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EDR Technology

An Interactive Qualifying Project Report

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by

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Abstract

Safety has always been the biggest priority of automobile manufactures. There have been constant advancements in technology to make vehicles a safe as possible. The evolution of Event Data Recorders has been a big step towards this goal. Event Data Recorders can provide information which can help in improving the existing technology for a safer tomorrow. This paper discusses the basic understanding of Event Data Recorders and how their use can be beneficial for the society.

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1 INTRODUCTION

Man has come a long way from the time he first invented the wheel around 4000-3500 BC. At that time man would have failed to realize what his invention would mean with the passage of time. Each era has brought new innovation to the transportation industry. Our way of living, the demands placed on us by our surroundings, the value of time have all worked hand-in-hand to get us where we are today in terms of the fast-paced evolution of the transportation sector. Earlier having a mode of transportation was the aim. After man explored and conquered his quest to travel on land, water and air, he moved to toy with enhancements. It was not long before he realized the value and importance of safety.

Whether it is aircrafts, ships, trains or cars, safety is of utmost importance. Even comfort and convenience should take back seat to safety. The invention of seat belts, air bags, anti-lock brake system and many more safety features became a necessity. Consumer demand and competition began a journey with a goal of consumer satisfaction and safety as being the priority. Soon the geniuses of technological invention realized that in order to create safer and better vehicles, they needed to understand the point of failure. Understanding of what caused an accident, and how it could have been prevented became the focal point.

> *"The fundamental purpose of investigating accidents is to determine the circumstances and causes of the accident with a view to the preservation of life and the avoidance of accidents in the future; It is not to apportion blame or liability". (1)*

1.1 Introduction to Flight Data Recorders

One big step towards increasing safety in transportation came with the evolution of Flight Data Recorders (FDRs). FDRs were introduced to understand the circumstances and causes of crashes. Flight Data Recorders date back to 1940's but very little progress was made till 1958 after which a minimum operating requirement for a FDR was established. The initial requirement was to record aircraft heading, altitude, airspeed, vertical acceleration and time. This first generation of flight data recorders used a metal foil as a medium of recording. One single strip was capable or recording 200 to 400 hours of data. This information alone could not provide all crash related information needed by the investigators. This gave rise to Cockpit Voice Recorder (CVR) technology which recorded sounds in the cockpit, air traffic control communications, crew conversations and engine noises. *(1)* In 1965, all commercial aircraft operators were required to install a CVR which would record the last 30 minutes of communication and noises within the cockpit environment. The second generation of FDRs came around 1970's. This generation of FDRs solved the problem of handling huge amounts of information coming from various sensors of the airplane. These FDR's had Flight Data Acquisition Units (FDAUs) which process sensor data, then digitized and formatted it so it could be transmitted to the FDR. These digital FDRs, or DFDRs, used tape (like audio tape) 300 to 500 ft long capable of recording 25 hours of data. These DFDRs could usually store up to 18 input parameters. In 1991 another rule changed which required the installation of digital FDAUs with DFDRs, using solid state memory. *(2)* This system recorded upto 34 parameters and was capable of processing 100 different sensor signals per second for a 25 hour period. Today Boeing, for example, uses DFDR systems on current production models which will store 64 12 - bit words per second over a 25 hour period. *(2)* This data is stored in electronic memory. When the 25 hour period is up the DFDR starts recording over the oldest data, so no tape removal is ever needed which saves on maintenance time and cost.*(2)*

FDRs collect data from different sensors in the airplane. Some of the typical data elements collected by an FDR are *(2)*:

- Time,
- Altitude,
- Air speed,
- Vertical acceleration,
- Heading,
- Time of each radio transmission, either to or from air traffic control,
- Pitch attitude,
- Roll attitude,
- Longitudinal acceleration,
- Thrust of each engine,
- Control column or pitch control surface position,

Using this data, investigators can analyze different factors that contributed to the crash. This data can also help prevent a crash in future by identifying mechanical malfunctions or pilot error that can be corrected through training on training.

