Internal Sensor Components
The following sensor components will be required to be internal to the recorder:

- Three-axis (i.e., longitudinal, lateral, vertical) high-resolution, high-frequency accelerometer
- Yaw rate sensor – high resolution, high frequency
- Tilt/roll angle sensor – high resolution, high frequency
- Internal clock to record mm/dd/yyyy h-m-s.sss

Driver ID Recording
The VDR will record a driver's ID if/when a driver ID is entered by means of a variety of devices (e.g., SmartCard reader, TWIC card reader, keyboard) that connect to the VDR via the

RS-232 input. The VDR will then keep a time history record of the driver ID when the vehicle is running and in motion (i.e., in service).

Data Extraction requirements
Data would be formatted and downloadable via RS-232.

Power Backup Requirements
Power should be maintained for a minimum of 10 seconds after an event to continue to record data, and for the additional time necessary to properly store this data permanently to prevent data loss or corruption.

Displays
None.

Programming Capabilities
The VDR should have basic programming capabilities to allow fleets and OEMs to program specific event triggers (based upon available inputs) and recording durations (before/after trigger), along with the type of summary trip activity information recorded (e.g., averages, minimum and maximum thresholds). This could be performed over the RS-232 port or J1939/J1708. Event programming capability would not be available to the operator of the vehicle, while trip activity information programming could be available to the operator.

Other Requirements

- The system would be contained within a separate electronic module. The module should have impact, heat, and other mechanical design specs similar to other electronic modules that would be mounted within the driver compartment (i.e., SAE J1455 for driver compartment mounted components).
- All processing of data would be done post-downloading during accident reconstruction (data would need to be simply recorded in a pre-defined location).
- Should be able to record up to two (2) events.
- Recording trigger would be based on exceeding preset deceleration rate or delta-V.
- All components will be selected to meet heavy-duty vehicle Class 6, 7, and 8 NVH standards (i.e., SAE J1455 for driver compartment mounted components).

CHAPTER 3. ADVANCED VDR TECHNOLOGIES

The following subsections describe each of the advanced VDR technologies (or "options") in detail, and provide an overview of the technology, implementation issues, infrastructure requirements, and costs. The optional or advanced technologies reviewed include:

- **Section 3.1:** Supplemental internal memory storage (e.g., EEPROM, flash memory)
- **Section 3.2:** Removable storage media (e.g., magnetic, optical, solid-state memory)
- **Section 3.3:** Onboard vehicle network communication and downloading (e.g., CAN, IDB, serial)
- **Section 3.4:** Vehicle location, direction of travel, and absolute time e.g., GPS)
- **Section 3.5:** Digital imaging (e.g., video)
- **Section 3.6:** Sensors for determining the relative location of nearby vehicles (e.g. radar, ultrasonic)
- **Section 3.7:** Short-range wireless communications (e.g., infrared, Bluetooth, WiFi 802.11)
- **Section 3.8:** Long-range wireless communications (e.g., satellite, cellular)
- **Section 3.8:** Driver performance (e.g., attentive driver monitoring, drowsy driver warning)
- **Section 3.10:** Tractor-to-trailer communications

The following questions are addressed for each technology or feature (where applicable):

- Technology Overview
  - How does the system function?
  - What components are required?
  - Are there different levels of implementation for this technology (i.e., is there an advanced or full-featured version? Is there a basic version?)?
  - Where is this technology currently used?
  - What information will it provide to the VDR? How could this information be used for accident reconstruction, operational management, driver training, or emergency personnel?
  - What are the current and near-term commercially available systems?
  - Are any long-term development projects underway that might impact the integration of the technology with a VDR?
- VDR Implementation Issues
  - How might this technology be implemented into an EDR on a heavy-duty vehicle?
  - What additional hardware will be required on the vehicle or VDR to use this technology (e.g., additional sensors, receiving and/or transmitting antennas, or databuses required)?
  - What are some of the disadvantages of using this technology over other similar technologies (e.g., removable media versus short-range wireless versus long-range wireless)?
- Infrastructure Requirements (if applicable)

- What kind of infrastructure is necessary for this technology to operate (e.g., cellular service, satellites, road markings, WiFi “hot spots”)?
- Is this infrastructure currently available? What is the timeframe for development?
- Who is likely to develop this infrastructure?

- Technology Implementation Cost
  - What is the range of costs, per vehicle, for the hardware required to implement the technology?
  - How might these costs decrease as the technology becomes more popular?

3.1 SUPPLEMENTAL INTERNAL MEMORY STORAGE

3.1.1 Technology Overview

One of the key components of any onboard data recording device is memory. The size and type of memory affects how much data can be stored, how quickly the data is saved, the durability of the recorder, and how long the data will remain intact. Typically, there are two main types of memory—volatile and non-volatile. Volatile memory requires a constant source of power for the memory contents to remain intact and is typically used for temporary, high-speed, data storage. Examples of volatile memory in computer electronics include random access memory (RAM) and cache (high-speed memory located in or near the CPU). In contrast, the contents of non-volatile memory remain intact when power is disconnected. Non-volatile memory is typically used for long-term storage of data and generally has slower read and write speeds. Examples of non-volatile memory include read-only memory (ROM); programmable read-only memory (PROM), which has many variants (e.g., erasable PROM or EPROM, electronically erasable PROM or EEPROM, and flash memory); and even magnetic storage disks (i.e., hard disk drives).

Most electronic devices, including VDRs, use both volatile and non-volatile memory. Program software is typically stored in non-volatile memory (usually ROM). When the device is turned on, that program is loaded into volatile memory (RAM and cache) and the CPU. Data can then be retrieved from another non-volatile memory source, typically one that allows for both read and write provisions (EEPROM, flash memory, or hard disk drive).

In a VDR, the size and speed of the volatile memory often determines how much data is stored in a continuous buffer before an event triggers the data to be saved permanently. Although this function could be accomplished using non-volatile memory, it is often significantly slower (especially when the non-volatile memory is an EPROM or EEPROM). While this is very important to the design of the VDR electronics, volatile memory is often not a limiting factor as the size required is typically small.

The non-volatile memory used for permanent data storage significantly impacts VDR design as it is a limiting factor for how much event or operational data a VDR records. Non-volatile memory is available in a range of capacity—from a small capacity to store only a few seconds of critical data to a large capacity able to store multiple data element streams for days or weeks.

The most basic non-volatile memory is PROM, a non-volatile integrated circuit memory chip on which data can be written only once. Once a program has been written onto a PROM, it remains there forever. PROMs retain their contents when the computer is turned off. To write data onto a PROM chip, you need a special device called a PROM programmer or PROM burner.

An EPROM is a special type of PROM that can be erased by exposing it to high-intensity ultraviolet (UV) light. Once it is erased, it can be reprogrammed. To accomplish this, EPROM chips normally contain UV-permeable quartz windows exposing their internals. The UV light clears the contents, making it possible to reprogram the memory. To write to an EPROM, you can use the same device as a PROM. Generally, EPROMs are used to store program code and static data, and are widely used in personal computers because they enable the manufacturer to change the contents of the PROM before the computer is actually shipped.

Largely, PROMs and EPROMs are used in computer systems to store program code generated by the manufacturer of an embedded computer system. Because these devices require additional hardware to record and erase data, they generally are not used to store data. A common alternative to the PROM and EPROM typically used in embedded computer system applications to store data is EEPROM, a special type of PROM that can be erased and written electrically. EEPROM maintains its contents without power backup and is frequently used to retain program data. EEPROMs have slow read and write times because they require data to be written or erased one byte at a time. EEPROM chips generally range in capacity from 128 bits to 512 KB, with write times in the 5 to 15 millisecond range.

Flash memory is a type of EEPROM that can be erased and reprogrammed in blocks of data instead of one byte at a time. Flash memory is also popular because it enables hardware manufacturers to support new protocols and technologies as they become standardized by simply installing updated program code. Flash memory is typically available in three formats, disk-on-chip, flash disk drive, and removable CompactFlash (see Section 3.2 – Removable Storage Media). With disk-on-chip, flash memory is contained in a single chip that can be integrated into a printed circuit board of an embedded computer directly. Disk-on-chip flash memory chips typically range from 1 MB to 32 MB, but can reach up to 300 MB. Flash drives are flash memory chips that are integrated in a package similar to a hard disk drive. Flash drives generally operate using similar computer protocols to that of hard disk drives, but are noiseless, rugged, and light weight. Flash drives are generally available to replace hard disk drives up to 1 GB in size.

Hard disk storage is another non-volatile memory alternative and is commonly used in personal computers. Hard disks are typically used when there is a large memory requirement, and can be sized up to 300 to 400 GB. While hard disks are robust enough for portable computers, they are susceptible to temperature, moisture, and vibration, which can reduce their long-term durability and reliability.

3.1.2 VDR Implementation Issues

EEPROMs and flash memory are uniquely suited to store data in a VDR—not only because they are non-volatile, but also because they are robust and can be integrated into the VDR or could be removable in the event of an accident (see Section 3.2 – Removable Storage Media).

Hard disks are susceptible to temperature, moisture, and vibration, which can reduce their long-term durability and reliability. Additionally, the high forces of an accident event could cause damage to a hard disk drive, thus preventing data from being recorded. Therefore, it is likely that hard disk drives would not be used for VDRs designed for accident event recording. VDRs designed for operational data recording would avoid the use of hard disks where possible.

Memory type and size selection for a VDR is important and depends largely on the intended application. For instance, a VDR might require the same memory capacity to record 5 high-resolution, high-frequency inputs for 2 seconds as a VDR designed to record 50 low-resolution, low-frequency inputs for 2 weeks. Exhibit 3.1 provides an order-of-magnitude estimate for the amount of memory required for various applications.

Exhibit 3.1 – Example Memory Requirements

Application	# of Inputs	Resolution	Field Size (bytes)	Sample Frequency (Hz)	Recording Duration (sec)	Raw Record Size (KB)
1) Accelerometer Data						
3-axis "high-resolution" accelerometer inputs	3	High	8	100	30	70.3
2) GPS Data						
GPS Longitude every 1 sec for 1 hr	1	High	8	1	3,600	70.3
GPS Latitude every 1 sec for 1 hr	1	High	8	1	3,600	
GPS Time every 1 sec for 1 hr	1	Low	4	1	3,600	
3) Accident Data Example						
5 "high-resolution" inputs for 5 sec +	5	High	8	100	5	24.4
5 "low-resolution" inputs for 20 sec +	5	Low	4	10	20	
5 digital inputs for 20 sec	5	Digital	1	10	20	
4) Operational Data Example (1 day)						
10 "low-resolution" inputs every 1 min +	10	Low	4	1/60	86,400	98.4
10 digital inputs every 1 min	10	Digital	1	1/60	86,400	
GPS Data (see above)	1	High/Low	8+8+4	1/60	86,400	

Exhibit 3.1 illustrates how much raw memory space would likely be required to record different amounts and types of data. For example, it shows that recording three high-resolution accelerometer inputs during a 30-second event at 100 Hz (100 times/sec) would require approximately 70 KB of raw (excluding any necessary memory overhead) memory space. This could easily be accomplished using a moderately sized EEPROM or a small flash memory chip. Similarly, to record GPS location and time for one hour at once per second would also require the same 70 KB of raw memory.

The third and fourth examples in Exhibit 3.1 illustrate the typical memory requirements to record accident event data and operational data respectively. Example 3 shows what a typical accident record might resemble—five high-resolution, high-frequency inputs (accelerometers, yaw, tilt) for 5 seconds; five low-resolution, low-frequency inputs (e.g., vehicle speed, engine speed, brake pressure) for 20 seconds; and five digital (on/off) inputs for 20 sec. Memory requirements for Example 3 would likely be modest.

Example 4 illustrates the memory requirements for a day's worth of operational data and GPS location and time. Typical operational data could include 10 low-resolution inputs (e.g., vehicle speed, engine RPM, engine temperature) recorded every minute, 10 digital inputs (e.g., gear, headlight activation) recorded every minute, and GPS location and time recorded every minute. Memory requirements for Example 4 (approximately 98 KB) would be more than for the accident data in Example 3.

3.1.3 Technology Implementation Costs

EEPROM chips vary in cost, and depend significantly on size and quantity purchased. Exhibit 3.2 shows typical costs for various size EEPROMs with a moderate purchase quantity.

Exhibit 3.2 – Typical EEPROM Chip Costs

Capacity (Megabit)	Approximate Cost (moderate quantity > 500)
128 B	$0.30 - $0.40
1 KB	$0.40 - $0.60
8 KB	$0.80 - $1.00
64 KB	$1.00 - $1.30
128 KB	$1.80 - $2.00
256 KB	$2.20 - $2.90

Both disk-on-chip and flash disk drive memory also vary in size and cost. Exhibit 3.3 shows typical costs for disk-on-chip and disk drive flash memory.

Exhibit 3.3 – Typical Flash Memory Costs

Capacity (Megabit)	Disk-On-Chip Approximate Cost (moderate quantity > 500)	Flash Disk Drive Approximate Cost (moderate quantity > 500)
1 MB	$2.00- $3.00	
4 MB	$2.50 - $3.50	
16 MB	$4.00 - $5.00	
256 MB		$500.00
512 MB		$700.00
1024 MB		$850.00

Exhibits 3.2 and 3.3 show typical costs for EEPROM and flash memory chips, based on moderate purchase quantities. Of course, these prices are intended to illustrate the relative cost differences between memory types and sizes. It should be recognized that there are many other design factors that affect the price of memory (e.g., access time, memory organization, packaging, power supply and usage, and temperature range).

3.2 REMOVABLE STORAGE MEDIA

3.2.1 Technology Overview

Removable storage media for a VDR could provide a relatively straightforward approach for retrieving data. There are many forms of removable storage available, but most would not be suitable for the vehicle environment. The most common types of removable storage media include:

- Removable Magnetic Storage

- 3.5” floppy disks
- Tapes
- Zip disks
- Super disks
- Removable hard disks

- Removable Optical Storage
  - CD-R (write once)
  - CD-RW (re-writable)
  - DVD-R/DVD+R (write once)
  - DVD-RW (re-writable)
- Removable Solid State Memory
  - CompactFlash
  - SmartMedia
  - Sony Memory Stick
  - SD Memory
  - XD Memory cards

Due to the automotive environment, removable magnetic storage (e.g., 3.5” floppy, Zip, and Super disks) is not practical because of its susceptibility to moisture, temperature, and vibration affecting both the long-term durability and the sensitive write heads. Optical storage (i.e., CDs and DVDs) have similar vibration issues that affect the recording ability and accuracy of the laser heads. In addition, these technologies have multiple mechanical components that are generally not very durable (limited application in vehicles with 100,000+ mile lifespan). Tape drives are very slow, have similar durability and environmental concerns, and are generally expensive. Removable hard disk storage, while more reliable than diskettes and CDs and DVDs, would likely still not be suited for automotive applications where vibration and moisture could cause data loss and premature failure of the disk drive. Hard disk drives have the advantage of very high-speed access and large capacity, and are a very mature technology in the mobile computer industry, but, for the reasons described above, have not been widely used in the automotive industry.

The most promising technology is solid-state memory. The trend toward mobile computing (e.g., handheld PC, cellular phones) and digital cameras has led to the mainstreaming and continued evolution of solid-state, non-volatile memory. Solid-state memory is a type of EEPROM on which data can be electronically written and electronically rewritten without any mechanical components. In addition, solid-state memory (unlike a computer’s RAM) does not require a continuous source of power to maintain data. The advantages of solid-state memory are numerous:

- Faster access speeds than hard disks
- Compact and lightweight
- Noiseless
- No mechanical parts
- Low susceptibility to environmental conditions and vibration with the appropriate packaging

The major disadvantage is cost. While the price continues to decrease as demand increases, solid-state memory still costs more than hard disk drives, CDs and DVDs, and diskettes.

There are a multitude of removable solid-state memory technologies and brands available, including:

- CompactFlash
- SmartMedia
- SD Memory
- XD Memory
- Memory Stick

Originally developed by SanDisk in 1994, CompactFlash is the oldest technology, and is common in embedded system applications. It is the largest (35.4x42.8x3.3/5.5 mm) and heaviest (11.4 g) of the technologies, but also the most affordable. CompactFlash cards can range from 4 MB to 2 GB in size and have a write time of 300 to 2,000 KB/sec.

SmartMedia, originally developed by Toshiba and called the solid-state floppy-disk card, ranges in capacity from 4 to 128 MB. SmartMedia has a very simple architecture and is one of the smallest (37x45x0.76 mm) and lightest (2.0 g) of the technologies. It has a capacity of up to 128 MB and a write time of 500 to 1,000 KB/sec. In general, however, for personal applications, it has been found to be less rugged than the other solid-state memory devices (i.e., it is generally very fragile) due to the packaging and electrical contacts.

SD Memory, developed as a "next-generation" memory card by both SanDisk and Toshiba along with Panasonic, is very small in size (24x32x2.1 mm) and lightweight (2.0 g). It supports up to 512 MB with a write speed of up to 10 MB/sec. Unlike both CompactFlash and SmartMedia, SD Memory has both copy protection and write protection built in; enabling data to be encrypted and protected from overwrites.

XD Memory is a similar "next-generation" technology with future capacities of up to 8 GB on a single tiny (only 20x24.9x1.8 mm) XD card. It is currently commercially available up to 256 GB in size.

Memory Stick is a proprietary Sony memory format. It is larger (50x21.5x2.8 mm) and heavier (4.0 g) than SD and XD memory, and is largely only found in Sony products. It is beginning to make headway in other manufacturer's equipment, but because it is proprietary, it is still slightly more expensive than newer and smaller technologies. It has a maximum capacity of 128 MB and a write time of 2.45 MB/sec. Its proprietary design means that, until recently, it was not often used in embedded applications.

3.2.2 VDR Implementation Issues

Integrating either magnetic or optical storage technologies into a VDR presents some significant challenges as these technologies would have to be proven to be reliable to withstand both the everyday environment and vibration of heavy-duty commercial vehicles and the impact force of an accident. The VDR's reserve backup power capabilities would have to be sufficient to complete all data acquisition and recording on the magnetic or optical storage after an event. It is not likely that either magnetic or optical storage systems would be suitable for an extended VDR application.

Again, solid-state memory appears to have a significant advantage in VDR integration as solid-state memory devices continue to be integrated into portable electronics and personnel computers. Solid-state memory devices are easily integrated into embedded systems because their interface is relatively straightforward. Technologies such as SmartMedia, SD, and XD use simplistic serial I/O to read and write data that could be integrated into the VDR's microcontroller. CompactFlash uses the common ATA/IDE standards for communication with disk drives.

3.2.3 Infrastructure Requirements

Little to no infrastructure requirements are required to support removable storage media. Specialized diagnostic tools with the appropriate memory slots or custom programming of existing equipment will be necessary to read data from removable solid-state memory cards, but this technology is readily available and should be straightforward to implement. Personal computers, laptops, and PDAs could readily be programmed to read and analyze data from a VDR's removable storage media. Adapter cards are currently available to read solid-state memory in a laptop's PCMCIA slot (used mainly for network cards), and many new computers are have dedicated memory card slots built-in.

3.2.4 Technology Implementation Costs

Integrating magnetic or optical storage into a VDR would likely be prohibitive as these technologies would require a significant amount of research and development in order to ensure they would withstand the environmental conditions and the impact of an accident. However, both magnetic (specifically removable hard disk drives) and optical memory are very inexpensive, typically less than $0.02 per MB. Solid-state removable memory would be significantly less costly to implement. Typical solid-state memory costs per MB are approximately:

- CompactFlash: $0.70 -$0.86 per MB
- SmartMedia: $0.74 -$1.14 per MB
- SD Memory: $1.94 per MB
- XD Memory: $0.95 per MB
- Sony Memory Stick: $1.49 - $2.65 per MB

Higher per MB prices can be expected for recently developed cards with larger MB capacity.

3.3 ONBOARD VEHICLE NETWORK COMMUNICATION AND DOWNLOADING

3.3.1 Technology Overview

Hardwired onboard communication (i.e., communication that uses physical electrical wiring as the medium) is widespread in the automotive industry. Applications are continuing to increase as manufacturers look for ways to reduce costs and simultaneously add features to vehicles. Both the light- and heavy-duty markets have seen the introduction of onboard vehicle networks to allow communications between different electronic control units on the vehicle. On the light-duty side, this was largely precipitated by the onboard diagnostics (OBD)[18] regulations requiring emissions control system monitoring. Since light-duty vehicle subsystems historically have largely been manufactured and integrated by the OEM or in close cooperation with its suppliers, a multitude of communications protocols have evolved, with the OBD regulations supporting many of them. In the heavy-duty industry, where common subsystems are provided by various suppliers (e.g., engines, transmissions, and brake systems) and integrated by vehicle OEMs, a need for common communications standards has facilitated only a few prominent network protocols.