The FDR or CVR is enclosed in a titanium box with heat insulation, such that it can withstand temperatures upto 1100° C for a 30 minute period and 260° C for 10 hours. The FDR must also be able to withstand a number of shock, vibration, impact, crush, pressure and fluid immersion tests, before it is allowed to go into service. FDRs are colored bright yellow or orange so that they can be easily located at the crash site. All recent flight recorders are equipped with Underwater Locator Beacons (ULBs) which assist locating the recorders if the crash is over water. The "pinger" as it's called is activated when the recorder is immersed in water. The signal transmitted is acoustical, with a frequency of 37.5 kHz, and can be detected with a special receiver. The signal can be detected from as deep down as 14,000 feet. *(2)*

FDRs have proved their worth over the decades. Airline accident rates have dropped dramatically over the last four decades. For instance, in 1960 there were 0.012 fatal accidents per million aircraft miles flown. In 1970, the number had dropped to 0.001, and by 1998 had dropped again to 0.0002, one-sixtieth the fatal accident rate of 1960. *(1)* Looking at these statistics we can see that the use of FDRs and analyzing the data collected by them has had a substantial effect on the air traffic safety over the years.

1.2 Introduction to EDRs

According to National Safety Council statistics, motor vehicle crashes are the leading cause of death between the ages of one and 33 in the U.S. *(3).* There is a death caused by a motor vehicle crash every 12 minutes and a disabling injury every 14 seconds. These crashes, and the injuries and fatalities they cause, are the nation's largest public health problem. *(3)* Since the first road crash fatality in 1896, motor vehicles have claimed an estimated 30 million lives globally. On average, someone dies in a motor vehicle crash each minute worldwide. *(3)* The concept of FDRs in aircrafts gave rise to the use of Event Data Recorders (EDRs) in automobiles. The evolution of EDRs was a big step towards automobile safety. The introduction of Event Data Recorders (EDRs) has contributed towards analyzing and understanding pre and post – crash scenarios. It has also aided in making vehicles more safe and reliable. Before the invention of EDRs it was very difficult to obtain information about how an accident happened and what factors contributed towards it. Some of the evidence that the investigators look for at a collision site are about injuries to the passengers, damage to the vehicle, and damage to the surroundings. Earlier it was very difficult to retrieve such information. Obtaining pre-crash information was very hard; investigators had to depend to a great extent on the driver or the passenger's word. Determining factors like whether the seat belt was in use or not is very difficult because often passenger's claim using seat belts when they are not.

The initial research into EDRs for the automobile industry was started in the 1970's by the National Highway and Traffic Safety Administration (NHTSA). These EDRs, called *Disc Recorders*, used analog signal processing and recording devices to analyze and store the crash data. In 1974 General Motors (GM) introduced the first regular production driver and passenger airbag systems in selected vehicles. These units contained data-sensing features for deploying air bags in severe crashes. *(4)* Since 1974, General Motors' (GM) airbag equipped vehicles have recorded airbag status and crash severity data that caused the deployment of the air bag. Many of these systems also recorded data during "near-deployment" events (i.e., impacts that are not severe enough to deploy the airbag). This information has been used to improve the performance of airbag sensing systems and understand the field performance of alternative airbag system designs.

1.2.1 GM Sensing Diagnostic Module

In 1994 model year GM introduced a combination of a single solid state analog accelerometer and a computer algorithm integrated in a Sensing and Diagnostic Module (SDM) was introduced. The SDM also computed and stored the change in longitudinal vehicle velocity (D V) during the impact to provide an estimate of crash severity. The SDM allowed GM engineers to obtain data when a vehicle was involved in a deployment event or experienced an impact related change in longitudinal velocity but did not command deployment (i.e., a near-deployment event). The SDM also added the capability to record the status of the driver's seat belt switch (i.e., buckled or unbuckled) for deployment and near-deployment events. Beginning with the 1999 model year, the capability to record pre-crash vehicle speed, engine RPM, throttle position, and brake switch on/off status has been added to some GM vehicles. *(5)* Some of the features that the 1999 SDM provided were: *(5)*

- State of Warning Indicator when event occurred (ON/OFF),
- Length of time the warning lamp was illuminated,
- Crash-sensing activation times or sensing criteria met,
- Time from vehicle impact to deployment,
- Diagnostic Trouble Codes present at the time of the event,
- Ignition cycle count at event time,
- Maximum DV for near-deployment event,
- DV vs. Time for frontal airbag deployment event,
- Time from vehicle impact to time of maximum DV,
- State of driver's seat belt switch,
- Time between near-deploy and deploy event if within 5 seconds,
- Passenger's airbag enabled or disabled state,
- Engine speed (5 sec before impact),
- Vehicle speed (5 sec before impact),
- Brake status (5 sec before impact) and
- Throttle position (5 sec before impact).

The block diagram shown in Figure 1 shows the functionality of the 1999 GM SDM System.

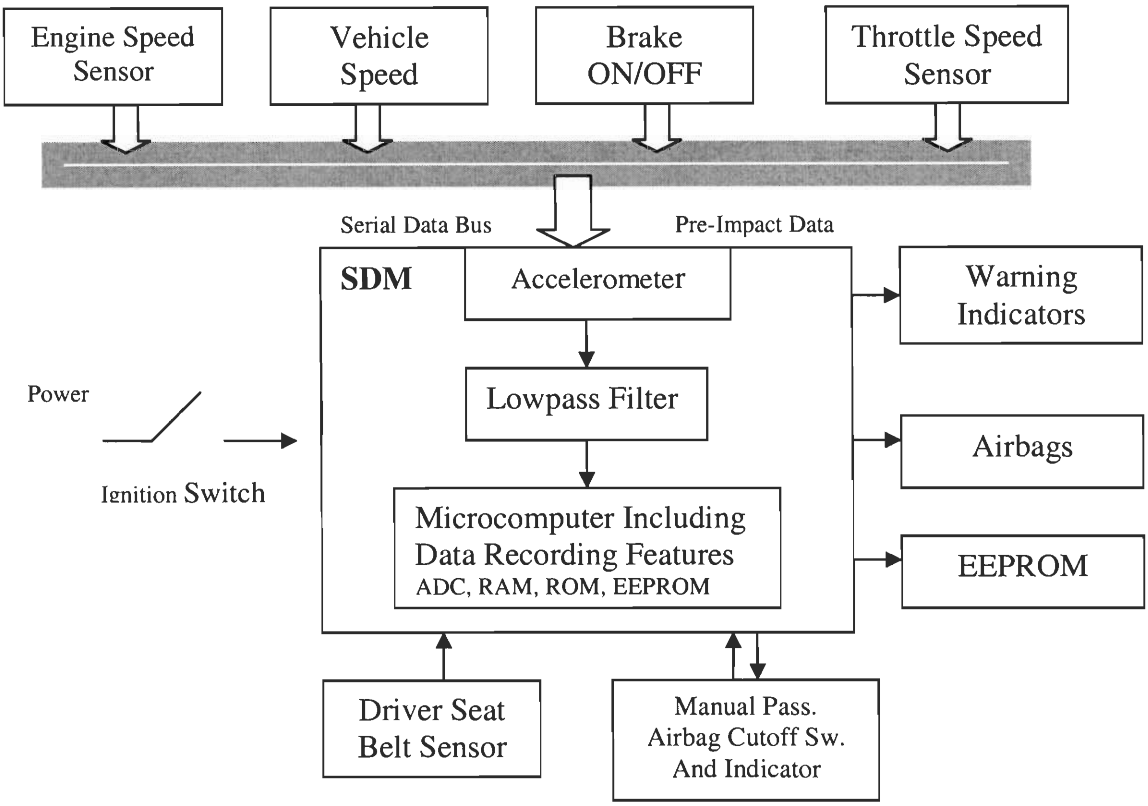


Figure 1: Simplified Block Diagram for the GM 1999 System *(5)*

The algorithm for the SDM makes the airbag deployment decisions within 15 – 50 msec after the impact. There are several other sensors that provide the engine speed, vehicle speed, throttle speed, and brake ON/OFF status. These sensors are monitored by various electronically controlled modules which feed the data into the SDM. The driver seat belt sensor is a direct input into to the SDM. If there is an airbag deployment, the Electrically Erasable Programmable Read-Only Memory (EEPROM) immediately stores the last five seconds of data. This data can be retrieved later by connection a laptop PC equipped with appropriate software and interface hardware. *(5)*