SAE, in particular, has defined three distinct protocol classifications for both light- and heavy-duty applications: Class A, Class B, and Class C.[19] Class A is the first SAE classification and maintains the lowest data rate, a rate that peaks as high as 10 Kb/s. Class A devices typically support convenience operations like actuators and "smart" sensors. The implementation of Class A has significantly reduced the bulk of automotive wiring harnesses. The second SAE classification is the Class B protocol. Class B supports data rates as high as 100 Kb/s and typically supports intermodule, non-real-time control and communications, including current OBD protocols. The use of Class B can eliminate redundant sensors and other system elements by providing a means to transfer data (e.g., parametric data values) between nodes. Class C is the last of these three classifications, and readily supports performance as high as 1 Mb/s. Because of this level of performance, Class C is typically used for critical, real-time control. Class C facilitates distributed control via high-data-rate signals typically associated with real-time control systems.

Light-duty protocols are largely focused around satisfying OBD regulations, but have been used more frequently for intermodule communications in recent years. Light-duty protocols include:

- SAE J1850 *Class B Data Communications Network Interface*
- ISO 9141 *Road Vehicles: Diagnostic Systems Requirements for Interchange of Digital Information*
- ISO 14230 *Road Vehicles: Diagnostic Systems Keyword Protocol 2000*
- SAE J2284 *High-Speed CAN (HSC) for Vehicle Applications at 125, 250, and 500 Kbps*

In addition, three other communications standards are gaining popularity for light-duty, non-OBD applications; Local Interconnect Network (LIN); Media Oriented Systems Transport (MOST); and Automotive Multimedia Interface Collaborations ITS Data Bus (IDB). LIN is designed as a low-speed network for use on doors, roofs, seats, dashboards, and steering wheels to connect switches and relays to actuators—reducing wiring costs. It is a single-wire network. MOST is a plastic fiber-optic digital media network for sound systems and video entertainment systems. It has largely been developed by European automakers and is in production on high-end European vehicles. IDB was designed to allow aftermarket suppliers to connect equipment using

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18 *OBD has been required on light-duty passenger vehicles in some form since 1988 and was intended to identify emissions control sensors, actuators, and other emissions control systems which are no longer functioning properly. The most recent light-duty OBD regulations, OBD-II, developed a set of monitors/checks for various emissions related components, as well as, specific diagnostic trouble codes, allowable communications protocols, and a specific data link connector for external diagnostic tools. OBD-II defined the way diagnostic data was made available on light-duty vehicles.*

19 *Society of Automotive Engineers, Glossary of Vehicle Networks for Multiplexing and Data Communications – SAE J1213/1, SAE Vehicle Network for Multiplexing and Data Communications Standards Committee, June 1991.*

a standardized connector and have access to vehicle information and systems without disturbing the vehicle control systems or OBD. To date, IBD has not largely been adopted due to low-transmission rate and lack of industry interest in a standard media protocol.

In the heavy-duty commercial vehicle market, a single OEM might offer vehicles with multiple types and manufacturers of engines, transmissions, ABS, and other vehicle subsystems. This necessitated a common method for communications between subsystems so that any engine could theoretically communicate with any transmission or ABS. In addition, there was a need for a common diagnostic interface to minimize cost and facilitate troubleshooting of vehicles with multiple subsystems. In North America, two main protocols have become standard, SAE J1708/J1587 and SAE J1939 for Class B diagnostics and a high-speed Controller Area Network (CAN) for Class A communications. In addition, in Europe, the ISO 11898 CAN standard is the most popular along with ISO 11992 for tractor-to-trailer communications.

SAE J1708, *Serial Data Communications Between Microcomputer Systems in Heavy-Duty Vehicle Applications*, defines a recommended practice for implementing a bi-directional, Class B serial communication link among vehicle ECUs. SAE J1708 defines the hardware and basic software compatibility such as the interface requirements, system protocol, and message format of the serial communications link. SAE J1708 does not define actual data to be transmitted by particular ECUs, which is an important aspect of communications compatibility, and is left to other standards and individual manufacturers to define. SAE J1587, *Joint SAE/TMC Electronic Data Interchange Between Microcomputer Systems in Heavy-Duty Vehicle Applications*, builds on J1708 to define the diagnostic serial communications link between onboard ECUs and off-board diagnostic equipment. It defines the format of messages and data to be transmitted including field descriptions, size, scale, internal data representation, and position within a message.

SAE J1939, *Recommended Practice for a Serial Control and Communications Vehicle Network*, is intended for light-, medium-, and heavy-duty vehicles used on or off road as well as appropriate stationary applications that use vehicle-derived components (e.g., generator sets). Vehicles of interest include, but are not limited to, on and off highway trucks and their trailers; construction equipment; and agricultural equipment and implements. The purpose of J1939 is to provide an open interconnect system for electronic systems. J1939 is designed to allow ECUs to communicate with each other by providing a standard architecture.

ISO 11898*, Road Vehicles: Interchange of Digital Information Controller Area Network (CAN) for High-Speed Communication*, describes the general architecture of CAN in terms of hierarchical layers according to the ISO reference model for Open System Interconnection (OSI), which is a standard for worldwide communications that defines a networking framework for implementing protocols in seven layers. The standard contains detailed specifications of aspects of CAN belonging to the physical layer and the data link layer. It specifies characteristics of setting up an interchange of digital information between electron control units of road vehicles equipped with CAN at transmission rates above 125 Kbit/s up to 1 Mbit/s. The CAN is a serial communication protocol that supports distributed real-time control and multiplexing.

ISO 11992, *Road Vehicles: Interchange of Digital Information on Electrical Connections Between Towing and Towed Vehicles*, describes the protocol used for the interchange of digital information between road vehicles with a maximum authorized total mass greater than 3,500 kg, and towed vehicles, including communication between towed vehicles in terms of parameters and requirements of the physical and data link layer of the electrical connection used to connect the electrical and electronic systems. It also includes conformance tests of the physical layer.

3.3.2 VDR Implementation Issues

Wired onboard vehicle networks can be used to both collect data from vehicle subsystems and download VDR data to an off-board reader. Current heavy-duty commercial vehicles have both J1708/J1587 and J1939 networks onboard, and a significant amount of data is currently being broadcast across these networks, including:

- Vehicle, engine, and wheel speeds
- Engine and emissions control information
- Transmission status and gear
- Brake system and ABS information
- Safety system status (e.g., seatbelt, airbag, and door lock)
- Subsystem fault codes

Connecting a VDR to these networks would be straightforward and would not only allow data collection but also downloading the diagnostic ports. The technology is commonplace in the heavy-duty vehicle industry and could be readily implemented.

Light-duty and ISO standard protocols would require slightly more development to implement in heavy-duty North American vehicle applications, but the technology is readily available and could be easily integrated. Most heavy-duty vehicle systems in North America do not currently use light-duty and ISO networks onboard, so data would likely not be available to be recorded over these networks in a VDR. While it is technically possible, it is unlikely that any of the light-duty networks will be used in the heavy-duty market in the future.

3.3.3 Infrastructure Requirements

Little to no infrastructure requirements are required to support vehicle-based wired downloading and data collection. Specialized diagnostic tools or custom programming of existing equipment will be necessary to download and read the VDR data, but this technology is readily available and should be straightforward to modify.

3.3.4 Technology Implementation Costs

The cost to connect a VDR to an onboard vehicle network and provide downloading of VDR data over the vehicle's diagnostic connectors would be minimal. For CAN network standards, microcontroller chipsets (CAN protocol controllers) can cost around \$5.00 with the additional transceiver interface (to interface between the microcontroller and the physical bus) costing around \$1.50. J1850 transceivers are priced similarly around \$2.00. LIN microcontrollers can cost approximately \$2.50 with transceivers costing less than \$1.00.

3.4 VEHICLE LOCATION/TIME/DIRECTION OF TRAVEL

3.4.1 Technology Overview

The Global Positioning System (GPS) has become the most popular and efficient means for determining location and direction of travel in mobile applications. The relative compactness, low cost, and commercial availability of the technology are key factors in its attractiveness as an accurate measure of location and direction of travel. In addition to providing location information, the design of the technology allows for the accurate measurement of time.

Originally developed by the U.S. military, GPS is a worldwide radio-navigation system formed from a constellation of 24 satellites and multiple land-based stations. GPS uses these satellites as reference points to calculate positions accurate up to a couple of meters. Advanced forms of GPS, such as Differential Global Positioning System (DGPS), can have accuracies close to a centimeter. Modern GPS hardware has been miniaturized into a few integrated circuits, yielding an economical and compact system for determining precise location, direction of travel, and time data for a variety of automotive, marine, aviation, construction, and computer applications. In addition, GPS hardware can be combined with Geographic Information Systems (GIS) data to overlay vehicle locations on maps to reference them to geographic features, streets, and buildings.

GPS uses distances from multiple satellites to triangulate a location, using the travel time of radio signals. GPS satellites transmit RF signals, and the signal's travel time is measured by the receiver. GPS receivers have an almanac programmed into them, which has the position of all the satellites. The U.S. military continuously monitors each satellite's position, and corrections are transmitted to the receivers within each timing signal. Using the timing signal from four satellites and knowing the location of each satellite, the receiver can calculate its location in 3-dimensional space.

DGPS supplements these satellite signals with a signal from a land-based, fixed location receiver. This fixed receiver knows what the actual signal travel time should be and compares that with what it receives. It then transmits this difference as a correction factor to nearby DGPS receivers over radio frequencies. The correction factors could also be post-processed if precise positioning is not needed immediately.

This GPS technology is not only used for tracking and mapping but also to distribute precise time and time intervals. GPS satellites carry highly accurate atomic clocks. In turn, ground receivers synchronize to these clocks in order to precisely calculate distances. This leads to GPS receivers having accuracy close to that of an atomic clock.

GPS technology can be implemented at various levels, from standalone chipsets to complete GPS and GIS systems and DGPS. At the lowest level, GPS chipsets, similar to those developed for the FCC's E911 regulations[20] governing cellular phones, are available that receive the GPS satellite timing signals but leave the distance calculations and triangulation to post-processing, often referred to as Assisted GPS (A-GPS). The chipsets are compact and require relatively little power for operation, but leave all of the calculations and analysis to be done externally from the chips either off-board or using separate processors. GPS receivers, similar to those in handheld applications, can receive timing signals; process distances using an almanac of known satellite locations; and provide calculated latitude, longitude, and elevation information along with speed, direction of travel, and time. GPS receivers can also be integrated with GIS to place this latitude, longitude, and elevation data on maps of terrain, roads, buildings, and other landmarks—similar to those systems for automotive and marine navigation systems.

DGPS systems are also available with built-in radio frequency receivers to pick up the correction factors from nearby land-based DGPS broadcast centers. The U.S. Coast Guard, military and government organizations, and many commercial companies have DGPS broadcast centers located throughout the U.S. and globally. DGPS is not currently available in all areas, but planned DGPS sites will cover most of the continental United States in the future. (DGPS receivers can operate on standard GPS if the correction factors broadcast is not available.)

Many commercial manufactures offer handheld GPS receivers for mobile and stationary applications. Leading manufacturers include Trimble, Garmin, and Magellan. E911 chipsets are also available and are currently being integrated into cellular phones for major U.S. telecommunications providers. Manufacturers of these chipsets include SiRF, Motorola, and RF Micro Devices. Additionally, many commercial heavy-duty vehicle products are available that use GPS technology, mostly for fleet management and tracking, and their manufacturers include Terion, Vetronix, and Qualcomm.[21] Most major light-duty automobile manufacturers also offer GPS-guided navigation systems that incorporate GIS data on CDs and DVDs.

3.4.2 VDR Implementation Issues

GPS technology for recording vehicle location, direction of travel, and time can be integrated into a VDR in a variety of levels of sophistication. At the lowest level, E911 chipsets could be modified (if not used directly) for integration into a VDR. The E911 chipsets could receive GPS timing signals and the raw timing data (not location calculations) could be stored in the VDR. Post-processing of the data could then be performed either externally at a later date or by the VDR's microprocessor. This would result in a very economical means of recording location. Correction factors, similar to those used for DGPS, could also be taken into account at a later date (pending availability from a nearby DGPS fixed receiver) to provide a very accurate account of the vehicle's location for crash investigators or fleet management personnel.

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20 *In 1996, the FCC mandated that all new cellular phones be capable of sending location information to emergency 911 operators by the year 2006. Phase I of the FCC Wireless E911 mandate requires that a dialable number accompany each 911 call and the location of the cellular site that received the call as rough indication of the caller's location. Phase II for the E911 mandate requires that carriers provide automatic location identification using either handset- or network-based technology. Handset technology requires new, modified or upgraded handset with technologies such as GPS to determine location. This location is then broadcast along with the 911 call to alert emergency personnel.*

21 *Qualcomm's wireless communications "messaging link" is a Ku band satellite-based mobile communications system. This system uses geosynchronous satellites orbiting the earth approximately 25,000 miles above the equator at a rate that synchronizes them with the rotation of the earth. Qualcomm on-board systems monitor tractor location using either GPS or QASPER. QASPER is a Qualcomm proprietary satellite-based location determination system similar to GPS, but not typically as accurate as GPS.*

A more advanced (and potentially more costly) implementation of geographic position could involve integrating the necessary GPS hardware to perform the distance calculations and location triangulation, similar to what a handheld GPS unit might have. This would provide the VDR with location, direction of travel, and time data directly and would minimize the post-processing requirements necessary. While this would require some additional cost (above the cost for E911-like hardware), systems and hardware are currently available and being manufactured by a variety of companies for commercial use.

Since VDRs are primarily targeted at accident reconstruction and operational efficiency improvements, integrating GIS data along with the geographic position information in a VDR would likely not prove overly beneficial. GIS maps of roadways, buildings, and terrain would provide useful information, specifically for accident reconstruction and causation analysis, but could be more efficiently overlaid during data analysis post event/trip. If, however, a VDR was to provide real-time data to the driver, then the integration of GIS data on top of the raw geographic position data would be relatively straightforward as many automotive, marine, and personnel navigation systems already use this technique.

This technology can easily be implemented into a VDR. Many of the products on the market have the capability to have additions, such as sensors, integrated into the product itself. Some systems, such as Qualcomm, are systems from which sensors and event triggers could be added. Other time and location technologies could be integrated into already existing VDRs through either a RS232 or a USB port. These connections could facilitate the storage and manipulation of location, time, and direction of travel data.

The most difficult challenge of integrating geographic position into VDRs is antenna placement. GPS receivers do require antennas to acquire the GPS signals, and since four GPS satellite signals are required, antenna placement can be important. Recent advances in GPS technology have allowed these antennas to become very small, specifically with the E911 mandate as they must fit into the compact space of a cellular phone. If a GPS antenna is integrated into the VDR package, then the VDR itself would have to be located in a specific location on the vehicle where it is able to receive GPS signals. An external GPS antenna is also an option, and most automotive (including commercial motor vehicles) navigation and tracking systems use an external GPS antenna mounted on top of the vehicle.

Additionally, it is likely that geographic position data will not be available at all times. If the vehicle is traveling through tunnels or under overpasses, the satellite signal could be interrupted. This will likely result in a temporary loss of location and direction of travel data if alternative algorithms are not employed to interpolate the location based on speed and direction of travel.

3.4.3 Infrastructure Requirements

The GPS satellite infrastructure is already in place. The U.S. military has completed the necessary satellites, land-based stations, monitoring equipment, and timing and synchronization equipment to provide GPS services globally. DGPS transmitters are in place globally, but DGPS coverage is still not universal. DGPS covers most of the continental United States, as well as Alaska, Hawaii, and bordering parts of Canada and Mexico, with future DGPS sites planned to fill in the remaining gaps (largely located in Idaho, Nevada, Oregon, Texas, West Virginia, Kentucky, and western Virginia and North Carolina).

Two other government-sponsored satellite navigation systems are available or in development, similar to that of GPS: (1) the Russian Global Navigation Satellite System (GLONASS), and (2) the European Galileo Global Navigation Satellite System (GNSS). Similar to GPS, these systems will provide global navigation coverage; however, it is still unclear as to what form of commercially available receiving hardware will be developed that uses this infrastructure.

3.4.4 Technology Implementation Costs

The cost to implement geographic position on a VDR is dependent on the level of integration necessary. Low-cost E911 chipsets are becoming increasingly more available as companies strive to meet the FCC mandate. These chipsets are small and compact, and in large quantities would likely cost around $25. GPS receiver boards that provide complete location, direction of travel, and time data (designed for integration into an automotive navigation system), such as those sold by RF Micro Devices, could cost as little as $40 for quantities over 10,000 per year, but likely would be initially in the range of $50 to $100. Commercial handheld and portable GPS units run from around $100 to $500, with units with advanced GIS topping out at $1,000. Complete automotive GPS navigation and/or tracking systems, some with built-in GIS or cellular location transmitting capability can range up to and over $2,000.

3.5 DIGITAL IMAGING

3.5.1 Technology Overview

Video imaging provides a unique approach for recording and analyzing vehicle accident events as it can often be difficult to understand crash dynamics by only interpreting data from sensors. Companies are beginning to look to video as a way of supplementing or even replacing the need for recording onboard sensors. Digital video differs from standard video in that video sequences are stored in memory as binary (1/0) digits instead of analog signals. With the development of low-cost and reliable digital video cameras and developments in video compression technology, it is becoming economical to install digital imaging and recording systems onboard vehicles. Cameras can be mounted on the front, sides, or rear of the vehicle, or even facing the driver to record all aspects of an event. Video information collected on the environment and the driver can play a significant role in determining the causes and effects of accidents. Showing actual footage of an accident or other event along with the other sensor information is one of the most effective ways to review causal factors and outcomes of accidents and other safety-critical events.

There are many aspects of digital video that effect how the image is perceived by the human eye, how much memory the video occupies, and how much it costs to produce and replay. Video can be decomposed into a succession of images (called frames) shown in rapid succession (called frame rate in Hz). Each frame is composed of tiny colored dots (called pixels). The most common format for video is 720x480 pixels per frame at 30 Hz (frames/sec).[22] Assuming that the video is in 16 bits color (i.e., each pixel's color is represented in binary by 16 bits), one

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22 *International Consultative Committee for Radio (CCIR).*

second of video would require over 16 Mbits (16 bits/pixel x 720 pixels x 480 pixels x 30 frames/sec = 160 Mbits) or 20 MBytes of memory. Therefore, a minute of video would require 120 MB, and a 90-minute movie requires 100 GB. These memory requirements for digital video are often termed as bit rate or Mbits per sec (Mbps).

The development of advanced video compression techniques facilitates the development of digital video systems, particularly in applications where minimal storage memory is available. Video compression is a method for reducing the memory necessary to store a video segment by reducing resolution, removing parts of the video that are not visible to the human eye, and eliminating duplicate elements of the video sequence that do not change from frame to frame.

The most common technique for video compression is the ISO standard MPEG, of which there are three variants—MPEG-1, MPEG-2, and MPEG-4. MPEG-1 is a low-resolution (typically 320 x 240, with a maximum of 352 x 288), low-bit rate (1.5 Mbps) standard designed for quality similar to VHS cassettes. MPEG-2 is a high-resolution (720 x 480, with a maximum of 720 x 576), higher bit rate (7.5 Mbps) standard. MPEG-4 uses a more sophisticated technique to deliver scalable high- to low-bit rate video from 10 Kbps to 10 Mbps. MPEG-4 is the current state of the art for video compression. Another technique for digital video compression is H.261 and H.263, but these are mainly designed for video conference applications where minimal bandwidth is available. Exhibit 3.4 provides a comparison of video compression.

Exhibit 3.4 – Video Compression Technique Comparison

Algorithm	Quality	Resolution	Frame Rate	Bit Rate
H.261	Hi-quality video conferencing	352 x 288	15 Hz	500 Kbps
H.263	Low-quality videophone	176 x 144	15 Hz	56 Kpbs
MPEG-1	VHS quality	352 x 288	30 Hz	1.5 Mbps
MPEG-2	No visually detectable quality loss	720 x 576	30 Hz	7.5 Mbps
MPEG-4	Varies	Max. 720 x 576	30 Hz	7.5 Mbps

The main components of a digital video recording system are cameras, a digital video recording input card, compression software (see previous discussion), and storage memory (see Section 3.1).