By 1990, GM added Diagnostic and Energy Reserve Module (DERM) technology to record closure times for arming and discriminating sensors as well as any fault code present at the time of deployment of the air bag. During the 1990's GM installed sophisticated crash data recorders on 70 Indy Formula One racecars. *(4)*

1.2.2 Ford Restraint Control Module

Ford started installing its Restraint Control Module (RCM) in the 1997 model year. *(4)* The primary purpose of the RCM is to control the deployment of occupant safety systems, such as air bags, seat belt pre-tensioners, etc. Ford introduced a more advanced RCM in its latest models. This system records lateral and longitudinal acceleration along with data related to driver and passenger air bag deployment including: deployment strategy of the dual – stage air bag system, seat belt use, pre-tensioner operation, and driver seat position. *(4)* This system was first introduced on the 2000 Ford Taurus and Mercury Sable. This system is now available on the following 2002 model vehicles: *(6)*

- Ford Explorer,
- Taurus,
- Focus,
- Windstar,
- Crown Victoria,
- Mercury Mountaineer,
- Sable,
- Grand Marquis,
- Lincoln Town Car,
- Jaguar XK8.

This safety system works with a group of sensors that feed crash-related information to the restraint control module. These sensors detect various data elements such as how close the driver is to the steering wheel, if the driver and/or front seat passenger is wearing a seat belt, and the severity of the collision. The RCM then accordingly decides which restraints to deploy. A weight sensor in the front passenger seat determines if the passenger airbag should deploy at all. If the sensor detects a small occupant, such as a child, or does not detect a passenger, the system will automatically turn off the front passenger airbag. A warning light illuminates, cautioning that the system is deactivated. Based on the circumstances, the system adjusts the rate of deployment of the airbags to enhance the protection of the front seat passengers. It does this with the help of several parts, including: *(6)*

- An electronic crash severity sensor. This sensor sends information to the RCM about the severity of the impact. This sensor is located at the front of the vehicle.
- A restraint control module. The RCM determines the appropriate energy level to inflate the airbags, and whether to activate the seat belt pre-tensioners. It is located under the instrument panel at the front of the passenger compartment.
- Dual-stage driver and front passenger airbags. This dual-stage sensor deploys airbags with low pressure (Stage 1) or high pressure (Stage 2), depending on the severity of the collision. This helps to reduce injuries due to airbag inflation.
- A driver's seat position sensor. This sensor tells the RCM how close the driver is to the steering wheel. It also determines whether the airbag will deploy with full force or at a lower pressure depending on the position of the driver. This also helps in reducing injuries.
- Front outboard seat belt usage sensors. These sensors determine if the driver and front passenger seat belts are buckled. If the occupants are not buckled during high speeds, the airbags will need to deploy with greater pressure. If the occupants are buckled during low speeds, the airbags can deploy at a lower pressure. This again helps to reduce the risk of airbag-related injuries.
- Front outboard seat belt pre-tensioners. The front outboard pre-tensioners cause the front seat belts to tighten firmly against the occupants before the airbag deploys. This helps to reduce the force of the belt on the occupants and holds them in position at the start of airbag deployment.

- Front outboard seat belt energy management retractors. These retractors let the seat belts lose once the seat belts have restrained the front passengers. This reduces the force of the belts on the occupants' chest, allowing them to ease into the airbag.

1.2.3 Automatic Collision Notification

In 1990's, NHTSA started a new program that combined EDRs with Automated Collision Notification (ACN) technology. *(4)* ACN technology provided faster and smarter emergency medical services in an attempt to save lives and reduce disabilities from injuries. This system determined a crash had occurred, initiated a request for assistance, determined the location of the vehicle, used a wireless communication system to send crash notification, and stored crash-data in its memory for post-crash investigations. Approximately 700 vehicles were equipped with this prototype technology and about 15 crashes were detected. *(4)* Figure 2 shows the basic working diagram of the CAN system.