Cameras are readily available and have been used for many years in surveillance equipment. Both black-and-white and color cameras are available in a variety of configurations—domes, balls, mini-pinhole cameras. Also, many styles of cameras come in a variety of levels of weatherproofing and casing, making them ideal for vehicle applications.

The most sophisticated hardware is the digital video recording (DVR) hardware. The DVR hardware is basically an analog-to-digital converter that converts the analog video signal from the camera into digital video. The hardware usually also includes the necessary software to perform the video compression. While this hardware could be incorporated directly onto the VDR's circuit board, it is usually in the form of an expansion card plugged into an expansion card slot (e.g., PCI, PC104, PCMCIA slot) in the VDR's motherboard. DVR cards vary in complexity and cost based on the number of video inputs (usually 2 to 16), frame rate, resolution, and compression technology.

There are digital video recording products and packages currently on the market for vehicle applications. The following are brief descriptions of some of the products that are commercially available.

- **Assistware Technologies** has developed a digital imaging product that analyzes and "grades" a driver's performance in maintaining position within a lane. The camera is mounted in the front windshield, and processes the white lines of the road ahead. This white line information is digitized and presented on a digital display in front of the driver. A numeric number represents the performance of the driver based on driving within the white lines of the road. This number represents the driver's alertness and is available through an RS232 connection. In addition, the forward video image is an RGB video signal and can be recorded prior to, during, and after the accident.
- **SeaView Technologies** is offering Power Line Carrier (PLC) video technology to the transportation industry. The technology will allow video communication via the existing power wires; thus, cameras can be incorporated into the lamps of the vehicle. For the commercial market with tractor/trailers, the existing SAE J560 connector can be used without an additional cable between the tractor/trailer. Furthermore, the PLC video technology can coexist with the FMVSS-121 PLC communications for the ABS warning. The technology will allow 360-degree visibility such as passenger-side visibility during right turn activation and trailer-rear visibility during backup lamp activation. This video image is displayed on a CRT/LCD display via an RSG video signal, which will be available to VDR systems.
- **Loss Management Systems** has developed a product called the MACBox (Mobile Accident Camera). This product not only provides a driver's eye view of an accident, but also provides vital information such as speed, brakes, acceleration in three axes, safety belt status, and distance to the vehicle in front. MACBox provides digital imaging before, during, and after an incident to provide the maximum amount of data.
- **Safety Vision** has a fully operational VDR system with its Road Recorder 5000. This product not only has video before, during, and after the event, but also has the data needed to further reconstruct an accident. It receives this data from an SAE J1708 interface and also through multiple sensor inputs. The Road Recorder 5000 also includes a GPS interface, which records longitude, latitude, speed, and direction of travel.
- **DriveCam's** Video Event Data Recorder is a comprehensive system that is either triggered by an event or manually. This system includes a real-time clock and provides information regarding the brakes, acceleration, and "Lateral G-Forces". This information not only could be used to reconstruct an accident, but also to monitor a driver's erratic driving, which could prevent accidents in the future.

3.5.2 VDR Implementation Issues

Implementing digital video recording in a VDR is straightforward and can be done with commercial-off-the-self (COTS) hardware. The surveillance industry has been moving toward digital video and has commercialized much of the hardware. Storage memory size is an issue, but with the latest MPEG-4 compression technology, video can be stored at varying levels of resolution.

In most, if not all, applications, video recording would be based on a triggered event. Since it is difficult to design software to discern objects or events in video directly, a sensor (e.g., accelerometer and brake pedal) would have to be integrated with the recording system to trigger the video capture.

3.5.3 Technology Implementation Costs

The cost of digital video recording varies with the level and complexity of the system. Black-and-white cameras can range from as little as $50 to $400 for a weatherproof unit. Color cameras start around $100 to $500. Smaller, circuit board-mounted cameras are around $100 for black and white or $150 for color. It should be noted that not all camera types and equipment can operate effectively in the commercial vehicle environment. Current camera systems can be susceptible to:

- Damage and degradation of quality from extensive vibration and shock
- Failure in extreme hot and cold climate conditions
- Image degradation in viewing conditions due to poor weather and lighting
- Electronic failure due to complex parts and powered components
- Failures related to camera positioning, field of view, distance, and obstructions in viewing area

It should be recognized that additional costs may be required to mitigate these issues and integrate a camera into a VDR designed for the commercial vehicle environment.

Digital video recorder cards can range from $80 for an economy single channel card to over $4,000 depending on the level of complexity. Typically, PCI-based cards with average performance are $100 for single channel, $150 for 2-channel, $300 for 4-channel, $700 for 8-channel, and $1,300 for 16-channel.

To better understand the cost and memory requirements of various levels of digital video recording, Exhibit 3.5 shows some typical operating scenarios for a digital video system in a VDR. The exhibit is not intended to be an exact estimation of the costs, but rather to provide a basis for how levels of digital video integration affect cost and storage.

Exhibit 3.5 – Example Digital Video Requirements

Increasing Recording Requirements ↓

# of Cameras	Recording Duration (sec)	Camera Type	Resolution (pixels)	Frame Rate	Compression	Data Storage (Mbps)	Approx. Cost (excl. storage memory)
1	10	B&W	320 x 240	30	MPEG-1	18.6	$130
1	45	B&W	320 x 240	30	MPEG-1	83.7	$130
1	60	Color	720 x 480	30	MPEG-4	450	$180
2	30	Color	720 x 480	30	MPEG-4	450	$360
4	30	B&W	320 x 240	30	MPEG-4	223.2	$520
4	30	Color	720 x 480	30	MPEG-4	900	$720

3.6 SENSORS FOR DETERMINING THE RELATIVE LOCATION OF NEARBY VEHICLES

3.6.1 Technology Overview

VDRs, specifically those designed to record accident event data, could benefit from an understanding of the relative location, speed, and direction of travel of nearby vehicles. This information would be particularly useful in accident reconstruction and crash causation determination.

Two main technologies have become popular for measuring the location of surrounding vehicles—radar and ultrasound. Radar and ultrasound use different media (radio waves and sound waves, respectively) in a similar manor to determine the speed and range of surrounding vehicles. A transmitter sends out a short, high-intensity pulse of high-frequency radio or sound waves. A receiver then listens for an echo and measures the time it takes for the echo to arrive and, with radar, measures the Doppler shift (change in frequency) of the echo.

Ultrasonic sensors use sound wave to detect objects and can be located in multiple locations around the vehicle to provide a 360-degree view. Ultrasonic sensors have long been used for parking aids and for detecting the range of objects—they are generally not used for detecting object speed and direction of travel. Ultrasound technology is mature and sensors are one of the lowest-cost technologies on the market. The major disadvantages of ultrasound are its limited range (usually less than 15 feet), inability to detect object speed and size, and inability to detect objects that absorb sound. One example of an ultrasonic sensor for commercial vehicles is Transportation Safety Technology's Eagle Eye system, which can utilize up to seven sensors and has a dash-mounted visual and audio display. It is intended to assist the driver during maneuvers such as backing up, but can also be used to assist during lane-change maneuvers by detecting objects in the vehicle's blind spot.

Radar sensors use high-frequency radio waves to detect objects' range, range rate, and azimuth. Typical radars use both monopulse (to determine range and azimuth) and Doppler radar (to determine range rate). Radar has become popular for use in forward-looking collision warning systems due to its long range (>350 feet), good range and speed resolution, and ability to estimate object size. The major disadvantage of radar is cost. The most common radar sensor for commercial vehicles is Eaton's VORAD Collision Warning System. VORAD uses both monopulse and Doppler radar in the 24 GHz band to measure up to 12 objects in a 12-degree radar beam. It has a range of 350 feet, and has an integrated yaw sensor to determine when objects are directly in front of the vehicle during turns. It is intended for use as a forward collision warning system, but also can be equipped with up to two side sensors for detecting objects located in the vehicle's blind spots. In addition, the VORAD system can also be equipped with an adaptive cruise control feature that allows a driver to set and maintain a desired following interval to the object directly in front rather than a particular speed setting.

A second forward-looking radar-based system is being introduced to the commercial vehicle market by Meritor WABCO. The system includes collision warning, adaptive cruise control, and collision mitigation functions. The collision warning and adaptive cruise control features operate in a similar manor to that of the Eaton VORAD system. Collision Mitigation, as Meritor WABCO has termed, initiates active braking for impending collisions both when this system is in adaptive cruise control mode and when the system in only in collision warning mode. This feature controls vehicle speed and braking by controlling the engine speed/torque, the engine brake, and applying the service/foundation brakes. Currently this system does not include side-mounted radar.

3.6.2 VDR Implementation Issues

It is unlikely, especially in the near term, that radar or ultrasonic sensors would be integrated directly with the VDR, but rather the VDR would record data from a separate radar or ultrasonic sensor package (e.g., Eagle Eye or VORAD). Transmitting data from a radar or ultrasonic sensor to a VDR could be straightforward if the object or target data was available on the vehicle's databus (J1939/J1587). If the particular sensor package was not connected to the databus, it would be necessary to have additional analog or digital inputs to the VDR from the sensor. While it is technically feasible, integrating a radar or ultrasonic sensor with a VDR would be very costly as these systems require a great deal of processing and electronics to properly identify objects and determine their range and speed. It is more likely that, to record the location of nearby vehicles, a VDR would communicate with a separate radar or ultrasonic system or package over one of the vehicle databuses.

3.6.3 Infrastructure Requirements

No infrastructure requirements would be necessary to support radar or ultrasonic sensors. However, it may be necessary to work with the industry and the FCC to further refine the operating frequencies allowed for these systems to prevent them from interfering with other devices and to prevent other devices using radio or sound waves from causing false alarms. For instance, typical radar-based systems currently use the 24 GHz band, which is also shared by other devices (namely police K-band radar). The FCC has allocated frequency spectrum in the 76-77 GHz band for vehicle radar-based systems to avoid these interference issues. The Eaton VORAD system has been operating on a waiver from the FCC to operate its system in the 24 GHz band. It is anticipated that future generations of vehicle radar systems would operate in the 76-77 GHz band.[23]

3.6.4 Technology Implementation Costs

Radar and ultrasonic sensor packages are currently commercially available and, while not commonplace, have gained acceptance in the industry for use in rear-end and side-collision avoidance and parking assistance. As previously discussed, it is likely that data from these packages will be used in VDRs—at least in the near term. The cost of these systems, specifically radar-based systems, will likely mean that additional product features (e.g., collision warning, adaptive cruise control) will be necessary to justify the cost. The Eagle Eye ultrasonic sensors cost approximately $750 per vehicle and have seven sensors that can be located around the vehicle. Currently, Eaton VORAD radar-based collision warning systems cost approximately $2,000 per vehicle for a basic system. The optional side sensors and adaptive cruise control (called SmartCruise) increase the cost. Exhibit 3.6 shows an estimated cost breakdown for the VORAD components.

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[23] *Federal Communications Commission, Amendment of Parts 2, 15, and 97 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications, Federal Communications Commission, ET Docket No. 94-124 RM-8308, Washington, DC, 1995.*

Exhibit 3.6 – Estimated Eaton VORAD Component Costs

Component	Cost*
Antenna Assembly	$800 - $900
Central Processing Unit – SmartCruise ACC	$900 - $1,100
Driver Display Unit	$400 - $500
Driver ID Cards (package of 20)	$80 - $100
Main Harness Kit	$100 - $200
Left Side Sensor	$500 - $700
Right Side Sensor	$500 - $700

* Based on estimated retail service parts cost

3.7 SHORT-RANGE COMMUNICATIONS

3.7.1 Technology Overview

Short-range wireless communication has been increasing in popularity for computer and network systems, and is just being introduced into the automotive market. Short-range wireless communications devices work by attaching a transmitter to a data source (such as an EDR) and "shooting" the data to a receiver using various transmitting media and protocols. The receiver operates over the same medium and protocol, collects the data, and formats it to be used in various applications. The two main short-range communication media are infrared (IR) and radio-frequency (RF). The most popular IR standard, IrDA, was developed by the Infrared Data Association and is commonplace in most PCs, PDAs, printers, and other computer systems. Two major RF protocols have gained widespread popularity:

1. **WiFi** – Developed by the Institute of Electrical and Electronics Engineers (IEEE) and commonplace in wireless computer networks.
2. **Bluetooth** – Developed by the Bluetooth Special Interest Group comprised of leading manufactures in telecommunications, computing, and networking, and designed for improving personnel connectivity between portable computers, mobile phones, PDAs, and other handheld devices.

A third RF standard, Dedicated Short-Range Communication (DSRC), designed specifically for vehicle-to-infrastructure and vehicle-to-vehicle communications is currently in development and leverages the WiFi standards framework.

IR light communication has been standard in many commercial products such as laptop computers, printers, digital cameras, and PDAs for many years. The Infrared Data Association's IrDA standard is comprised of two segments, Data and Control. The IrDA standard defines an interoperable universal two-way cordless IR data port used primarily for device-device data transfer. IrDA Control allows cordless peripherals (e.g., keyboards, mice, joysticks) to interact with intelligent host devices (e.g., PCs or PDAs). IrDA Data, the most applicable standard for VDRs, is used for high-speed, short-range, line-of-sight, and point-to-point data transfer, and requires continuous operation within 1 meter (20 cm for low power consumption devices). IrDA data operates from a transmission rate of 9600 bit/sec up to 4 megabits/sec.

The most popular RF technology, WiFi, is spreading rapidly across multiple markets, from computer networking to automotive communications. There are three main WiFi standards—802.11a, 802.11b, and 802.11g, with 802.11b being the most popular. Finalized four years ago, 802.11a works in the 5- to 6-GHz band at speeds of up to 54 Mbps, but with a limited range of about 60 feet. The 802.11b RF standard operating in the 2.4-GHz band delivers speeds of up to 11 Mbps with a range of about 330 feet. The third WiFi standard, 802.11g, operates in the same 2.4-GHz band as 802.11b, but provides speeds of up to 54 Mbps, with a similar 330-foot range, and is completely interoperable with 802.11b.

The DSRC standards currently in development by the ASTM and IEEE working groups leverage the WiFi 802.11a standards and are designed to operate in the 5.9 GHz range (designated by the FCC as ITS Radio Service). The DSRC frequency band is subdivided into seven channels dedicated to specific functions:

- One 10-MHz channel dedicated specifically to vehicle-to-vehicle communications
- Four 10-MHz service channels for public safety and private communications (two 10-MHz channels can be combined to create a 20-MHz channel)
- One 10-MHz control channel for announcements and warnings
- One 10-MHz channel for high-power public safety, intersection, and emergency vehicle communications

DSRC is intended to support both public and private applications including:

- Emergency and transit vehicle signal preemption
- Roadway condition warning
- Vehicle-to-vehicle collision warning
- Intersection collision warning
- Cooperative vehicle systems (including platooning)
- Private access control and payment
- Data transfer and infotainment
- Fleet management
- Vehicle safety inspections
- Onboard safety and emissions control data transfer

The range of DSRC depends on the application and channel allocation, but can be up to 3,000 feet for emergency vehicle services and approximately 1,000 feet for data transfer and messaging services. DSRC hardware will be very similar to that of 802.11a since the lower layer standards (physical and medium access control) are based on 802.11. Field testing of the first DSRC system is just starting. The Crash Avoidance Metrics Partnership, a light-duty OEM venture to facilitate collaboration on crash avoidance research, is currently working to define communication parameters for a variety of safety applications.

It is also worth noting that a second ITS Radio Band in the 902-928 MHz band has also been designated by the FCC. It is currently used for toll pass applications and emergency vehicles. Its limited range (300 feet), limited data rate (0.5 Mbps), interference potential (i.e., 900 MHz phones), and implementation cost make it an unpopular option for future development, especially with the 5.9 GHz DSRC standard almost complete.

The popular RF wireless communications standard Bluetooth was designed primarily for interconnection of portable and handheld devices. Bluetooth uses the 2.4-GHz band that is based on the IEEE 802.11 standard. However, Bluetooth requires little power and is intended for transmitting small amounts of data over short distances (up to 10 meters). Bluetooth operates at a speeds between one to two Mbps, which is significantly slower than WiFi. However, Bluetooth chips and components are cheaper and more compact than those needed for WiFi, and have lower power consumption. Bluetooth is still an emerging technology and is, therefore, less mature than WiFi. The low cost, compactness, and low power consumption of Bluetooth hardware make it ideal for portable applications such as mobile phones and PDAs, where WiFi would not be viable.

Wireless infrared IrDA products are available from many commercial manufacturers, including Acer, Agilent, Intel, Maxim, National Semiconductor, and Texas Instruments among others. In addition, many manufacturers of computer components offer completely integrated IrDA products and add-on IrDA transceiver peripherals. Detroit Diesel Corporation (DDC), a subsidiary of DaimlerChrysler Corp., markets and distributes an aftermarket IrDA product called IRIS for the heavy-duty vehicle industry. This product interfaces to the SAE J1708 databus and retrieves information useful to mechanics and fleet managers, and that could be used for investigating accidents. The IRIS product has the capability of bi-directional communications at 9,600 baud and costs about $300.

WiFi products operating on the 802.11b standard are readily available in multiple levels of integration. New products based on the 802.11g standard are just emerging in the marketplace, while 802.11a products (released over the last two to three years) have not found a large acceptance due to their limited range and the new compatibility of 802.11g and 802.11b systems, but might begin to reemerge in the automotive industry as DSRC continues to develop and the first DSRC systems begin to be tested. Many commercial manufacturers offer a wide range of WiFi products, from chipsets to consumer WiFi transceivers. WiFi chipset manufacturers include Atheros Comm., 3Com, Intel, Texas Instruments, and Intersil Corp. Manufacturers of consumer WiFi transceivers include Cisco, Apple, D-Link, Linksys, NetGear, Microsoft, Vivato, Proxim, and Dell.

Bluetooth technology is still emerging, but many commercial companies are currently offering Bluetooth hardware modules (complete chipsets), including 3Com, Ericsson, IBM, LG Innotek, Lucent, Motorola, Siemens, Philips, and others. Many commercial products are also available with Bluetooth technology. Nokia, Ericsson, Motorola, and LG manufacture cellular phones with Bluetooth technology. IBM, Motorola, Xircom, National Semiconductor, Hewlett Packard, and 3Com manufacture Bluetooth PC cards for wireless connectivity of laptop PCs. Visteon, Nokia, Kenwood, Johnson Controls, DiamlerChrysler, and several other manufacturers have Bluetooth-enabled automotive products largely focused around hands-free functionality of cellular phones.

3.7.2 VDR Implementation Issues

Integration of short-range wireless communication using IrDA, WiFi, or Bluetooth standards into a vehicle data recorder would be relatively straightforward as these technologies (especially IrDA and WiFi) have been commercialized heavily and have had a high level of acceptance in the industry. For each of these technologies, there are two possible approaches. The first approach would be to integrate the wireless chipsets, transceivers, antennas, and software into the VDR hardware directly. This would likely reduce costs, reduce power consumption, and make the VDR more compact. A second approach would be to use a commercially available IrDA, WiFi, or Bluetooth card that could be integrated into the VDR through a PCI, PCMCIA, or other bus slot. This would likely increase the flexibility of the VDR as hardware could be switched between either of the three protocols.

The most difficult challenge of integrating short-range wireless communication into the EDR is antenna and transceiver placement. With infrared, direct line of sight is necessary between the VDR and an external transceiver. If the transceiver is a handheld unit, then placement of the VDR infrared transmitter could be internal to the vehicle cab or in another protected location. However, if the external transceiver is in a fixed location, the infrared VDR transmitter will have to be located on the vehicle such that the two align to transfer data (e.g., perhaps the vehicle passed by a gate reader). With WiFi or Bluetooth technology, line of sight is not necessary, but the sheet metal body of a heavy-duty vehicle would likely limit the range of these technologies, especially if the antenna is located within the metal structure of the vehicle (e.g., cab, engine compartment, storage compartment). Therefore, it is likely that an external antenna will be needed to obtain the necessary range to transmit data from a VDR to a stationary external receiver. As with the infrared technology, if a handheld receiver is used, the placement of the antenna would be less critical.

3.7.3 Infrastructure Requirements

The infrastructure requirements are similar for each of the three short-range communications protocols. As these technologies are intended for local broadcasting of data, receivers would likely need to be installed at locations where VDR data is needed (e.g., maintenance garage, inspection and weigh station, or fueling station), or handheld or mobile devices would be needed. Receivers for WiFi and Bluetooth technologies would have to be installed so that they are within effective range of the VDR, while infrared would require direct line of sight to the VDR transmitter. Stationary infrared, WiFi, and Bluetooth receivers and base stations are readily available and could easily be integrated into a PC software package to collect, filter, and store data from a VDR that enters its range. In addition, portable receiver hardware is also readily available and would only need to be integrated into a handheld or mobile device.