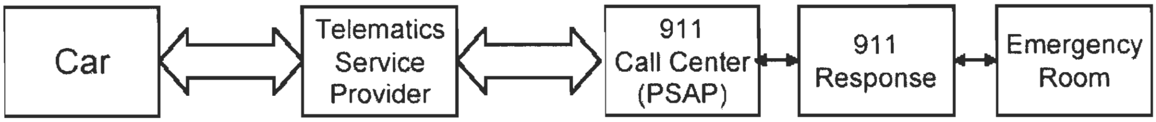


Figure 2: ACN System *(7)*

1.2.4 Crash Collecting Programs

NHTSA has three major crash data collecting programs:

- NASS – CDS →A national statistically sampled data base,
- SCI → A collection of targeted crash investigations looking at emerging safety issues, and
- CIREN → A system of crash investigations conducted at hospitals.

NHTSA's crash data investigation teams collect data from two OEMs GM and Ford vehicles. EDR data has proved vital in the performance of advanced occupant protection system. EDRs are also used to verify and supplement crash severity indicators. *(4)*

1.3 On-Vehicle Networks

The SDM system mentioned above is just one of the many different EDR modules present. There are many other systems present in a modern vehicle which retrieve a lot of other information. All the inputs to the EDR are from on-vehicle networks, associated on-board microcontrollers, and sensors. These on-board networks, such as Control Area Network (CAN), Local Interconnect Network (LIN) Protocol, On–Board Diagnostic System (OBD II), and others are communication pathways between microprocessors which control several safety related systems including ABS (anti-lock braking), cruise control, and the power train. Microprocessors on the CAN bus have access to the hosts of other sensors, such as headlights (indicates lighting conditions), windshield wipers (indicates weather conditions), power door locks (ejection prevention), time of the day, and others. There are some other sensors which are accessible only through a lower speed sub-bus such as LIN which in some cars connects with CAN bus.

1.3.1 CAN Bus

Control Area Network (CAN) was initially created by German automotive system supplier Robert Bosch in mid-1980s for automotive applications as a method for enabling robust serial communication. The goal was to make automobiles more reliable, safe and fuel-efficient while decreasing wiring harness weight and complexity.

CAN Bus is high-integrity serial data communications bus for real-time applications. It is especially suited for networking devices as well as sensors or actuators within a system or a sub-system. Its basic design specification called for a high bit rate, high immunity to electrical interference and an ability to detect any errors produced. Not surprisingly due to these features, the CAN serial communications bus has become widely used throughout the automotive, manufacturing and aerospace industries. One of the outstanding features of the CAN protocol is its high transmission reliability. Some of the car manufactures in the US use CAN in power-engine applications. CAN networks used in engine management connect several Electronic Control Units (ECUs). Daimler-Benz was the first manufacturer to implement CAN. DaimlerChrysler, Ford, and General Motors are heavily involved in CAN network developments. In the Far East, Toyota has already implemented CAN. Some of the applications that CAN controls are, lighting control units, air-conditioning system, door internal networking, and embedded seat control. DaimlerChrysler has announced the CAN-connected Sensortronic Brake System (SBS). The SBS has sensors of the ABS (antilock braking system) and the EPS (electronic stability program) in such a way that the system's micro-controller calculates the ideal braking pressure depending on the situation. The electronically controlled hydraulic brake requires information on wheel speed, steering wheel angle, transverse acceleration, and rotary motion. This data is communicated via the CAN-based in-vehicle networks. Based on this data the micro-controllers compute the optimal braking pressure individually for each wheel. The performance of ABS, ESP, and ASC (automatic slip control) will be increased as well. The use of a high-pressure accumulator means that the braking enhancement is no longer dependent on the vacuum created by the engine. There are many other units also which are controlled by the CAN bus network. Presently, CAN is the major communication standard in vehicle networking. *(8)*

1.3.2 LIN BUS

LIN (Local Interconnect Network) is a new low cost serial communication system intended to be used for distributed electronic systems in vehicles. It is a lower speed bus as compared to the CAN bus. The LIN Protocol is designed to communicate low-rate data such as switch positions at the lowest possible cost. It will be used for simple on-off devices such as car seats, door locks, sun roofs, rain sensors, HVAC flaps, cruise control, windshield wipers and mirrors, and any other application where high speed is not a requisite. The network within the door connects the window motor, door lock actuator, side view mirror motors, and external keypad to the main controller. Since these devices are accessed infrequently and do not require constant monitoring, the LIN bus can be a cost-effective bus to use. Typical applications for the LIN bus are assembly units such as doors, steering wheel, seats, climate regulation, lighting, rain sensor, or alternator. In these units the cost sensitive nature of LIN enables the introduction of elements such as smart sensors, actuators, or illumination. They can be easily connected to the car network and become accessible to all types of diagnostics and services. Some of the typical applications of LIN are shown in the figure 3.

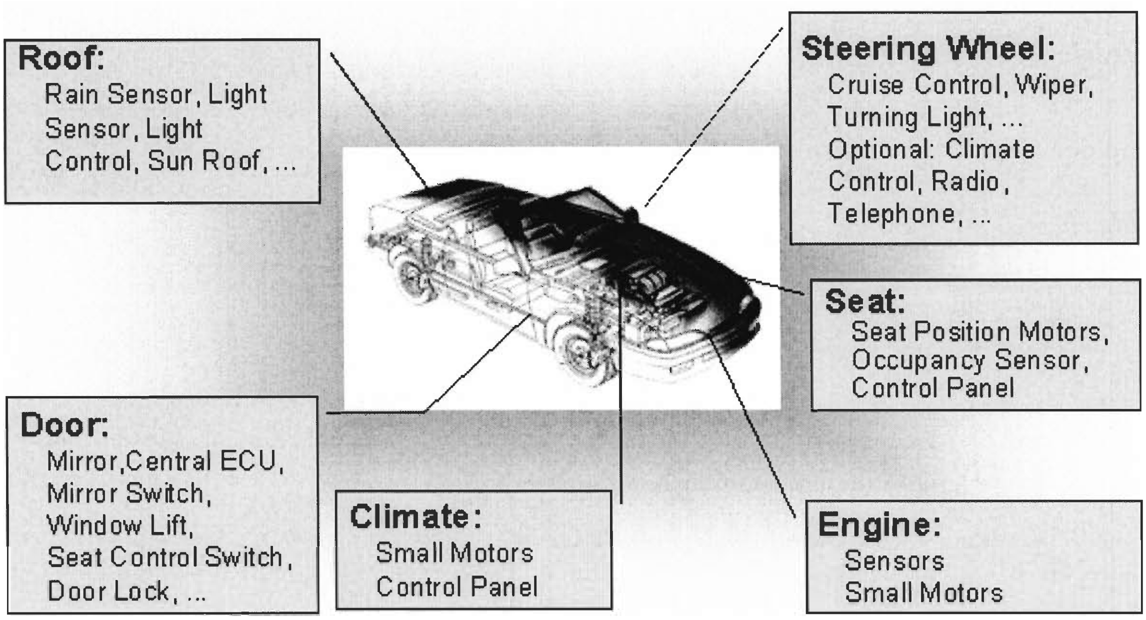


Figure 3: Typical Applications for LIN *(9)*

1.3.3 OBD II

On-Board Diagnostic System present in most of the cars and light trucks on the road today. OBD introduced in the mid-nineties, provides almost complete engine control and also monitors parts of the chassis, body and accessory devices, as well as the diagnostic control network of the car. All cars manufactured since January 1, 1996 have OBD-II systems. 1994 vehicles equipped with the early OBD II systems include Buick Regal 3800 V6, Corvette, Lexus ES3000, Toyota Camry (1MZ-FE 3.0L V6) and T100 pickup (3RZ-FE 2.7L four), Ford Thunderbird & Cougar 4.6L V8, and Mustang 3.8L V6. 1995 vehicles with OBDII include Chevy/GMC S, T-Series pickups, Blazer and Jimmy 4.3L V6, Ford Contour & Mercury Mystique 2.0L four & 2.6L V6, Chrysler Neon, Cirrus and Dodge Stratus, Eagle Talon 2.0L DOHC (non-turbo), and Nissan Maxima and 240 SX. Not all of these early applications are fully OBDII compliant, but do include the major diagnostic features of the current system. *(10)* OBD - II is strictly emissions oriented. In other words, it will illuminate the Malfunction Indicator Lamp (MIL) anytime a vehicle's hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOX) or evaporative emissions exceed 1.5 times the federal test procedure (FTP) standards for that model year of vehicle. That includes anytime random misfires that causes an overall rise in HC emissions, anytime the operating efficiency of the catalytic converter drops below a certain threshold, anytime the system detects air leakage in the sealed fuel system, anytime a fault in the EGR system causes NOX emissions to go up, or anytime a key sensor or other emission control device fails. In other words, the MIL light may come on even though the vehicle seems to be running normally and there are no real drivability problems. The main purpose of the MIL lamp on an OBDII-equipped vehicle, therefore, is to alert motorists when their vehicles are polluting so they'll get their emission problems fixed. Some of the OBD – II generic parameters are *(11):*