The commercial infrastructure for the WiFi technology is continuing to expand. Access points called “Hot Spots” are being created for a variety of applications, mostly centered around wireless high-speed Internet connectivity. As WiFi proliferates, it will most likely serve large populations in concentrated areas, such as downtown districts, universities, and business centers. Companies such as Cometa Networks intend to build a 20,000-node nationwide WiFi network before 2007, while AT&T, IBM, and Intel will deploy a nationwide network of public wireless access points, named Project Rainbow. SiriCOMM Inc. is also planning a nationwide wireless access point network that will be based in full-service truck stops. It remains to be seen how these access points will integrate with DSRC systems since they are mostly 802.11b or 802.11g and operate in a different frequency band.

Intel, Nokia, Proxim, and other companies have launched WIMax, a non-profit group formed to certify and promote the wireless broadband standard 802.16. This standard will apply to communications equipment that will connect 802.11 access points to the Internet and provide a wireless extension to cable and DSL for last-mile broadband access (between local hard-wired access points and wireless customers). The 802.16 standard provides for up to 31 miles of linear service area range and allows users connectivity without a direct line of sight to a base station.

The technology also provides data rates of up to 70 Mbps with enough bandwidth to simultaneously support more than 60 businesses (or heavy-use modes) with high-speed connectivity. Hot Spots connected to the Internet through 802.16 will offer wireless access to citywide areas bringing WiFi closer to cellular network levels of availability.

Due to the limited range of both IrDA and Bluetooth, commercial infrastructure is limited (almost nonexistent for IrDA due to its requirement for line of sight). It is not likely that wide-scale Bluetooth or IrDA access points will be available nationally.

3.7.4 Technology Implementation Costs

Bluetooth chipsets that could be integrated directly into the embedded hardware of a VDR or handheld receiver can cost as low as $5 to $10, but would require significant development and integration costs. Commercially available Bluetooth adaptor cards designed for PCI or PCMCIA buses range from $150 to $250 and require less development time and cost, but would also be less compact and flexible, and consume more power.

WiFi chipset prices have been falling steadily as the market grows and more companies begin manufacturing 802.11-compliant hardware. In 2002, the average price of 802.11b chipsets was $16, while in February 2003 the price reached $6. In June of 2004, WiFi 802.11b chipsets cost between $4 and $6, while 802.11g chipsets cost $12 to $13. Manufacturers are now supplying combination 802.11b/g chips for $14 to $20. WiFi adaptor cards cost between $30 and $150 and are commercially available. It is likely that DSRC equipment will be priced in a similar range.

IrDA chipsets cost between $1.50 and $2.50 for the IrDA controller. An additional infrared receiver/transmitter will be necessary at a cost of around $2.50 in production quantities. Commercially available IrDA adaptor cards for PCI or PCMCIA buses are also available and would cost between $50 and $150.

3.8 LONG-RANGE COMMUNICATIONS

3.8.1 Technology Overview

Advanced long-range wireless communications devices were introduced into the transportation industry in the 1980s. Long-range communications technology, paired with a VDR (or integrated with VDR-like functionality), would provide another dimension to monitoring vehicle and event data. Long-range vehicle communications has been used by fleets for several years, mainly for vehicle tracking purposes. Recently, however, fleets and service providers have begun implementing recording and vehicle health monitoring capabilities within the long-range communications packages. There are two main avenues for information to be exchanged using long-range communication products—satellite-based technologies and land-based technologies.

There are two main satellite-based technologies available to North American users—geosynchronous satellites and low earth orbiting satellites (LEO):

- Geosynchronous means orbiting at the same rate and position relative to the earth, which is the reason, from Earth, a satellite in geosynchronous orbit appears to remain stationary over one spot on the Equator. This type of satellite is not motionless. It is in a very high orbit where it circles the Earth once a day, matching the Earth's rotation on its axis. This allows a receiving dish to spot the satellite at one point in the sky—and it does not have to track its movements. There are many satellites in this type of orbit that are needed for important and timely information such as weather satellite pictures, satellite television, or communications. Geosynchronous satellites are reliable enough for the National Aeronautics and Space Administration (NASA) to use them to relay communications and data between spacecraft and control centers on earth. Qualcomm, a supplier of commercial vehicle long-range communications equipment and services, uses satellites in geosynchronous orbit.

- Low orbiting satellites or LEO satellites are the second type of satellite technology used for long-range communication. An LEO satellite orbits generally 500 to 2,000 km above the surface of the earth, and is typically grouped with several other LEO satellites forming a constellation that achieves wide-area coverage with lower power requirements and shorter propagation delays (delays between when a signal is transmitted from a satellite and received by a receiver on the ground, or vice-versa). Two distinct LEO groups have emerged—Little LEO for data-communications satellites and Big LEO for data-and-voice communications, each using pre-assigned frequency ranges. The LEO satellite system works by employing a large constellation of satellites, each in a circular orbit at a constant altitude of a few hundred miles. The orbits of the satellites take them nearly over the geographic poles. Each revolution takes anywhere from about an hour and a half to a few hours. The satellite groups are arranged in such a way that, from any point on the surface at any time, at least one satellite is in line of sight of a receiver. LEO systems operate in a manner similar to the way a cellular phone works. Unlike geosynchronous satellites, LEO satellite systems require directional antennas whose orientation must be constantly adjusted to follow the satellite's path across the sky. Orbcomm, a long-range communications provider for commercial vehicles, uses satellites in an LEO constellation.

Land-based technologies are also available to support long-range communications. Most land-based systems use cellular phone technology as a way of distributing and collecting information. Most land-based systems are very reliable in urban settings where a cellular system is readily available and working, but if these products move to areas where cellular towers are either non-existent or sparse, the service quality diminishes. Over the last 10 years, the cellular coverage area has increased dramatically, particularly in urban areas and along major transportation corridors.

Mobitex is similar to the digital cellular technology. The network consists of interconnected cells, each of which is served by a radio base station that provides wireless access to the network for mobile users. The base stations and other network nodes are connected together by fixed links. Despite these basic similarities, Mobitex is unique in several key respects. It is a narrowband data-only network that uses packet switching, and it is based on an open international standard. A packet-switched network breaks the data stream up into small packets, each of which can be sent across the network individually. Unlike voice cellular networks, dedicated connections are not needed, and network access is virtually instantaneous because each data packet contains the destination address and can be routed dynamically as network conditions change. For subscribers, the benefits are that they are always connected and online, yet pay only for the number of packets sent—not connection time.

Long-range communications technologies will continue to play a major role in the VDRs for the transportation industry. Many fleets use this long-range technology for transmitting fleet and truck data. Dispatchers know when and where the vehicle is, as well as other information they need to maintain the vehicle and maximize the productivity of the fleet. Current long-range systems give the capability of sending large amounts of data in very short periods of time, sometimes just a few seconds. It would allow accident data to be sent to the fleet, police, and emergency crews in a matter of a few seconds. These systems could also send information needed to properly determine the reason for the crash. The benefits implemented into long-range systems are the reason many vehicles already use such equipment. This technology improves the performance related to trucking and, more importantly, will give a clearer picture of the cause of certain events.

3.8.2 VDR Implementation Issues

Satellite-based communications systems are self-contained and integrated into the trucks onboard databuses.

3.8.3 Infrastructure Requirements

The majority of the infrastructure and Qualcomm and Orbcomm satellites are already in place. New satellites are sent up periodically to replace old and worn-out equipment.

Cellular networks for land-based systems have been in place for the past decade and are growing on a daily basis. Older analog cellular systems are beginning to be replaced by digital networks that provide more reliable and higher speed data transmission. Also, with the advent of General Packet Radio Service (GPRS) technology, the amount of area in the United States covered by cellular networks is rapidly approaching 99 percent. However, there are still numerous gaps in the cellular infrastructure.

Mobitex networks consist of the Mobitex base stations, routers, and the network control centers. Mobitex base stations are typically 13"x17"x7"; router/switch racks are 29"x24"x31"; and the network control center consists of servers, client computer, and terminals with LAN connections to the routers and switches. A Mobitex network might consist of a single network control center connected to several router and switches, each connected to multiple base stations covering an area from a few hundred feet to nationwide. Mobitex networks can be configured in different ways, from a large public nationwide network to a small, privately owned network serving a single region or company. The networks can be configured to match a particular service mix and requirements and re-configured as service uptake and demand changes over time.[24]

3.8.4 Technology Implementation Costs

There are many commercially available products on the market today. The following are several products that incorporate different types of long-range communication. Prices range from a few hundred dollars to a few thousand dollars, with the land-based technologies the less costly of the two.

- Qualcomm is the leader in the long-range communication market. It has approximately 400,000 users in the trucking industry, using geosynchronous satellite-based infrastructure to provide geographic location information and packet data bi-directional communications. Qualcomm uses a free-form data packet communication format via SAE J1708. The Qualcomm free-form data communications would be a means to collect VDR information and send it to a home base for analysis. This free-form packet data is similar to a zip file and

[24] *Mobitex Technology AB, http://www.mobitex.co, SE-417 56 Gothenburg, Sweden.*

can only be decoded by the appropriate and approved system. The Qualcomm system, OmniTRACS, varies in cost depending on the number of vehicles to be equipped, from about $1,000 per vehicle to around $3,000 per vehicle for the communication equipment and software. Qualcomm also requires the purchase of monthly service plans that range in price from $35 to $50 that may include the frequency and type of data transfers a vehicle is permitted to communicate. The $35 plan is basically a connection fee that only includes one GPS position poll per hour. The $50 plan also includes one GPS position poll per hour, but also allows for data transfers of up to 180 messages or 18,000 characters. As an alternative to its satellite communication system, Qualcomm offers a terrestrial-based communication system using the Sprint PCS cellular network called OmniExpress. The OmniExpress system can communicate the same amount and type of data as the OmniTRACS system, and can do so at a much lower cost. The tradeoff with this lower cost, however, is that the OmniExpress system can only transmit or receive data while the vehicle is in range of a cellular tower.[25]

- Orbcomm is an example of an LEO application. The company owns and operates a network consisting of 30 LEO satellites and terrestrial gateways deployed around the world. Small, low-power, and commercially proven subscriber communicators can connect to private and public networks via these satellites and gateways. Through this network, Orbcomm delivers information to and from virtually anywhere in the world on a nearly real-time basis. Volvo Trucks North America has selected the Orbcomm system to provide two-way data communications for a tracking and monitoring for use on heavy trucks. Orbcomm can be interfaced to a VDR system via RS-232.[26]
- Terion uses a land-based system for trailer tracking and security. Its FleetView product is used to track trailers throughout the United States. Data is communicated using a cellular-based infrastructure. FleetView has many benefits such as reducing the trailer-to-tractor ratio, eliminating yard checks, minimizing loss from theft, and allowing fleets to be more responsive to their customers. The FleetView unit mounts on the front inside wall of the trailer, while the antenna is enclosed within a marker light. FleetView comes with a standard movement sensor to record the beginning and end of a drive. The system can also report when the door is opened or closed or when the trailer is loaded or unloaded with added sensors.[27]
- XATA's Mobile Asset Management solutions integrate enterprise software, onboard computing, global positioning, and wireless communications to provide an integrated asset management system. XATA systems support multiple onboard computing platforms and have their own proprietary onboard computer, called the XATA Application Manager (XAM). The XAM incorporates a microprocessor, dual-mode wireless communications, and a 12-channel GPS receiver, all housed in an aluminum alloy base with a UV-resistant plastic dome. The XAM is equipped with both an Orbcomm satellite modem and a CDMA cellular terrestrial modem to communicate wirelessly with a host server. The CDMA cellular modem is the primary communication system and sends and receives data over the Sprint PCS wireless network. The satellite modem is used to communicate data only if the vehicle is not within range of a cellular tower. GPS location satellites ping the XAM every 30 minutes to

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[25] *Qualcomm Fleet Management Solutions, http://www.qualcomm.com/qwbs/solutions/flt_mgt_overview.shtml,5775 Morehouse Drive, San Diego, CA 92121.*

[26] *Orbcomm, http://www.orbcomm.com, 21700 Atlantic Boulevard, Dulles, VA 20166.*

[27] *Terion, http://www.terion.com,6505 Windcrest Drive, Suite 200, Plano, TX 75024.*

track the vehicle's location and provide location data for use in state fuel tax calculations and geo-fencing applications. All other data collected by the XAM, such as vehicle diagnostics and driver data, is compressed into a zip file and transmitted once a day (or more frequently if necessary) to a host server managed by Agility Web Hosting. The data can then be used in fleet management applications and remain on the host server, or it can be transferred to the fleet's back office computer system via Microsoft Web Services. XATA's application packages encompass multiple applications, including:

- Asset tracking
- Operations profiling
- State fuel tax calculating
- Vehicle call back
- Daily mileage reporting
- Diagnostic warnings reporting
- Accident analysis
- DOT driver logs

- XATANET can connect to a range of display devices including driver terminals, in-cab computers, printers, handheld computers, and other peripherals. XATANET can be coupled with a variety of wireless services such as WiFi, cellular, or satellite. However, nearly all XATANET systems produced today are equipped with an Orbcomm satellite modem and a CDMA cellular modem. The cost to incorporate the XATANET system consists of the initial purchase of the equipment and a monthly service plan that is similar in structure to a cellular phone plan. The monthly plans are billed as a flat rate, not by number of transmissions, and vary in price based on the amount of features included in the plan. To install XATANET on a fleet of 400 trucks, for example, the cost of purchasing the XATANET hardware is approximately $1,700 per vehicle. The monthly services charges vary by plan type and are listed in Exhibit 3.7.

Exhibit 3.7 – Typical XATANET Monthly Service Charges

Plan Type	Plan Price /Month	Premium Support /Month
Bronze	$29	$5
Silver	$34	$5
Gold	$39	$5
Platinum	$49	$5

The optional premium support package shown in the exhibit includes a rapid replacement parts service, an extended warranty on equipment (two to five years), 24/7 technical support, and automatic software updates sent wirelessly.[28]

- Tripmaster is another manufacturer of asset management solutions. Its product line includes long-range and short-range communications, GPS, route scheduling, maps, handheld input terminals, time clock, driver performance monitoring, and fuel tax calculators. The base of the Tripmaster system is the DT-240/GPS ECU, which incorporates a GPS receiver, I/O ports, and J1708 connectivity. There are several input terminal options, from portable to

[28] *XATA Corporation, http://www.xata.com/, 151 E. Cliff Road, Suite 10, Burnsville, MN 55337.*

hard-mounted. Tripmaster's wireless LAN provides a short-range wireless connection solution to a terminal. The long-range communication option, Mobilecom, uses cellular GPRS technology to send and receive data. The Mobilecom unit costs approximately $2,500 per vehicle and requires a monthly service plan that costs roughly $45. The DriveRight package allows fleets to set speed, acceleration, deceleration, and other limits and then records when those limits are exceeded. The DriveRight Trip 500AL hardware provides a driver performance score, driver ID, and location; stores data from over 500 independent trips; and maintains 5 accident logs. The unit also contains a tamper indicator as notification of a disconnection or if an unauthorized person attempts to change limits or other settings.[29]

- Trimble's Telvisant Mobile Resource Management (MRM) platform includes a line of intelligent vehicle tracking units that determine and report vehicle location and other data without driver involvement. Trimble currently offers two "smart" mobile units that mount in the vehicle and an optional in-cab messaging terminal. The CrossCheck GPRS 1900 Mobile Unit consists of a GPS receiver, GPRS wireless communication platform, and computer processor—all integrated into a single compact enclosure. The unit can be used as a standalone device to report vehicle location and speed data, or it can be interfaced with external sensors to monitor vehicle status and activate security systems such as ignition lockout and audible alarms. The CrossCheck GPRS can also be interfaced with the EchoLDX, which is an in-cab messaging terminal that is offered as an optional accessory. The EchoLDX allows the driver and fleet dispatcher to communicate via text messages by displaying and storing messages received from the dispatcher, and enabling the driver to send a predefined response back to the dispatcher. The CrossCheck GPRS 1900 Mobile unit costs approximately $550 per unit and requires a monthly service charge of roughly $40. The EchoLDX messaging terminal costs $235 and requires either the CrossCheck GPRS or the CrossCheck CDPD mobile units to operate. The CrossCheck CDPD (cellular digital packet data) mobile unit is nearly identical to the CrossCheck GPRS mobile unit, except it communicates over a CDPD wireless platform instead of a GPRS wireless platform. Trimble is currently developing another intelligent vehicle tracking unit that communicates using CDMA technology.[30]
- PeopleNet offers a wireless fleet management system that communicates between the vehicle and the PeopleNet Network Operations Center (NOC) using cellular technology. PeopleNet has partnered with over 180 cellular service providers to provide its system with a wide operating area. The PeopleNet system can be customized to meet the specific needs of a fleet vehicle, but will typically include a base computer unit, message display or PDA type device, voice handset (hardwired cell phone), PerformX engine diagnostics cable, and a keyboard. The system is also equipped with a GPS receiver that is pinged every 15 minutes on long-haul vehicles or as often as every 5 minutes on local route vehicles. The PerformX tool monitors the vehicle's engine performance by connecting directly to the vehicle's J1708 databus to record data such as speed, distance, fuel efficiency, and idle time. The PerformX tool does not currently report J1708 fault codes, but PeopleNet is developing this capability. PeopleNet is also developing the capability to enable the driver to use printers and scanners, and to access the Internet from inside the cab.[31]

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29 *Tripmaster Corporation, http://www.tripmaster.com, 805 Avenue H, Suite 501, Arlington, TX 76011.*

30 *Trimble Navigation Limited , http://www.trimble.com/vt_telvisant.shtml, 749 North Mary Ave, Sunnyvale, CA 94085.*

31 *PeopleNet Communications Corporation, http://www.peoplenetonline.com/, 1107 Hazeltine Blvd, Suite 350, Chaska, MN 55318.*

- There are also products implemented by light-duty OEMs in the market today. One such product is the OnStar product offered by General Motors. This is a land-based system that automatically communicates to the emergency officials once an airbag has been activated, and is also used for driver communication.

These are a few examples of commercial products available on the market today. There are other products that use similar technologies, but these perform similar functions as those mentioned before. Overall, long-range communication products are and will continue to be beneficial to fleet logistics management, and could provide a conduit for VDR data transmission.

3.9 DRIVER PERFORMANCE

3.9.1 Technology Overview

Recording driver distraction and drowsiness levels could provide important driver training and monitoring information to a fleet's dispatchers and management. In a survey conducted for NHTSA in 2002 by The Gallup Organization, 3.5 percent of all drivers (light- and heavy-duty) involved in a crash in the past 5 years attribute it to being distracted—equating to an estimated 6.0 to 8.3 million drivers. The same survey showed that 37 percent of drivers have nodded off for at least one moment or fallen asleep while driving at least once in their driving career—8 percent have done so in the last 6 months.[32] While this survey did not particularly call out commercial drivers, it does illustrate the dangers of distracted and drowsy drivers. FHWA performed a commercial vehicle driver fatigue and alertness survey in 1995. Of the 511 interviews conducted, 14 percent of drivers admitted to dozing or falling asleep at the wheel one to two times within the past month—9 percent admitted to dozing or falling asleep three to six times.[33]

There are several commercially available systems that can detect drowsy or distracted drivers, most use one of two methods: (1) lane position monitoring, or (2) driver eye monitoring.

Lane position monitoring systems use video cameras and digital video processing to determine the location of the vehicle relative to the lane. In some systems, this data is supplemented by forward-looking radar. The digital video processing tracks road features (e.g., lane markings) to determine the relative location of the truck. It then provides alert indicators (i.e., audible and/or visual) when the vehicle begins to drift out of the lane. Lane position monitoring to detect weaving and erratic steering behavior can provide an indication of driver fatigue or inattentiveness. Since these are video-based systems, they often have difficulty tracking during adverse conditions (e.g., white-out snow storm, heavy and nighttime rain, or glare). There are several companies offering lane guidance systems, including Visteon, Delphi, and Assistware Technology.

Assistware Technology has developed the SafeTRAC lane guidance system targeted toward commercial vehicles. The system uses a small video camera to monitor the road and digital image processing to track road markings and determine the vehicle's location in the lane. It then

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[32] *National Highway Traffic Safety Administration, National Survey of Distracted and Drowsy Driving Attitudes and Behaviors – Volume I Findings Report, The Gallup Organization, Washington, DC, 2003.*

[33] *Abrams C., Shultz, T., & Wylie, C.D. Commercial Truck Driver Fatigue, Alertness, and Countermeasures Survey, Federal Highway Administration, FHWA–MC–97–002, Washington, DC, 1997.*

provides an audible and visual indication (on the dash-mounted display) during an un-signaled lane change or roadway departure. The side-to-side sensitivity of the system can be adjusted between EARLIEST, EARLIER, EARLY, AT EDGE, LATE, LATER, LATEST, and NEVER. A later sensitivity setting will allow the vehicle to depart the lane further before triggering a warning. The default threshold, AT EDGE, will trigger an alert at the moment that the outside tire crosses the lane boundary. Setting the threshold to EARLY, EARLIER, or EARLIEST will result in the triggering of an alert at successively earlier locations, approximately 8 inches for the EARLY setting, 13 inches for the EARLIER setting, and EARLIEST being approximately 1.5 feet before the tire reaches the lane boundary. Setting the threshold to LATE, LATER, or LATEST will result in the triggering of an alert at successively later locations after the tire has passed the lane boundary, approximately 10 inches for the LATE setting, 20 inches for the LATER setting, and approximately 2.5 feet past the boundary for the LATEST setting. Setting the drift alert threshold to NEVER turns drift alerts off. In addition, the unit could be pre-programmed (by the manufacturer or the operator when purchased with the serial communications link option) to an explicit drift alert threshold from 3.25 feet before to 13 feet after the point where the tire crosses the lane boundary. Additionally, the system provides an alertness index (AI) that scores a driver's performance. This score is also shown in the dash-mounted display. The AI factors in how well you maintain the vehicle's position in the lane and how quickly and consistently you react when the vehicle begins to drift towards the edge of the lane. If driving becomes inconsistent or erratic, the score will drop, alerting the driver to pay more attention. The AI ranges from 0 to 99, the higher the AI, the better the driver's steering and the less drowsy they appear to be. Typically, an AI score from 70-90 can be considered good steering performance, while an AI score below 50 may indicate some form of driver impairment (e.g., drowsiness). A visual and audible "Get Rest" indicator will be given if the score drops to an unsafe level; the default setting is 50 for approximately 10 minutes.

SafeTRAC also has an optional fleet management and driver monitoring feature that continuously logs performance data to be retrieved by fleet management. Driver performance data is time stamped and recorded including un-signaled lane changes, roadway departures, alertness index, and vehicle position in the lane. Fleet management can customize the sensitivity, visual and audio indicators, and limit operator access.

A second option with the SafeTRAC system is a video recording feature. Called the "black-box" option, the feature stores 10 seconds of video immediately preceding an accident. It uses an internal accelerometer to determine when an accident occurs, then stores the previous 10 seconds of video in non-volatile memory. In addition to the video, the "black-box" feature, coupled with the fleet management feature, also records data on the vehicle's position in the roadway and any lane departures over several miles prior to the incident. This data can then be downloaded by fleet management for accident reconstruction.

Iteris, Inc. manufactures another lane-guidance system called AutoVue. The system, available for both light- and heavy-duty applications, is a small integrated camera, processor, and software that attaches to the windshield. It uses image recognition software to determine the lane markings. When an un-signaled lane change or roadway departure occurs, the system emits a left or right directional audio signal (similar to the noise from "rumble strips"). The heavy-duty system communicates over the J1939 network to acquire the vehicle speed (it only operates above 35 mph) and outputs a message over the network when an un-signaled lane change or roadway departure occurs. The AutoVue system is currently available on several Freightliner and International vehicles.

Monitoring the behavior of a driver's eye and eyelid is another method for drowsy-driver detection. A metric of drowsiness that has gained popularity, particularly with NHTSA, is PERCLOS. PERCLOS is the percentage of eyelid closure over the pupil in a given period of time, and reflects slow eyelid closures rather than blinks. The PERCLOS metric, established in a 1994 NHTSA study on drowsy-driver detection algorithms, is the portion of time in a minute that the eyes are at least 80 percent closed.[34] The PERCLOS metric provides an accurate measurement of driver drowsiness. However, accurately measuring PERCLOS in a vehicle during operation has proved difficult. Typically, PERCLOS systems use small cameras and an infrared illumination source to pickup and discern a driver's eye. Daytime sunlight can cause the infrared camera signal to become "washed-out." These systems operate best during nighttime. Additionally, driver's glasses and sunglasses can cause interference. Technology has been developing, and NHTSA is currently conducting with the Virginia Tech Transportation Institute a field operational test of a PERCLOS system developed by Attention Technologies.

The Attention Technologies system uses a single camera and two different frequency infrared emitters to capture two images of a pupil. There is an LED display that has three amber LEDs for moderate drowsiness levels, and three red LEDs for severe drowsiness levels. However, the system is still in development and is not yet commercially available.

A third type of driving performance monitoring technology is currently under development at George Washington University that uses steering-wheel monitoring. Algorithms are under development that use artificial neural networks to analyze steering-wheel motion. This type of technology is still under development; no commercially available product is yet available.

3.9.2 VDR Implementation Issues

Integrating these systems with a VDR could be relatively straightforward. The output of a drowsy and distracted driver detection system could be connected to a VDR input, similarly to how other external systems connect (e.g., forward radar and GPS). This process can be simplified if the output is available on a vehicle network databus (e.g., J1939 or J1587). The Iteris AutoVue system for heavy-duty vehicles already transmits a message over the J1939 bus when an un-signaled lane change or roadway departure occurs. Additionally, the AutoVue system has a discrete output that could be connected to a VDR via an analog or digital input.

3.9.3 Technology Implementation Costs

Most drowsy and distracted driver monitoring systems are still in development as this is an emerging technology and pricing data is therefore difficult to obtain. However, Assistware Technology's SafeTRAC is currently available for purchase by fleets and individuals. The base SafeTRAC system, without the fleet management or "black-box" features, costs around $1,500. The fleet management and "black-box" options are customizable, but start around $500 each. The system is customizable to record various amounts of data and can use multiple data extraction protocols at additional costs. Accelerometers with different resolutions also add to the cost.

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[34] *Wierwille et al., Research on vehicle-based driver status/performance monitoring: development, validation, and refinement of algorithms for detection of driver drowsiness, National Highway Traffic Safety Administration, DOT HS80824, Washington, DC, 1994.*

The Iteris system has been available on Mercedes trucks in Europe for several years and recently has become available on Freightliner Century, Columbia, and Argosy trucks in North America. The system has a list price in Freightliner's data book for $2,492, but can be obtained for between $1,000 and $1,100 with various Freightliner incentives. The retrofit OEM cost is approximately $1,100 to $1,250.

3.10 TRACTOR-TRAILER COMMUNICATIONS

3.10.1 Technology Overview

There is currently only one electrical interface between highway tractors and trailers, and that is the SAE J560 7-pin connector. The SAE J560 connector was designed to provide a standard connection for trailer power, lighting, and signals. It provides six switch-controlled 12-volt signals (i.e., clearance, stop, left turn, right turn, tail, auxiliary) and a return ground. The J560 connector has no available (i.e., unassigned) pins for data, and the quality of the contacts is only capable of supporting the basic light and power loads and should not be considered for any future data network usage. The J560 connector has a typical lifetime of 6 months to a year because it is subject to physical damage from improper disconnection, stowage, and the possibility of being open to the elements when a tractor is not connected to a trailer.

There are a number of reasons that the trucking industry has resisted installing any new connectors (or a second connector)—most notably, initial cost and maintenance concerns. The industry is at a stalemate in its ability to satisfy the long-term needs for high-quality, reliable data communications between the tractor and trailer.

Other parties (i.e., tractor and trailer OEMs) have strongly resisted most potential solutions primarily on the basis of the increased costs they anticipate. Adding a second connector is viewed as doubling these replacement costs and the downtime resulting from these failures. Adding a backwards compatible connector that would provide a connection suitable for reasonable data networking would add considerable costs, not just for the initial installation, but also for the frequent replacements that are inevitable in the CMV environment.

Experience has shown that any new connector must be implemented with the plan of keeping it in use for a period of 20 to 30 years. The problem that the industry faces in defining a connector is that no one can predict the kinds of communication needs that will exist over that long period of time.

Several possible solutions have been proposed over the past decade, but all have been rejected largely due to cost, backward compatibility, long-term maintenance cost, and future expandability issues. These proposed solutions include:

- Adoption of a second high-speed connection (similar to the European ISO 11898)
- Modification of the pins in the current J560 connector to install a multiplexing network (a 1998 NHTSA study called TRUCKMUX[35])

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[35] *National Highway Transportation Safety Administration, Development, Evaluation, and Demonstration of a Tractor Trailer Intelligent Communication and Power Link. DOT HS 808685, Washington, DC, 1998.*

- Development of a new backward compatible connector system with additional pins
- A “piggy-back” carrier approach called Power Line Carrier (PLC) that uses the auxiliary power connection and some low-cost chips to communicate
- An infrared approach using the IRDA standards
- A radio-frequency approach

Currently, the PLC approach is being used for illuminating the trailer ABS warning light on the dashboard. The SAE J2497 standard, often referred to as PLC4TRUCKS, superimposes a spread-spectrum frequency carrier on the auxiliary power connection in the J560 connector. The standard uses the same electronic data interchange standard, SAE J1587, as the standard SAE J1708 network, so interoperability is streamlined. The PLC network connection is limited in bandwidth (9600 baud) and dependent on the carrier power signal for reliability. The diagnostic data could possibly be transmitted over the PLC connection to a tractor-based VDR, but the PLC connection is likely not suitable for the high-speed, high-reliability, low-latency communications that would be necessary for advanced safety systems (i.e., rollover control) that would need to interface with the trailer. To date, the PLC solution is the only solution for tractor-trailer communications that has gained acceptance by the industry. It is being implemented on new trailer ABS systems due to regulations requiring that a warning light be lit on the dashboard when there is a problem with the trailer ABS system. To accomplish this, ABS tractor and ABS trailer ECUs are equipped with this PLC transceiver. In the event of a trailer ABS fault, the trailer ABS ECU sends a message to the tractor ABS ECU. The tractor ABS ECU then communicates with the vehicle dash display (either over J1587, J1939, or a discrete signal) to illuminate a fault indicator.

Currently, there is a SAE J1587 message standard (PID 204) under development that will allow the tractor and trailer ABS ECUs to act as a bridge between the J1587 networks and PLC. This message standard will allow ECUs connected to the tractor J1587 network to communicate with ECUs connected on the trailer J1587 network to communicate with each other by passing messages through the ABS ECUs onto the PLC network. This will allow a tractor-based VDR to record data from any electronic ECU located on the trailer.

3.10.2 VDR Implementation Issues

Changes in tractor-trailer communications will have an important impact on the development of VDRs since the amount and type of data to be recorded is directly impacted by this communications link. While the use of a separate trailer-based VDR would solve the above communications issues, it would likely prove too costly, and properly synchronizing tractor and trailer data may be difficult to implement.

In a situation where the PLC connection’s bandwidth and reliability are not suitable, the connection of a VDR to a more appropriate connection will be necessary, but it remains to be determined as to which standard or technology the industry will eventually adopt.

3.10.3 Technology Implementation Costs

On new tractors and trailers manufactured after January 1, 2004, PLC communications between tractor and trailer ABS ECUs is standard. Therefore, there would likely be minimal cost associated with PLC-based tractor-trailer communications (specifically with the standards development of PID 204 if the VDR is connected to the tractor J1587 network).

CHAPTER 4. VDR COST-BENEFIT ANALYSIS

This Chapter focuses on understanding the benefits of VDRs based on the hypothetical product profiles (operational concepts) developed in Chapter 2. In addition, estimated costs (engineering development, application programming, and hardware) are developed for these same product concepts. Finally, while return-on-investment calculations are very fleet-specific, and made difficult due to the "soft" nature of both the benefits and costs, the final section of this Chapter presents an overview of the business-case justification that typical fleets use in purchasing VDRs and related products.

To understand costs and benefits associated with single-purpose accident event data recording (EDR), Concept 1 was analyzed. To understand costs and benefits of VDRs targeted at improving operational efficiency (including driver and vehicle monitoring, vehicle tracking, and maintenance management), Concept 3 was selected. Concept 5 was also profiled in order to develop a costs-benefits analysis for a "full-featured" VDR that would record accident event data as well as provide more traditional operational data used by fleets.

4.1 BENEFITS ANALYSES

To better understand the benefits associated with various configurations and concepts, the following sections address benefits from the perspective of a fleet operator for devices that: (1) could be used to record event data, and (2) could be used to record operational data.

4.1.1 Benefits of Accident Event Data Recording – EDRs

Accident event data recording (or EDRs) have been used for years in the commercial aerospace and railroad industry for crash causation and accident reconstruction analysis. Several light-duty passenger vehicle OEMs have been building EDR capabilities into their airbag control modules, called Sensing and Diagnostic Module (SDM), for several years. The rationale for including such functionality includes:

- **Vehicle Design Benefits** – The high-resolution crash data files collected from thousands of real-world accidents has provided light-duty manufacturers with valuable data for enhancing occupant safety through improved designs in areas such as crush zone requirements and performance, seatbelt design and operation, seating systems, and steering column and dash design. As importantly, the information collected provides important insights for tailoring and balancing airbag firing algorithms to minimize premature deployment while ensuring proper operation when the severity warrants deployment. Unfortunately, similar data on real-world crashes of commercial vehicles is largely unavailable. It is logical that if commercial vehicles were equipped with EDRs, the data collected during crashes could be leveraged by heavy-duty vehicle manufacturers to improve vehicle safety and design in a manner similar to the improvements demonstrated in the light-duty vehicle industry.
- **Warranty Management and Auditing of Customer Use** – Light-duty manufactures have also benefited from the data provided by EDRs in helping to understand, monitor, and audit warranty claims related to onboard safety systems. The EDR provides a clear record of whether various safety systems are properly functioning, or whether defects are being detected. For example, an EDR would help provide a high-resolution record of braking applications, including detailed performance of the ABS and/or stability control system to

help the vehicle OEM determine if the braking systems (purchased from suppliers) were indeed performing properly.

- **Driver Behavior** – Various studies show that the presence of EDRs has a preventative effect when parameters such as seat belt use, turn-signal use, horn application, and speed are monitored and are known by the driver to be recorded in the event of an accident.[36]
- **Infrastructure Design** – Roadway infrastructure engineers and designers can take advantage of aggregated accident event data to better understand how intersection and/or highway designs can be modified to both prevent accidents as well as mitigate severity (through better signaling and signage, road surface design, pavement transitions, etc.).
- **Reduction in Litigation Expenses** – Plaintiffs, defendants and lawyers can use EDR data to help in litigation resulting from accidents (e.g., in determining who is at fault). In the long term, this will reduce lawsuit costs, which will benefit fleets in the form of reduced premiums for those with EDRs onboard.

4.1.2 Benefits of Operational Data Recording – VDRs

VDRs are being used by numerous fleets to help improve operations, train drivers, enhance asset utilization, and improve maintenance efficiencies. Key benefits reported by fleets are listed as follows:

- **Equipment Utilization** – VDRs, when combined with GPS tracking *and* long-distance communications systems (satellite or cellular), are leveraged by fleets to better manage their assets (trucks) by maintaining an awareness of truck location, delivery status, estimated time of arrival, and verification of load status and description. Such information can be linked with sophisticated dispatching and load-assignment software in order to optimally match available trucks with shipping requests, thus reducing empty backhauls, increasing driver utilization, and improving scheduling.
- **Enhanced Shipper Services** – VDRs, when combined with appropriate back-office software, can also provide a record of the date, time, and status of freight delivery and pickup.
- **Driver Monitoring** – A VDR can record a driver's average speed, over speed and idle time, or engine "sweet spot". The output of the VDR can be used for both training and incentive-based programs that reward optimal (and safe) driving patterns. The VDR can also be programmed to record instances of hard braking, heavy accelerations, ABS activity, and other triggers that signal possible poor driver behavior.
- **Maintenance Scheduling** – A VDR can be used to help identify maintenance requirements based on actual activity levels rather than on pre-scheduled mileage intervals—thus reducing overall maintenance costs. For example, the VDR could be programmed to record actual braking activity (in terms of frequency of brake applications and associated deceleration rates) in order to develop brake application "histograms," which could then be used to more precisely determine when maintenance is required. Over time, the use of the VDR might allow fleets to avoid unnecessary scheduled inspections while still ensuring safe and effective maintenance of critical safety systems. The VDR could be leveraged in a similar fashion for

[36] National Highway Transportation Safety Administration, Event Data Recorders – Summary of Findings, NHTSA EDR Working Group. NHTSA-99-5218-9, Washington, DC, 2001.

monitoring of tire pressures (if equipped with a tire pressure monitoring systems) in order to more precisely and efficiently perform tire maintenance. Additionally, the VDR could automatically upload odometer readings, or use built-in "maintenance monitor" features, with factory set maintenance intervals to ensure that required scheduled maintenance activities are indeed completed.

- **Fault Diagnosis** – VDRs can be used to record various system fault codes as well as important vehicle operating conditions immediately preceding the fault in order to aid in diagnosing the problem. While most ECUs on a commercial vehicle (e.g., ABS, Engine, Dash Controller) will routinely record a fault code specific to that unit, they do not (usually), record operating conditions such as vehicle speed, engine RPM, braking application, and other parameters at the time the fault is recorded. Such data could likely be used to speed diagnosis and repair of the system. In this sense, the VDR is a natural complement to the ECUs controlling various systems on the truck.
- **IFTA Fuel Tax Log** – VDRs, if equipped with GPS units, can be programmed to automatically log miles accumulated in each State during a given time period, thus facilitating fuel tax calculations and required data submissions to State tax agencies. Vehicle latitude, longitude, and odometer readings can automatically be logged at user-specified intervals.

Our fleet interviews suggest that fleets often purchase and use the VDRs for what they believe is the "killer application" for their particular situation. For example:

- Some fleets offer driver fuel economy incentive programs. They can use the VDR to conveniently monitor fuel use, odometers, hours of operation, and idle time data (as well as other basic trip data such as average speed, time in each gear, etc.), and then download the data at a centralized fueling depot after each trip. One customer reported that the fuel economy incentive program amounted to a 0.2 mpg per vehicle gain, or about $900 per year per vehicle.
- Some fleets noted that the VDR is key to their "reliability-centered maintenance" strategy. These fleets are trying to move away from scheduled maintenance and towards maintenance based on need. The VDR can provide a variety of histogram data (using either hours or miles as the "bin" metric) related to oil temperatures, oil pressure, air system usage (compressor run time), brake applications, steering pump pressures, and/or run time of other auxiliaries. This data can then be gathered and analyzed to help tailor when maintenance and/or replacement of components is really needed.
- Some fleets reported that they purchased the VDRs to help with warranty enforcement. The VDRs can offer "proof" related to the hours and/or miles logged—and the conditions (pressures, temperatures, voltages, etc.) that were experienced surrounding a particular event, or for the average life of the component.
- Some fleets reported using the VDRs to primarily help with evaluating replacement parts from various vendors. For example, friction brakes from different suppliers could be evaluated very accurately using brake application histogram data to determine whether one particular aftermarket supplier was better than the other. Similar comparisons for oil filters, fuel filters, fuel injectors, and other wear items are also facilitated using the VDRs.
- TL fleets that cross several States during regular trips (but whose routing is not always identical) use the VDR to record miles in each particular State. One fleet reported that the VDR saves about $100 per year per truck in costs related to fuel tax logging and reporting.

- Many local and regional fleets (that have high driver turnover) report using the VDRs primarily to provide closer oversight of their drivers. For example, one company reported that its drivers were sometimes late to start work and came back to the depot early. The company was concerned that its drivers were not accurately reporting their location and status throughout the day using a two-way radio. Essentially, the drivers were taking longer to complete trips than the owner thought necessary. VDRs can be programmed to record specific data based on events including time and date stamps for individual trip activities such as engine starts, stops, idle time, power-take-off activation (such as lift gate activity), vehicle over-speeding, and/or ABS braking events. The fleet owner can then use this data to validate (or refute) the driver's adherence to the scheduled routing and deliveries.
- For many smaller and/or cost-conscious fleets, the VDRs, if equipped with GPS capabilities, can be an inexpensive way to track the vehicle's location—and adherence to programmed routes in a "post-trip" fashion. These fleets may not need to have continuous and/or real-time information on vehicle location (that could be obtained using satellite communications systems), but they still want to be able to have a record of where the truck was and when. The VDR can provide a means for doing this without having to pay the monthly service and connection charges associated with satellite communications providers.

In general, both VDR and EDR devices will benefit the commercial vehicle industry and society as a whole, but these benefits will likely be spread across three primary stakeholder groups: (1) fleets, (2) OEMs, and (3) the public sector.

For fleets, benefits will primarily be focused around improving operational efficiency and reducing operational costs. For OEMs, benefits will likely come from reducing liability costs and improving vehicle designs and safety. Public sector stakeholders—such as transportation agencies, law enforcement, and the general public as a whole—will likely benefit from improved vehicle safety; fewer crashes, injuries, and fatalities; and improved inspection capabilities. Exhibit 4.1 shows the possible benefits to each of these stakeholder groups as well as whether or not Concept 1, 3, or 5 will likely lead to a realization of that benefit.

Exhibit 4.1 – Vehicle Data Recorder Benefits

		Concept #1 EDR	Concept #3 VDR	Concept #5 EDR+VDR
FLEETS	**Efficiency**			
	- Improved Equipment Utilization (asset management)	0	4	4
	- Improved Fuel Economy Through Incentive Programs	0	3	3
	- Better Route Planning and Adherence Through Location Tracking	0	3	3
	- Enhanced Dispatching and Reduced Backhauls	0	3	3
	- Enhanced Customer Service (shipment tracking, records of P/U & delivery, etc.)	0	4	4
	Maintenance			
	- Reduced Maintenance Costs Through Need-Based Maintenance Planning	0	4	4
	- Fewer OOS Violations Through Early Failure Detection/Preventative Maint.	0	4	4
	- Reduced Diagnostic Time Through Fault and Freeze-Frame Recording	0	4	4
	Administrative			
	- Reduced Fuel Tax Administrative Costs Though Location and Mileage Tracking	0	4	4
	- Improved Monitoring of Driver Hours/Miles (payroll functions)	0	3	3
	- Automated Driver Log (HOS) Capabilities	0	3	3
	Safety			
	- Positive Influence on Driver Behavior	2	3	4
	- Reduce Overall Litigation Costs	3	3	4
	- Lower Insurance Premiums	2	3	3
	- Customized "Alerts" Based On Speed, Braking, and Drowsiness Measures, etc.	0	4	4
	Security			
	- Geo-Fencing (if equipped)	0	4	4
	- Stolen Vehicle Recovery	0	4	4
	- Mandated Periodic Reporting	0	4	4
OEM	**Reduced Product Liability Costs** Though More Accurate "Who's At Fault" Analysis	4	1	4
	Improved Vehicle Design (Safety Systems) by Utilizing Crash Field Data	3	1	4
	Potential For Value-Added Services Related to Maintenance and Diagnostics	0	3	3
	Reduced Warranty Costs Through Availability of Vehicle Use Data	1	3	3
PUBLIC SECTOR	**Transportation Agencies**			
	- Accurate Roadway Usage and Crash Statistics	3	3	4
	- Improved Safety Analysis and Regulatory Support Data Availability	3	3	4
	- Improved Infrastructure Design	3	3	4
	General Public			
	- Fewer Crashes, Fatalities, and Injuries	2	2	4
	Law Enforcement & Security			
	- Reduced Inspection Costs Through Access to Stored Driving Data	0	3	3
	- Improved Hazardous Materials Security Through Location Tracking	0	3	3

0	If implemented, the concept would have no impact/correlation on stated benefit
4	If implemented, the concept would fully support the stated benefit

4.2 COST ANALYSES

In an effort to better understand likely development and production costs for the concepts outlined in Chapter 2, technical and performance descriptions of each concept were shared with a leading suppler of high-volume custom vehicle electronics for commercial heavy-duty vehicles. The supplier went through the standard development and estimation process, working with both its engineering and sales and pricing team to gain a detailed understanding of the concepts. This supplier then developed an estimated cost analysis for each concept. The team felt that this approach provided a more accurate estimate of the costs broken down into three parts—engineering development costs, application programming costs, and hardware piece costs. In addition, a combined per-unit cost was totaled based on order quantities of over 10,000 units per year supplied to OEMs for installation as part of new vehicle builds. In developing a cost estimate for this concept, a cost precision of ±15 percent was used in the estimation.

It should be noted that this is only the estimate of one vendor and is only intended to provide a preliminary, rough cost estimate for each generalized concept. It is entirely possible that should an OEM choose to source and install such a concept in its vehicles, the cost would vary, perhaps significantly, depending upon quantities, vendor incentives, and manufacturing and component technologies used. In addition, these costs are intended to represent manufacturing and assembly costs, not necessarily retail costs to a customer or fleet.

4.2.1 Core EDR (Concept 1)

To review, Concept 1 is a low-cost event triggered data recorder for recording various types of onboard data that might be used to assist with accident reconstruction. It would include provisions for recording vehicle dynamics before, during, and after an event.

Most of the data would come from existing subsystem ECUs and would be available over one or more of the vehicle's communications networks (e.g., J1587, J1939). The EDR would need to contain a three-axis accelerometer (i.e., longitudinal, lateral, vertical). It would also have five digital inputs (on/off) to record service brake, emergency brake, trailer brake, driver seatbelt latch, and passenger seatbelt latch status. Two analog sensor inputs would be available for accelerator and brake pedal position sensors. Because Concept 1 would be designed to record data both before and after an accident event, it will require an internal backup power supply that would enable the EDR to record data for the short period immediately following an accident should the vehicle main battery be disabled. The complete high-level specification can be found in section 2.3.1.

Estimated Cost
Concept 1's estimated cost per piece would be approximately $260 for quantities over 10,000 units, ± 15 percent. One-time tooling and layout cost for the printed circuit board would be approximately $20,000. Software development cost would likely range between $15,000 to $30,000. Therefore, the amortized per-unit cost for 10,000 units would be approximately $265 each (assuming $25,000 for software development). Of course, this would be cost per unit as sold by a vendor to a vehicle OEM. It is anticipated that there would be additional costs associated with integrating the unit into the vehicle (e.g., mounting, wire harnesses, service and repair manuals) and adding the product to the line card and assembly line. It is likely that an

OEM would add a 30- to 50-percent markup to a fleet to cover these costs and provide for warranty expense and profitability.

4.2.2 Core VDR (Concept 3)

To review, Concept 3 is a "continuous" VDR that records a variety of operating data that can be used for improving maintenance planning (predictive maintenance) and for monitoring driver performance and operations. The VDR would include a core operational efficiency data set to provide basic measures of vehicle and fleet efficiency. To this end, both summary data (minimums, maximums, averages, cumulative totals) and histogram data (segmented data categorized in various "bins") would be recorded for a variety of channels.

The modest parameter set and storage algorithm requirements result in a VDR with a small storage capacity, and would likely not require fast processing capability as only summary-type data are recorded at a much slower frequency than that of Concept 1 (EDR). Additionally, all of the data elements should be available over one of the vehicle networks (J1587/J1939) from either the engine, transmission, or ABS ECUs. It may be necessary, however, for Concept 3 to have two analog inputs for the accelerator pedal position and brake pedal position if these data are not available over either databus.

The complete high-level specification can be found in section 2.3.3.

Estimated Cost
Concept 3's estimated cost per piece would be approximately $140 for quantities over 10,000 units, ± 15 percent. One-time tooling and layout cost for the printed circuit board would be approximately $20,000. Software development cost would be from $15,000 to $30,000. Therefore, the amortized per-unit cost for 10,000 units would be approximately $145 each (assuming $25,000 for software development). Of course, this would be cost per unit as sold by a vendor to a vehicle OEM. It is anticipated that there would be additional costs associated with integrating the unit into the vehicle (e.g., mounting, wire harnesses, service and repair manuals) and adding the product to the line card and assembly line. It is likely that an OEM would add a 30- to 50-percent markup to a fleet to cover these costs and for profitability.

4.2.3 Comprehensive VDR and EDR (Concept 5)

To review, Concept 5 is a "full-featured" VDR and EDR, and combines advanced accident reconstruction capabilities with advanced operational efficiency and driver monitoring capabilities. It is not only designed to record high-resolution data before, during, and after an accident event, but also to continuously record histogram and summary data to improve fleet efficiency, improve fleet maintenance, and monitor driver performance. This recorder would, therefore, require several internal sensors (e.g., three-axis accelerometer, yaw rate, tilt/roll angle) and several inputs for additional sensors not normally found on a commercial vehicle (e.g., steering wheel position, tire pressure monitoring, and vehicle/axle load). Additionally, this recorder would record the status of most vehicle subsystems (e.g., lights, retarder, inertia brake, traction control, stability control, airbag).

The recorder would record an extensive amount of data and would, therefore, require significant storage capacity. Additionally, because it would be recording data at a high frequency before and after an event trigger, it will require a fast data-processing capability and an internal backup power supply. The extensive list of data elements means that Concept 5 would require several analog (six) and digital (five) inputs to record data that is not available on the vehicle's databuses (J1587/J1939).

The complete high-level specification can be found in section 2.3.5.

Estimated Cost
Concept 5's estimated cost per piece would be approximately $450 for quantities over 10,000 units, ± 15 percent. One-time tooling and layout cost for the printed circuit board would be approximately $20,000. Software development cost would be from $20,000 to $40,000. Therefore, the amortized per-unit cost for 10,000 units would be approximately $460 each (assuming $40,000 for software development). Of course, this would be cost per unit as sold by a vendor to a vehicle OEM. It is anticipated that there would be additional costs associated with integrating the unit into the vehicle (e.g., mounting, wire harnesses, service and repair manuals) and adding the product to the line card and assembly line. It is likely that an OEM would add a 30- to 50- percent markup to a fleet to cover these costs and for profitability.

4.3 RETURN ON INVESTMENT

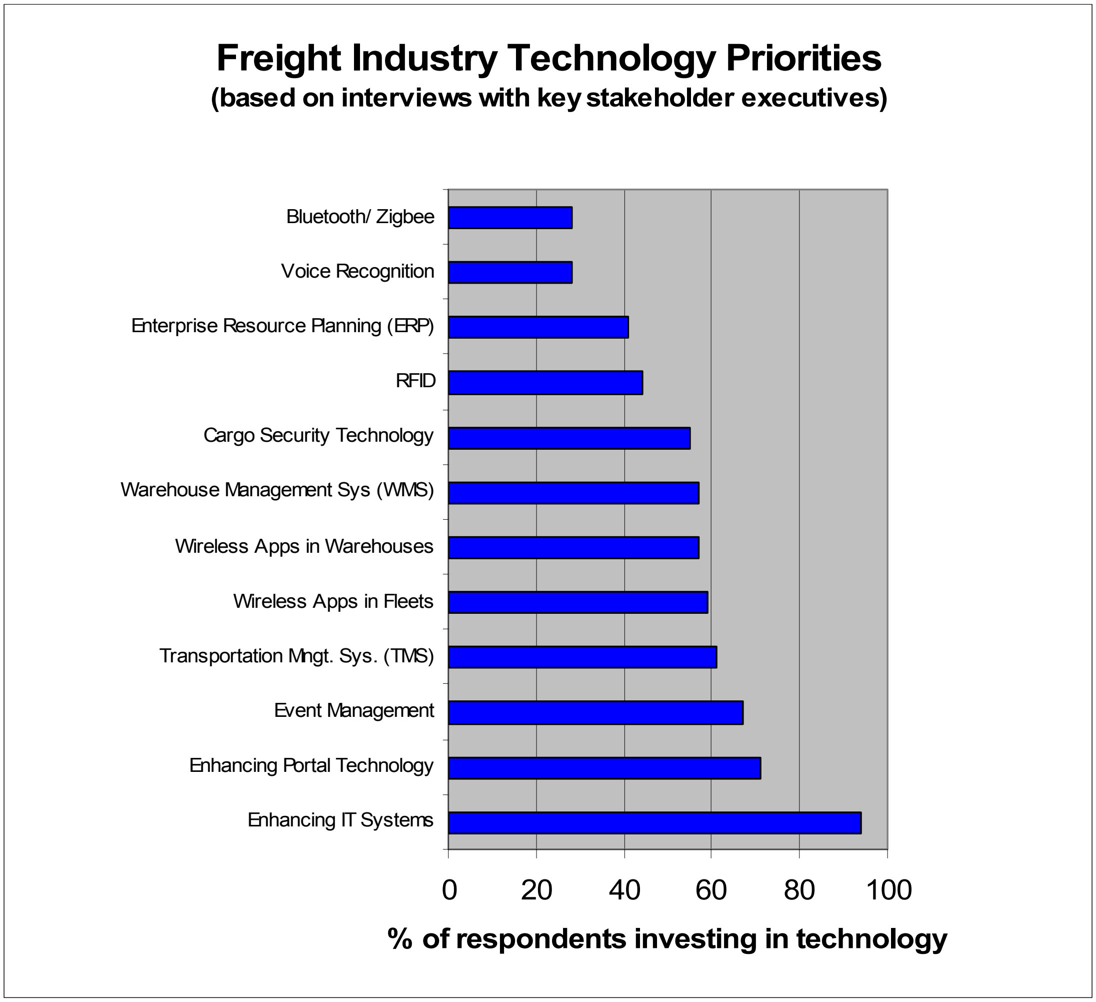
In conducting this study, it became clear that return-on-investment calculations for VDRs (from the fleet operator's perspective) are challenging due to:

- Benefits are often defined in terms of increased productivity, efficiency, competitiveness and/or improved safety. All of these measures will vary depending on a particular fleet's situation—and are very hard to quantify even for a specific fleet's situation.
- Costs are also difficult to obtain from commercial suppliers of VDR equipment and services. The costs are often embedded (or bundled) within a vehicle price and/or within a larger telematic service offering. More importantly, the market price of some of the products and services reviewed in earlier chapters is not necessarily indicative of cost. The commercial vehicle telematics, communications, and VDR industry is in many ways in its infancy. As such, suppliers with innovative ideas that improve a fleet's competitiveness may well be able to command premium prices that are not cost-based.

While costs and benefits are difficult to quantify, VDRs and related products and services are nevertheless enjoying market success. Although market penetration data is generally not available (or is closely guarded by suppliers), nearly all vendors contacted reported consistent increases in annual sales volumes. This includes various satellite and terrestrial-based tracking services and upgraded or enhanced recording functionality embedded within the engine control modules. Standalone VDRs and/or EDRs, however, do not appear to be enjoying the same level of success. It would appear, at least anecdotally, that the functionality that might typically be available with a VDR is being incorporated directly into satellite and/or terrestrial tracking systems. Alternatively, if a fleet does not wish to (or cannot afford) such systems (which require a monthly fee), but still desires some vehicle monitoring capability, then it opts for the functionality that can be provided by the engine OEMs within the engine ECUs (see Appendix B). Thus, the standalone VDR and EDR market seems to be waning.

However, fleet managers need for information related to the driver, vehicle health, location, and load status continues to grow. Interviews with industry stakeholders suggest that the information provided by "conventional" fleet tracking and management services is now just "part of the cost of doing business and staying competitive." As a simple example, some truck load companies cannot calculate a straightforward return-on-investment in their onboard tracking and communications systems, but shippers (their customers) may have become accustomed to knowing the exact status of their shipments—and therefore a trucking company simply needs this capability to be competitive. For example, in a recent survey of over 300 leading freight industry executives administered by e*yefortransport* magazine, respondents were asked to list, in order of priority, the technology investments that they have recently made or intend to make in the near future. Partial results of the survey are shown in Exhibit 4.2 below.

Exhibit 4.2 – Freight Industry Technology Priorities



As can be seen in the exhibit, there appears to be considerable interest in the commercial freight community in technologies related to event management and in wireless applications in fleets.

In summary, while return-on-investment calculations for devices and systems that incorporate VDR and EDR functionality are difficult to quantify, fleets nonetheless appear interested and willing to invest in such technology.

APPENDIX A – BIBLIOGRAPHY

A.1 REPORTS/PAPERS

American Trucking Associations' Technology and Maintenance Council, *Recommended Practices 1214 - Guidelines for Event Recording – Collection, Storage, and Retrieval,* Alexandria, VA.

Bishop, Richard, *Intelligent Vehicles: A New World Coming – Presentation to the Casualty Actuarial Society,* May 8-9, 2000.

Carroll, Joseph, and Michael Fennell, *An Autonomous Data Recorder for Field Testing*, The International Symposium on Transportation Recorders, Arlington, VA, 1999.

Champion, Howard, et al, *Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Rating from Crash Recorders to Emergency Medical Service Providers*, The International Symposium on Transportation Recorders, Arlington, VA, 1999.

Chidester, Augustus, et al, *Recording Automotive Crash Event Data*, International Symposium on Transportation Recorders, Arlington, VA, 1999.

Dobranetski, Ed, and Dave Case, *Proactive Use of Recorded Data for Accident Prevention*, The International Symposium on Transportation Recorders, Arlington, VA, 1999.

Federal Highway Administration, *Development of Requirements and Functional Specifications for Event Data Recorders*, U.S. Department of Transportation, Washington DC:2005 http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14146.htm

The Gallup Organization, *National Survey of Distracted and Drowsy Driving Attitudes and Behaviors: 2002 Volume I – Findings Report*, National Highway Traffic Safety Administration, Washington, DC, 2003.

Haight, W. R., *Automobile Event Data Recorder Technology – Evolution, Data, and Reliability*, Collision Safety Institute, San Diego, CA, 2001.

Kithil, Philip, et al, *Development of Driver Alertness Detection System Using Overhead Capacitive Sensor Array*, International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Aspen, CO, 2001.

Lehmann, Gerhard, and Tony Reynolds, *The Contribution of Onboard Recording Systems to Road Safety and Accident Analysis*, The International Symposium on Transportation Recorders, Arlington, VA, 1999.

National Highway Safety Administration, *Notice of Proposed Rulemaking Federal Motor Vehicle Safety Standards - Event Data Recorders*, DOT NHTSA-2004-18029, Washington, DC, 2004.

National Highway Traffic Safety Administration EDR Working Group, *Event Data Recorders – Summary of Findings Final Report Volume II: Supplemental Findings For Trucks, Motorcoaches, and School Buses*, Washington, DC, 2002.

National Highway Traffic Safety Administration EDR Working Group, *Event Data Recorders – Summary of Findings Final Report*, Washington, DC, 2001.

National Transportation Safety Board, *Safety Recommendations (H-99-45 through H-99-54)*, Washington, DC, 1999.

Prasad, Aloke, *Performance of Selected Event Data Recorders*, Vehicle Research and Test Center, NHTSA, USDOT, 2001.

Risack, R., et al, *Video-based Lane Keeping Assistance, IEEE Intelligent Vehicle Symposium, Dearborn, MI, 2000.*

Society of Automotive Engineers, SAE J1698-1 "Vehicular Event Data Interface – Vehicular Output Data Definition," Detroit, MI, 2003.

A.2 ARTICLES

Balancia, Donna, "DriveCam Tests On Board Video Systems with Commercial Fleets," http://www.localbusiness.com, April 10, 2001.

Barnes, David, "Commentary: The Debate on 'Black Boxes" *Transport Topics*, March 2000.

Brown, Barry, "Black Boxes Face Car-Crash Test," http://www.msnbc.com/, March 20, 2001.

Kelly, Tom, "Black Boxes, Big Help or Big Brother? – Part 1", http://www-nrd.nhtsa.dot.gov/edr-site/uploads/Black_Boxes--Big_Help_Or_Big_Brother.pdf, August 2001

Lienert, Anita, "Society of Automotive Engineers Convention: Auto Industry Tests 'black box' for Car-Truck Troubleshooting," *The Detroit News,* February 27, 1997.

Martin, Bill, "Transportation 2000 – The Big Black Box," May 8, 2000.

Martin, Norman, "Big Brother Is Watching," *Cahners Publishing Company*, October 1999.

Paton, Vince, "Black Boxes on Board," http://www.wfaa.com, May 2001.

Stoffer, Harry, "Promise and Pitfalls Seen in Black Box" *Automotive News*, September 17, 2001.

"Automobile 'Black Boxes' Ready to Roll," *USA Today*, June 13, 2000.

"'Black Box' to Be Introduced for Commercial Vehicles," *Diversified Auto Technology*, June 16, 1999.

"Black Box – Airplane Tech for Your Auto," *Revelation File News Service*, 1997.

"Car Crash Data Is in the Bag," *DOT Life*, BBC News, March 26, 2001.

"Charting the Electronics Path," *Automotive Engineering International Online.*

"Company Cars Next for 'Big Brother' Black Boxes," *The Royal Society for the Prevention of Accidents*, October 19, 2000.

"DAT Announces Intent to Release the Ultimate Vehicle Black Box," *Automotive Intelligence*, June 17, 1999.

"Delphi's Next Generation Accident Data Recorder to be Featured on Race Cars," *Delphi Automotive Systems*, May 18, 2000.

"DriveCam Video Systems Debuts Next Generation Video Event Data Recorder for Commercial Vehicles," *DriveCam Video Systems*, June 19, 2001.

"GM Sued over Automobile 'Black Box,'" *USA Today*, December 1, 2000.

"Vetronix Corporation Launches the Crash Data Retrieval (CDR) System," *Vetronix Corporation*, March 7, 2000.

A.3 WEB SITES

Accident Reconstruction Network
http://www.accidentreconstruction.com

Harris Technical Services – Traffic Accident Reconstruction
http://www.harristechnical.com

The International Symposium on Transportation Recorders
http://www.ntsb.gov/events/symp_rec/proceedings/symp_rec.htm

NHTSA Event Data Recorder Website
http://www-nrd.nhtsa.dot.gov/edr-site

A.4 PROFILED SYSTEM REFERENCES

Accident Data Recorder (ADR2) – Delphi Automotive Systems
http://www.delphi.com
5725 Delphi Drive, Troy, MI 48098.

AP+ Series Data Recorders – Accident Prevention Plus
http://www.applus.com

21 North Hepburn Ave, Suite #21, Jupiter, FL 33458.

Bendix Tractor ABS ECU – Bendix Commercial Vehicle Systems
http://www.bendix.com
901 Cleveland Street, Elyria, OH 44035.

DataLogger – Arvin/Meritor
http://www.arvinmeritor.com
2135 West Maple Road, Troy, MI 48084.

DriveCam – DriveCam Video System
http://www.drivecam.com
3954 Murphy Canyon Road, Suite D # 205, San Diego, CA 92123.

Haldex Trailer ABS ECU – Haldex
http://www.haldex.com
Biblioteksgatan 11, Box 7200, SE-10388 STOCKHOLM, Sweden.

Incident Data Recorder, Bowmonk, Ltd.
http://www.bowmonk.com
Diamond Road, St. Faith's Industrial Estate, Norwich, Norfolk, NR6 6AW, England.

MACBox – Loss Management Services, Inc.
http://www.safetyintelligence.com.

Meritor WABCO Tractor ABS ECU – Meritor WABCO
http://www.meritorwabco.com
2135 West Maple Road, Troy, MI 48084, USA.

Mobius TTS – Cadec
http://www.cadec.com
8 E Perimeter Road, Londonderry, NH 03053.

Pro Driver – Detroit Diesel
http://www.detroitdiesel.com
13400 Outer Drive, West, Detroit, MI 48239.

Road Recorder 6000 – Safety Vision
http://www.safetyvision.com
6650 Roxburgh Drive, Suite 100, Houston, TX 77041, USA

Road Relay 4 – Cummins
http://www.cummins.com
P.O. Box 3005, Columbus, IN 47202, USA

Tacholink Millennium – Bowmonk, Ltd.
http://www.bowmonk.com
Diamond Road, St. Faith's Industrial Estate, Norwich, Norfolk, NR6 6AW, England

UDS accident data recorder – Mannesmann VDO
http://www.vdo.com
Westfield Corporate Center, 4905 Tilghman Street, Suite 120, Allentown, PA 18104, USA

Vehicle Accident Video Recorder – Personal Eyewitness,
Mitsubishi Electric Research Laboratory (MERL)
http://www.merl.com/projects/eyewitness
201 Broadway, Cambridge, MA 02139, USA

Wabash Trailer ABS ECU – Wabash National
http://www.wabashnational.com
P.O. Box 6129, Lafayette, IN 47903, USA

The Witness – Independent Witness
http://www.iwiwitness.com
1515 West 2200 South Suite E, Salt Lake City, UT 84119, USA

Vital Information Management System (VIMS) – Caterpillar
http://www.cat.com
100 NE Adams Street, Peoria, IL 61629, USA

V-Mac II Engine ECU, Co-Pilot, InfoMax Wireless – Mack Trucks
http://www.macktrucks.com
2100 Mack Boulevard, P.O. Box M, Allentown, PA 18105, USA

APPENDIX B – VDR CAPABILITY AND COST PROFILES

B.1 APPROACH

An important first step in determining the cost and benefit of various VDR implementations and applications was to profile the capabilities and costs of current commercially available VDRs and supporting technologies. This work provided key inputs and basic building blocks for the cost-benefit analysis in Chapter 4.

The primary objective of this process was the identification-specific VDR features and capabilities, and the estimation of the costs associated with those features to develop an understanding of cost drivers for VDR design. There is a considerable amount of information available regarding recommended data elements, sampling rates, and measurement accuracy needed to support various levels of crash causation and safety analyses (e.g., NHTSA's Summary of Findings of the EDR Working Group, Volume 2, Supplemental Findings for Trucks, Motorcoaches, and Buses). However, there is virtually no information available related to the costs associated with incorporating various data-gathering capabilities into a particular VDR design.

For example, it will be important to have high-resolution recording of numerous vehicle operating parameters just seconds before and after the event (e.g., What was the deceleration rate when the accident occurred?) to support crash reconstruction. However, a long-term histogram record of data will be needed (e.g., What percent of brake applications last week or month were above some preset deceleration rate?) to support various operational efficiency improvement initiatives (such as driver training or maintenance prognostic tools). The data storage requirements, resolution, and accuracy are very different for these two applications. In this example, the goal of this task would be to understand the cost implications for incorporating each or both of these types of capabilities into a VDR design. Key VDR cost drivers examined included:

- Number of sensors (or inputs) monitored
- Type of inputs monitored (e.g., analog, digital, on/off)
- Data collection rates (sampling frequency)
- Required accuracy (this is more likely a function of the sensor or transducer input than of the VDR, but is nevertheless a cost driver for the VDR system)
- Memory capacity and/or memory features
- "Virtual" VDR systems (distributed processing and storage) versus centralized (or conventional) VDR designs
- Level of "hardening" (i.e., vulnerability to damage from a crash)
- Data extraction methods (hand-held diagnostic tool versus various types of wireless communication protocols)
- Various supporting VDR capabilities (e.g., GPS, forward-looking radar)

In addition, it was important to understand the impacts of incorporating various combinations of capabilities and features since there are design “economies” associated with grouping selected features together.

To accomplish these objectives, the team interviewed technical staff from several stakeholder groups:

- Vehicle OEMs (Class 3 through 8)
- Trailer OEMs
- Commercial vehicle component suppliers focusing on electronic, electrical, communications, and safety specific components and systems
- Manufacturers of VDRs

The team also contacted manufacturers and suppliers of so-called “data loggers” that traditionally are used for vehicle development and research purposes (e.g., Dearborn Group, National Instruments, Link, IOtech Inc.). These manufacturers had valuable insight regarding cost and capabilities of VDR type devices. The team also interviewed selected government officials to gain a better knowledge of the experiences associated with implementing various forms of VDRs.

The intent in this task was to focus primarily on commercially available technologies, since accurate cost data for systems or components still in the research and development stages was difficult to obtain and even more difficult to extrapolate to the realm or “market ready” devices. However, to the extent possible, these developmental technologies were researched and industry stakeholders were asked to estimate the relative cost impacts of emerging technologies and capabilities. Where specific cost data was not available, costs assumptions were based on best professional judgment.

The team developed a detailed “features and performance” matrix that was used to profile each commercially available and prototype system. This profile includes:

- The parameters or data elements stored
- Sensor inputs and vehicle network communications
- Data collection frequency, accuracy, memory capacity, and storage algorithms (e.g., event triggers, histogram data)
- Data extraction methodology
- The level of “hardening” (temperature and environment ratings)
- Intended application and cost

It should be noted that while a large number of systems were profiled in this task, and every effort was made to sample as many systems as possible, there are likely other systems currently available or that have recently been introduced that were likely not sampled. As the market for VDRs is continuing to change and develop, new and redesigned systems are continuing to be introduced into the marketplace. This profiling task was intended to be a snapshot of what was available at the time.

B.2 SYSTEM DESCRIPTIONS

Several different types of systems that incorporate varying VDR functionality were researched, including:

- EDRs
- Video event data recorders
- Vehicle data loggers
- Trip activity report systems built into engine ECUs (e.g., Cummins, DDC, Caterpillar, Mack)
- ABS-based recording systems

Each of these types of systems are described in the following subsections.

B.2.1 EDRs

Several systems are available that are intended to record vehicle data triggered on an event or accident. These systems are what are typically referred to as EDRs. Generally, EDRs are programmed with a set of conditions or triggers that when reached cause the recording and storage of high-resolution vehicle data. Exhibit B.1 summarizes the EDRs that were profiled during this task. Appendix A includes more detailed references and sources for information about these systems.

Exhibit B.1 – Event Data Recorders

System/Component	Provider	Application
AP+ Series Data Recorders	Accident Prevention Plus, Long Island, NY	Event Data Recorder
UDS accident data recorder	Mannesmann VDO www.vdo.com	Event Data Recorder
MACBox	Loss Management Services, Inc.	Event Data Recorder
Incident Data Recorder	Bowmonk, Ltd. England	Event Data Recorder
Accident Data Recorder (ADR2)	Delphi Automotive Systems	Event Data Recorder
The Witness	Independent Witness	Event Data Recorder

AP+ Series Data Recorders – Accident Prevention Plus
The AP+ Series data recorders are a series of programmable data recording systems for both event data logging and logging of operational data. They are custom programmable and have provisions for an optional driver smart card. The optional smart card can store driver identification information along with summary and histogram data on driving behavior (e.g., maximum speed, hours of service, vehicle and engine speed histograms, braking intensity and occurrence histograms). This system can use the SAE J1939 network as the source for much of

this information, or it can use discrete analog or digital inputs.

UDS Accident Data Recorder – Mannesmann VDO
The UDS accident data logger is designed to record lateral and longitudinal acceleration, vehicle speed, vehicle direction, and 10 status inputs (e.g., ignition on/off, left and right turn signal status, brake light status) for 30 seconds before an incident and 15 seconds after. The system has the ability to record up to 12 events (9 triggered events and 3 manual events). The system is marketed through VDO for truck, bus, and taxi fleet markets. The USD recorder has a number of analog and digital discrete inputs to record these various parameters.

Loss Management Services (LMS) – MACBox
The Mobile Accident Camera Box (MACBox) developed by LMS records both video and accelerometer data before, during, and after an accident event. The unit can then either be returned to the manufacturer for downloading and analysis, or it can be wirelessly transmitted to the manufacturer via a cellular transceiver. LMS charges a fee for an accident report along with an annual service fee. The MACBox has a digital discrete input.

Incident Data Recorder – Bowmonk, Ltd.
The Incident Data Recorder is an event triggered data recorder that records data 45 seconds prior to and 20 seconds after an incident. The system incorporates a bi-directional accelerometer for measuring longitudinal and lateral acceleration (an optional second accelerometer is available to record vertical acceleration). In addition, the system stores histogram data on average speed, distance, and time on one-minute intervals. There are eight additional inputs available for recording both analog or digital signals. The Incident Data Recorder is capable of recording these data elements over both analog and digital discrete inputs.

Accident Data Recorder (ADR2) – Delphi Automotive
The Delphi ARD2 is a second-generation accident EDR designed for motorsport applications. It has an internal three-axis accelerometer and can record data from external sources with seven analog and three timer inputs. It also features four communications links (three serial, one CAN). It is designed to withstand the high g-force (500 g) impacts of race cars and has an uninterruptible power supply to record data in the event of data loss. It is currently being used in all CART racing series vehicles. The ADR2 has CAN inputs for ISO 11898 and SAE J1939, along with analog and digital discrete inputs.

The Witness – Independent Witness
The Witness is a incident data recorder that monitors the acceleration profile of a vehicle during an accident. The system measures and records the acceleration of the vehicle in three directions along with the date, time, and direction of the accident using all internal sensors. The system uses a portable reader to download the accident data. In 2002, the National Association for Stock Car Auto Racing (NASCAR) began installing The Witness in all of its race vehicles. There are no connections to vehicle databuses with this system.

B.2.2 Video Event Data Recorders

Several systems are currently available in the marketplace that record video data during an event or accident. As a subset of EDRs focused on video recording, they have been termed Video Event Data Recorders. These systems often record multiple views (e.g., frontal, rear, side) of video along with a minimal set of data parameters triggered on various events or accidents. Exhibit B.2 summarizes the systems that were profiled in this task.

Exhibit B.2 – Video Event Data Recorders

System/Component	Provider	Application
Road Recorder 6000	Safety Vision, Houston, TX	Video Event Data Recorder
DriveCam	DriveCam Video System	Video Event Data Recorder
Vehicle Accident Video Recorder (Prototype)	Personal Eyewitness	Video Event Data Recorder

Road Recorder 6000 – Safety Vision
The Safety Vision Road Recorder 6000 is a digital video recording system designed for mobile applications. The system records up to five video sources (cameras or other image capturing devices like infrared), and has a built-in monitor output. The video is stored in a removable hard drive and is stamped with the date and time. The system also includes a GPS interface that allows it to record longitude, latitude, speed, and heading. It also has multiple discrete analog sensor inputs that are configurable and a J1807/J1587 interface. The system is focused primarily on the school bus market.

DriveCam – DriveCam Video System
DriveCam is a palm-sized video recorder that mounts behind the vehicle's rearview mirror. The DriveCam records both video and audio 10 seconds before, during, and after a trigger. Additionally, the DriveCam includes an accelerometer to record g-forces. DriveCam is designed to record erratic driving behaviors (e.g., hard braking and acceleration, and hard cornering). The DriveCam also records crash events, and can be manually triggered.

Vehicle Accident Video Recorder (Prototype) – Personal Eyewitness
The Vehicle Accident Video Recorder continuously records video into Flash memory, overwriting old video every 30 seconds until an accident triggers the system to permanently store the video (using airbag deployment or crash sensors). The system includes a video camera, built-in accelerometer, and backup battery. The video is stored for 30 seconds—20 seconds before and 10 seconds after an incident occurs. The system can then retain the video for up to one week on the internal battery. The data/video can be extracted using a serial or infrared connection. The system is designed initially for the truck, bus, and taxi fleet markets.

B.2.3 Vehicle Data Loggers

Three systems were profiled that were designed to monitor and record vehicle information for fleet management, maintenance, and operations monitoring purposes. This type of system, referred to as Vehicle Data Loggers, is intended to continuously monitor and record, in a histogram-type format, various vehicle parameters while in operation. Vehicle data loggers typically are not focused on recording event or accident data based on triggers, but occasionally do have such capabilities. Exhibit B.3 summarizes the vehicle data loggers profiled.

Exhibit B.3 – Vehicle Data Loggers

System/Component	Provider	Application
DataLogger	ArvinMeritor	Vehicle Data Logger
Mobius TTS	Cadec	Vehicle Data Logger
Tacholink Millennium	Bowmonk, Ltd. England	Vehicle Data Logger

DataLogger – ArvinMeritor
The ArvinMeritor Data Logger, referred to as a Data Logging Unit (DLU), is an onboard data recorder designed specifically for heavy-duty commercial vehicles. The DLU uses the vehicle's onboard J1708/J1587 network to continuously monitor and record information from the engine, instruments, ABS, collision warning system, and any other ECU that is connected to the serial databus. The DLU can be programmed to be triggered by up to 14 events, including air bag deployment, hard deceleration rate, J1587 Diagnostic Message (#194), out-of-range engine parameters, and out-of-range battery voltage. The driver can also manually activate a trigger to record data. The system is mainly marketed for maintenance monitoring and fault reporting applications, and is available as a factory-installed option on select Freightliner heavy-duty vehicles.

Mobius TTS – Cadec
The Mobius TTS is an onboard logistics management system. The system provides fleet asset tracking, paperless driver logs to support DOT regulations (e.g., hours of service, CDL information, manifest data), driver performance coaching (e.g., fleet speed standards, idling guidelines, handling practices), maintenance monitoring, and fault code warnings. The system consists of a touch-screen display panel, onboard computer, GPS receiver, J1708/J1939 network connections, 18 digital or analog I/O channels, and multi-mode wireless communication (e.g., 802.11, cellular, GPRS, iDEN, 1xRTT).

Tacholink Millennium – Bowmonk, Ltd.
The Tacholink Millennium is an onboard computer system that monitors and records various vehicle information for maintenance and fleet efficiency purposes. The system performs several functions including recording a histogram data of the vehicle speed, excessive RPM events, heavy braking events, fast acceleration events, trip summaries, fuel tank level, driver identification, GPS position, idling time, engine hours, and status of other inputs. This system is designed primarily for heavy-duty commercial vehicles, buses and coaches, emergency vehicles, car fleets, and construction equipment.

B.2.4 Trip Activity Report Systems

Several of the major heavy-duty vehicle engine manufacturers offer add-ons to their engine ECU systems that monitor, summarize, and record vehicle information for trip activity reporting purposes and fault code warnings. These systems are typically built into the engine ECU, but can have additional components (e.g., ECUs, displays, transceivers). A great deal of information on the vehicle activities can be reported by these systems purely by data available within the engine ECU. Exhibit B.4 summarizes the trip activity report systems profiled.

Exhibit B.4 – Trip Activity Report Systems

System/Component	Provider	Application
Road Relay 4	Cummins	Trip Activity Report System built into the engine ECU
Pro Driver	Detroit Diesel	Trip Activity Report System built into the engine ECU
Messenger	Caterpillar	Trip Activity Report System built into the engine ECU
V-Mac II Engine ECU Co-Pilot InfoMax Wireless	Mack Trucks	Trip Activity Report System built into the engine ECU/Driver display unit/WiFi transceiver

Road Relay 4 – Cummins
The Cummins RoadRelay 4 is a dashboard-mounted display unit that connects with the SAE J1587 or J1939 databus to display engine parameters, trip data, or other subsystem data. The unit reads stored engine data such as vehicle speed, engine speed boost pressure, oil temperature, coolant temperature, battery voltage, and fuel consumption. It also monitors distance traveled, travel time, and estimated time of arrival, and can be connected to a GPS receiver to monitor heading and location. The Road Relay can also read information on the vehicle databuses from other subsystems (e.g., transmission gear, gear selected, transmission fluid temperature).

Pro Driver – Detroit Diesel
Detroit Diesel's Pro Driver system records data inside the engine ECU. Pro Driver manages three types of data—activity-based data, time-based data, and event-based data. Activity-based data includes trip activity reports, life-to-date activity, and engine service intervals. Time-based data uses a built-in clock and calendar to record monthly activity summaries, daily engine usage, and engine service intervals. Event-based data records hard-braking incidents (e.g., total count and detailed information for the last two) with an adjustable event threshold, detailed last stop records, and engine fault events. Data can be extracted and displayed using a variety of methods (e.g., dashboard displays, vehicle communications networks, or PC software).

Vital Information Management System (VIMS) – Caterpillar
The Caterpillar Messenger display unit provides real-time, visual feedback on engine or truck operating conditions. Messenger uses a graphics information LCD display. Multiple communication data links (J1939, J1708) can be utilized to provide real-time performance and operating information while the vehicle is in use. The information can be displayed in either multilingual text (even graphical languages) or a graphical format.

VMac II Engine ECU/Co-Pilot/InfoMax Wireless – Mack Trucks
The Mack Truck Co-Pilot is an optional dash-mounted driver display system that can display engine and vehicle information to the driver. It can display trip summaries, fuel economy, vehicle system status, and engine sensor data. In addition, the VMac engine ECUs can record histogram and driver event data (e.g., vehicle over speed, engine over speed, hard braking). This data can then be downloaded via the J1708/J1587 connector or sent wirelessly over short-range

WiFi service using Mack's InfoMax Wireless module to a terminal at a fleet's distribution center. The InfoMax Wireless system includes an onboard module, WiFi antenna, and optional GPS receiver. The terminal or depot requires a network access point (NAP) and a PC running dedicated InfoMax software from Mack.

B.2.5 ABS ECUs

In addition to the trip activity report systems available from engine suppliers, several of the manufacturers offer ABS ECUs that have some limited data recording capabilities, both from ABS data (e.g., speed sensors, brake light, fault codes) and external data via analog and digital inputs. Exhibit B.5 summarizes the ABS ECUs profiled.

Exhibit B.5 – ABS ECUs

System/Component	Provider	Application
Tractor ABS ECU	Bendix	ABS ECU VDR
Tractor ABS ECU	Meritor WABCO	ABS ECU VDR
Trailer ABS ECU	Haldex	ABS ECU VDR
Trailer ABS ECU	Wabash National	ABS ECU VDR

Tractor ABS ECU – Bendix
The Bendix tractor ABS ECU can monitor ABS components (e.g., wheel speeds, ABS brake control status, ABS retarder control status, ATC (Automatic Traction Control) brake control status, ATC retarder control status, road speed, ABS faults). The Bendix tractor ABS ECU connects to the J1587 and J1939 networks to provide diagnostic information and control the engine and retarder during ATC events, respectively. Additionally, the Bendix Tractor ABS ECUs can communicate with the trailer over the PLC, SAE J2497, signal for the purposes of illuminating an in-cab trailer ABS indicator lamp. There are currently no provisions for recording other data.

Tractor ABS ECU – Meritor WABCO (MW)
The MW tractor ABS ECU can monitor ABS components (e.g., wheel speeds, ABS brake control status, ABS retarder control status, ATC brake control status, ATC retarder control status, road speed, ABS faults). The MW tractor ABS ECU connects to the J1587 and J1939 networks to provide diagnostic information and control the engine and retarder during ATC events, respectively. There are currently no provisions for recording other data.

Trailer ABS ECU – Haldex
The Haldex trailer ABS ECU has the ability to monitor up to five channels (two analog inputs, one digital input, two digital I/O). These channels can be configured to monitor a number of systems or sensors and report this information on Haldex's Info Centre or over PLC 4 Trucks, and SAE J2497. These systems or sensors could include Air-Weigh trailer axle load sensing

systems, PSI Tire Inflation Systems, reservoir pressure sensors, trailer door latches, brake lining wear sensors, backup distance warning sensors, or trailer rollover warning systems.

Trailer ABS ECU – Wabash National

The Wabash National trailer ABS ECU can monitor ABS components (e.g., wheel speeds, wheel end temperature, trailer ID, brake light status, fault codes, ABS activation, trailer odometer) and has two additional analog or digital inputs that could be used to monitor other sensors or systems, such as yaw sensors, control pressure, or door latch sensors. The system can then report this information over PLC 4 Trucks, SAE J2497.

B.3 DATA PARAMETER PROFILE

The systems in Exhibits B.1 through B.5 have the capability to record multiple vehicle parameters (e.g., speed, acceleration, ignition status) at multiple rates (e.g., 1 Hz, 10 Hz, 100 Hz) and during various operational states (e.g., at impact, before and after impact, throughout a specific trip, continuously). Exhibit B.6 lists the systems along with the parameters they are capable of recording. It should be noted that most of these systems are re-programmable and could be reconfigured to record more, less, or different parameters by the manufacturer (or in some cases the fleets) based upon customer requirements.

Exhibit B.6 – Commercial VDR Data Parameter Profiles

Parameters	Trip Activity Report Systems				Event Data Recorders						Vehicle Data Loggers			Video EDRs			ABS			
	Cummins Road Relay 4	Detroit Diesel Pro Driver	Caterpillar Messenger	Mack Co-Pilot/InfoMax	AP+ Series Data Rec.	UDS	MACBox	Incident Data Recorder	ADR2	The Witness	ArvinMeritor DataLogger	Mobius TTS	Tacholink Millennium	Road Recorder 6000	DriveCam Video EDR	Video Accident Recorder	Bendix Tractor ABS	MW Tractor ABS	Haldex Trailer ABS	Wabash Trailer ABS
General Vehicle																				
Ignition Status			X	X		X		X												
Vehicle Speed	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X
Wheel Speed									X								X	X	X	X
Longitudinal Acceleration					X	X	X	X	X	X			X		X	X				
Lateral Acceleration					X	X	X	X	X	X					X	X			X	
Vertical Acceleration					X		X		X	X										
Yaw Rate									X											X
Tilt Angle																				
Steering Wheel Position									X											
Axle Load																			X	
Cruise Control Status		X	X	X							X									
Odometer	X	X	X	X	X	X					X	X	X	X					X	X
VIN	X	X	X	X	X		X				X	X		X					X	
Subsystem Fault Codes				X							X	X		X					X	X
System Voltage	X			X							X	X		X						X
Alternator Current																				
Turn Signal Status						X		X						X						
Wiper Status																				
Headlight Status						X								X						

Parameters	Trip Activity Report Systems				Event Data Recorders						Vehicle Data Loggers			Video EDRs			ABS			
	Cummins Road Relay 4	Detroit Diesel Pro Driver	Caterpillar Messenger	Mack Co-Pilot/InfoMax	AP+ Series Data Rec.	UDS	MACBox	Incident Data Recorder	ADR2	The Witness	ArvinMeritor DataLogger	Mobius TTS	Tacholink Millennium	Road Recorder 6000	DriveCam Video EDR	Video Accident Recorder	Bendix Tractor ABS	MW Tractor ABS	Haldex Trailer ABS	Wabash Trailer ABS
Marker Light Status						X														
Door Status																				
Cell Phone/CB Status					X		X													
Engine and Emissions																				
Throttle Percentage									X		X	X		X						
Accelerator Pedal Pos.	X			X							X	X		X						
Intake/Boost Pressure	X		X	X							X	X		X						
Exhaust Temperature				X							X	X		X						
Engine Temperature	X		X	X							X	X		X						
Engine RPM	X	X	X	X	X			X			X	X	X	X						
Airflow(MAF,AFM,MAP)[37]					X															
Fuel Consumption	X		X	X							X	X	X	X						
Fuel Pressure			X								X			X						
Engine Retarder Status				X							X	X		X						
Oil Pressure	X		X	X							X	X		X						
PTO Status												X								
Engine Operation Hours													X							
Coolant Level			X										X							
Transmission																				
Transmission Gear	X	X			X															
Clutch Position		X									X			X						
Trans. Fluid Temperature	X																			
Brake Systems																				
Brake Pedal Position	X	X			X		X					X		X						
Air Reservoir Pressure																			X	X
Control Pressure					X															X
Activation Pressure																				X
ABS Status	X										X	X					X	X	X	X
Traction Control Status																	X	X		
Brake Camber Stroke																			X	
Brake Light Status						X		X									X	X		X
Safety Systems																				
Impact Sensors										X										
Seatbelt Latch Status							X													
Door Lock Status																				
External Elements																				
Ambient Temperature			X	X							X	X		X						
Time	*X*	X			X			X	X			X	X						X	
Location												X	X	X						
Direction of Travel						X								X						
Other																				
Proximity to Objects							X													

37 *MAF Mass Air Flow, AFM Air Flow Meter, MAP Manifold Absolute Pressure*

Parameters	Trip Activity Report Systems				Event Data Recorders						Vehicle Data Loggers			Video EDRs			ABS			
	Cummins Road Relay 4	Detroit Diesel Pro Driver	Caterpillar Messenger	Mack Co-Pilot/InfoMax	AP+ Series Data Rec.	UDS	MACBox	Incident Data Recorder	ADR2	The Witness	ArvinMeritor DataLogger	Mobius TTS	Tacholink Millennium	Road Recorder 6000	DriveCam Video EDR	Video Accident Recorder	Bendix Tractor ABS	MW Tractor ABS	Haldex Trailer ABS	Wabash Trailer ABS
Driver ID		X	X										X							
Trailer ID/VIN																				X
Video														X	X	X				
Audio														X	X					
Hours of Service																				
Temp of Wheel Ends																				X

Exhibit B.6 shows that systems intended for similar applications (e.g., EDRs, trip activity report systems, data loggers) record similar sets of parameters. EDRs, for example, all record longitudinal and lateral accelerations, and most record vertical acceleration also. Data loggers and trip summary recorders record several engine and transmission parameters, odometer, VIN, and system fault codes.

Exhibit B.6 demonstrates, however, that there is considerable overlap of functionality among the devices, and, in some respect, the product categories are notional (or directional) rather than absolute clear-cut divisions.

B.4 SENSOR INPUTS AND VEHICLE NETWORK COMMUNICATION PROFILE

To record each of these parameters, each system requires some combination of analog or digital inputs and/or vehicle communication network connections.

Analog inputs are used to record a signal that has a continuous nature rather than a pulsed or discrete nature. An analog signal may vary in frequency, phase, or amplitude in response to changes in physical phenomena, such as sound, light, heat, position, or pressure. For example, engine speed, pedal position, temperature, or control pressure would likely use an analog signal.

Digital inputs are used to record a signal in which discrete steps are used to represent information. Digital inputs generally have steps that typically refer to voltages on the signal. Often digital inputs can be thought of as “on” or “off”. For example, left turn signal status, headlight status, or wiper status would likely use a digital signal.

Pulse Width Modulation (PWM) is a way of digitally encoding analog signal levels on a digital signal. Through the use of high-resolution counters, the “on” or “off” cycle of a digital signal is modulated, creating a square wave, to encode a specific analog signal level. By varying the length of time the signal is “on” versus “off”, a cycle (called the duty cycle) can be used to represent analog values. The PWM signal is still digital because, at any given instant of time, the voltage signal is either fully on or fully off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

Many of the systems also have the ability to record information over a pre-existing vehicle communications network. On heavy-duty commercial vehicles, there are a number of communications networks that, if installed, could provide a centralized source for data. These protocols include:

- ISO 11898 European controller area network communications standard
- SAE J1708/J1587 North American serial communications standard
- SAE J1939 North American controller area network communications standard
- SAE J2497 North American power-line carrier communications standard

Exhibit B.7 shows the inputs and connections each system is capable of using.

Exhibit B.7 – Commercial VDR Sensor Inputs and Vehicle Network Connections

Systems	**Heavy-duty Vehicle Comm. Protocols**				**General Purpose Inputs**		
	ISO 11898 – CAN	**SAE 1708/J1587**	**SAE J1939**	**SAE J2497 (PLC)**	**Analog Inputs**	**Digital Inputs**	**PWM (Pulse Width Modulation) Inputs**
Trip Activity Report Systems							
Cummins Road Relay 4		X					
Detroit Diesel Pro Driver		X					
Caterpillar Messenger		X	X		X		X
Mack Co-Pilot/InfoMax		X	X				
Event Data Recorders							
AP+ Series Data Rec.			X		X		
UDS					X	X	
MacBox						X	
Incident Data Recorder					X	X	
ADR2	X		X		X	X	
The Witness							
Vehicle Data Loggers							
ArvinMeritor Data Logger		X					
Mobius TTS		X	X		X	X	
Tacholink Millennium					X	X	
Video Event Data Recorders							
Road Recorder 6000		X				X	
DriveCam Video EDR						X	
CarCam						X	
ABS EDUs							
Bendix Tractor ABS ECU		X	X	X			
Meritor WABCO Tractor ABS ECU		X	X	X			
Haldex Trailer ABS ECU				X	X	X	

Systems	Heavy-duty Vehicle Comm. Protocols				General Purpose Inputs		
	ISO 11898 – CAN	SAE 1708/J1587	SAE J1939	SAE J2497 (PLC)	Analog Inputs	Digital Inputs	PWM (Pulse Width Modulation) Inputs
Wabash Trailer ABS ECU				X	X	X	

Exhibit B.7 shows that many of the systems use analog and digital inputs as well as connections to the vehicle networks. The vehicle communications networks provide a centralized source of data to these systems, minimizing the need for discrete wiring and numerous extra analog or digital inputs (which require analog-to-digital converters and sampling hardware that increases the cost and complexity of the systems). A number of the systems use general purpose discrete analog and digital inputs to record data directly from the source as opposed to reading it off of a vehicle databus. This is largely advantageous because these systems could be fitted or retrofitted onto many different vehicles that may or may not have a databus.

B.5 DATA STORAGE MEDIUM PROFILE

The systems listed in Exhibits B.1 though B.5 were designed to perform several different functions, from event-triggered recording to trip summary recording, which require different data storage and triggering algorithms. In general, data is collected in two ways in these systems:

- Summarized data on a per trip interval (e.g., maximums, minimums, averages, histograms)
- Event-triggered continuous data (i.e., data channels are recorded at a specific frequency for a given interval, usually before and after an event trigger)

Exhibit B.8 describes how these systems store data and their available memory capacity.

Exhibit B.8 – Commercial VDR Data Collection and Storage Methodology

Systems	Data Collection Frequency	Event Storage Algorithm	Operational Data Storage Algorithm	Memory Capacity
Trip Activity Reporters				
Cummins Road Relay 4	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Detroit Diesel Pro Driver	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Caterpillar Messenger	Trip/Summary		Max, min, averages, timestamps, trip histograms	RAM: 512 KB Flash: 1 MB EEPROM: 32 KB

Systems	Data Collection Frequency	Event Storage Algorithm	Operational Data Storage Algorithm	Memory Capacity
Mack Co-Pilot/InfoMax	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Event Data Recorders				
AP+ Series Data Rec.	Trip/Summary Event-triggered	50 sec Before 10 sec After Trigger	Max, min, averages, timestamps, trip histograms	Memory Card: 120 KB SmartCard: 8 KB
UDS	Trip/Summary Event-triggered Manual-triggered	30 sec Before 15 sec After Trigger	Max, min, averages, timestamps, trip histograms	1 MB
MacBox	Event-triggered	15 sec Before 15 sec After Trigger		N/A
Incident Data Recorder	Event-triggered	45 sec Before 20 sec After Trigger		512 KB
ADR2	Event-triggered	N/A		2 MB
The Witness	Event-triggered	1.2 sec After Trigger		4 MB
Vehicle Data Loggers				
ArvinMeritor Data Logger	Trip/Summary Event-triggered	180 sec Before 60 sec After Trigger	Max, min, averages, timestamps, trip histograms	N/A
Mobius TTS	Trip/Summary		Max, min, averages, timestamps, trip histograms	96 MB
Tacholink Millennium	Trip/Summary	N/A	Max, min, averages, timestamps, trip histograms	512 KB

Systems	Data Collection Frequency	Event Storage Algorithm	Operational Data Storage Algorithm	Memory Capacity
Video EDRs				
Road Recorder 6000	Event-triggered	Programmable		60 GB
DriveCam Video EDR	Event-triggered	10 sec Before 10 sec After Trigger	N/A	64 MB (32 MB optional)
CarCam	Event-triggered	20 sec Before 10 sec After Trigger		4 MB
ABS ECUs				
Bendix Tractor ABS ECU	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Meritor WABCO Tractor ABS ECU	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Haldex Trailer ABS ECU	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A
Wabash Trailer ABS ECU	Trip/Summary		Max, min, averages, timestamps, trip histograms	N/A

N/A – Data not available or proprietary

It is interesting to note that for VDRs that record event-triggered data, no clear standard is being followed in terms of how many seconds before and after the trigger data is stored. Also, these systems vary in memory capacity from a few hundred KB to almost one hundred MB, and even many GB for the video recorder systems.

B.6 DATA EXTRACTION METHOD PROFILE

These systems use a variety of methods for data extraction and downloading for analysis. There are five main approaches for data extraction:

- The manufacturer provides a proprietary reader that attaches directly to the system
- The system or a portion of the system must be returned to the manufacturer for download and/or analysis

- A removable storage device (e.g., CompactFlash card, hard disk)
- Wired downloading via various onboard vehicle networks or communications standards
- Wireless downloading of the data to a land-based hub

Wireless downloading of data can also be classified into two general categories:
1. Local short-range communication (e.g., infrared, WiFi 802.11, Bluetooth)
2. Long-range communication (e.g., cellular, satellite, QualComm)

Exhibit B.9 shows each system's methods for data extraction.

Exhibit B.9 – Commercial VDR Data Extraction Methods

	Visual Display Only	Proprietary Reader Req.	Return to Manufacturer	Removable Media	Wired Downloading						Wireless Transmission							
											Long Range				Local			
					J1587/J 1708	J2497 (PLC)	J1939	Serial	Ethernet / USB	Other	QualComm	Satellite Modem	Cellular Modem	Other	WiFi 802.11a/b	Bluetooth	Infrared	Other
Trip Activity Report Systems																		
Cummins Road Relay 4					X												X	
Detroit Diesel Pro Driver					X												X	
Caterpillar Messenger	X																	
Mack Co-Pilot/InfoMax				X	X		X								X		X	
Event Data Recorders																		
AP+ Series Data Rec.				X			X	X	X									
UDS			X					X										
MacBox			X															
Incident Data Recorder				X						X								
ADR2				X				X										
The Witness		X						X				X						
Vehicle Data Loggers																		
ArvinMeritor Data Logger				X	X				X								X	
Mobius TTS				X	X		X	X	X			X	X	X	X		X	
Tacholink Millennium								X							X			
Video Event Data Recorders																		
Road Recorder 6000				X						X							X	
DriveCam Video EDR				X					X									
CarCam								X									X	
ABS ECUs																		
Bendix Tractor ABS ECU					X	X	X											
MW Tractor ABS ECU					X	X	X											
Haldex Trailer ABS ECU						X												
Wabash Trailer ABS ECU						X												

Exhibit B.9 shows that a number of methods are currently being used by manufacturers of VDR systems to extract data. In general, most of the EDR and VDR systems have removable media options and some form of wired downloading capability. There are a number of systems that offer infrared wireless downloading, and a couple use WiFi.

B.7 APPLICATION AND COST PROFILE

Exhibit B.10 shows various design aspects of each system along with their cost and intended application, and includes:

- The level of "hardening" or resistance to both the environment and vehicle impacts
- Additional or optional capabilities of the system
- Cost of the system[38]
- Additional costs required (e.g., infrastructure costs, proprietary reader costs, software costs)
- Intended application of each system

Exhibit B.10 – Commercial VDR Intended Application and Cost

Systems	Level of "Hardening"	Additional Capabilities	Cost	Additional Costs Required
Trip Activity Reporters				
Cummins Road Relay 4	SAE J1455	GPS (Optional)	$800	N/A
Detroit Diesel Pro Driver	SAE J1455	N/A	N/A	N/A
Caterpillar Messenger	SAE J1455	N/A	N/A	N/A
Mack Co-Pilot/InfoMax	SAE J1455	N/A	N/A	N/A

[38] *Unless otherwise noted, costs are for individual quantities, aftermarket, not installed. Cost data is intended to provide an approximate cost for each system, and was provided by each vendor through interviews and/or published pricing. It should be noted that, while this data is intended to provide a general cost feel for each system/category of VDR, the actual price of each system could vary depending upon numerous factors, including: options/accessories selected, quantity discounts, customization, or installation and sensor hardware costs.*

Systems	Level of "Hardening"	Additional Capabilities	Cost	Additional Costs Required
Event Data Recorders				
AP+ Series Data Rec.	SAE J1455	SmartCard	$1,500	
UDS	SAE J1455		$800-$1,200	
MacBox	Cab Mount	Video-based Technology	Annual Fee	Report Fee
Incident Data Recorder	Cab Mount	Accelerometer, GPS, GSM cellular	$975 no accelerometer $1,450 2 axis accelerometer $1,580 3-axis accelerometer	+$790 GPS +$920 GSM +$1,835 GPS/GSM
ADR2	N/A	N/A	N/A	N/A
The Witness	N/A		$600 w/ 6 accelerometers $1,200-$1,500 w/ GPS + satellite comm	$200 Software $1,500 Handheld Reader
Vehicle Data Loggers				
ArvinMeritor Data Logger	SAE J1455		N/A	N/A
Mobius TTS	SAE J1455		N/A	N/A
Tacholink Millennium	Cab Mount	GPS, GSM, DriverTag	$1490 +$790 GPS +$920 GSM +$1,835 GPS/GSM	$19 DriverTag (ID only) $48 DriverTag (256 trip memory)
Video EDRs				
Road Recorder 6000	Cab Mount		$6,500	$200-$600 B&W Camera $350-$750 Color Camera

Systems	Level of "Hardening"	Additional Capabilities	Cost	Additional Costs Required
DriveCam Video EDR	Cab Mount	Front- and Rear-Facing Lenses	$1,000 (dual lenses)	$100 Software
CarCam	Cab Mount		$100	
ABS ECUs				
Bendix Tractor ABS ECU	SAE J1455	Tractor ABS	Included w/ tractor ABS	
Meritor WABCO Tractor ABS ECU	SAE J1455	Tractor ABS	Included w/ tractor ABS	
Haldex Trailer ABS ECU	SAE J1455	Trailer ABS	Included w/ trailer ABS	
Wabash Trailer ABS ECU	SAE J1455	Trailer ABS	Included w/ trailer ABS	

N/A – Data not available or proprietary

In Exhibit B.10, most systems are designed to be either mounted in the cab of the vehicle or designed to meet the "hardening" environmental standards of the SAE J1455 standard for heavy-duty vehicles.[39]

The costs in Exhibit B.10 also vary, with many of the systems having additional or optional components that can significantly add to the cost.

[39] *SAE J1455 "Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-duty trucks)" – This SAE Recommended Practice includes test methods used to simulate climatic, dynamic, electrical environmental conditions from natural and vehicle-induced sources that influence the performance and reliability of vehicle and tractor/trailer electronic components. This guideline is intended to aid the designer of automotive electronic systems and components by providing material that may be used to develop environmental design goals.*

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