- A/C System Refrigerant Monitoring Status,
- Auxiliary Input Status,
- Catalyst Monitoring Status,
- Comprehensive Component Monitoring Status,
- ECT (Engine Coolant Temperature),
- EGR (Exhaust Gas Recirculation) System Monitoring Status,
- Engine Load,
- Engine Speed,
- EVAP Vent Solenoid Command,
- Evaporative System Monitoring Status,
- Fuel Pressure,
- Fuel System Monitoring Status,
- Fuel System Status Bank 1,
- Heated Catalyst Monitoring Status,
- IAT (Intake Air Temperature),
- Ignition Timing,
- MAF (Mass Air Flow),
- MAP (Manifold Absolute Pressure),
- Misfire Monitoring Status,

- Oxygen Sensor Heater Monitoring Status,
- Oxygen Sensor Monitoring Status,
- Secondary Air System Monitoring Status,
- Throttle Position,
- Vehicle Speed.

1.4 EDR and On-Vehicle Network Interaction

On–vehicle networks control the entire working of the vehicle; they connect different parts of the vehicle such that they can work simultaneously. EDRs are on-board recorders and thus all the information they can access is from the various on-vehicle networks. Some of the data elements that EDRs have are *(12)*:

- Lateral, longitudinal, and vertical acceleration,
- Heading,
- Vehicle and engine speed,
- Engine throttle,
- Driver's seat belt status and status of additional seat belts,
- Crash pulse information,
- Braking and steering input,
- Gear Selection,
- Turn signal, brake light, head/tail light, and hazard light status,
- Brake system status,
- Passenger and door status,
- Cruise control status,
- Airbag deployment criteria, time, and energy,
- Location and time of the crash, and
- Automatic collision data notification (ACN).

The parameters listed above are some of the data elements which can be retrieved from EDRs. The control systems of all these parameters are managed by various on-vehicle networks. Yet, there are many other parameters which can be obtained from on-vehicle networks that can help in making EDRs even more useful for future. This project is geared towards acquiring data elements which can by added to future EDRs so that they help in increasing highway safety in future.

2 METHODOLOGY

Objectives

The main objectives of this project and the proposed approach to achieve these objectives are discussed in this chapter. The main intent of this project is to expand existing on-vehicle network and Event Data Recorder (EDR) interface such that it can help making EDRs more useful for future.

2.1 Research on EDRs

The basic approach for this project will be to understand the working of EDRs and how they can be improved. For this it will be important to have an understanding of the following:

- How current EDRs function.
- Various features they have in the current generation of EDRs.
- How these features help in analyzing crash scenarios,

2.2 Research on On-Vehicle Networks

To understand the working of EDRs it is essential to understand on-vehicle networks which control the EDRs. This will be achieved by understand the following:

- Different types of on-vehicle networks that control the working of the vehicle.
- What are the various systems controlled by on-vehicle networks.
- Having knowledge of different on-vehicle network manufactures will be indispensable for understanding the various on-vehicle networks.

2.3 Analyze EDR data

This project is geared towards making EDRs more useful for future. Thus, it is very important to analyze EDR data and see what features have helped in making vehicles safer and what more can be added to it. This research will be performed using:

- Crash data retrieval systems,
- NHTSA's EDR working groups, and
- Current crash data collecting programs.

2.4 Improving EDRs

The next step after analyzing EDR crash data will be to look into additional features that can be added to EDRs to help make vehicles safer. This is possible by expanding on-vehicle network/EDR interface such that more data can be retrieved from EDRs. As mentioned before, a strong handle on the working of EDRs and various on-vehicle networks is essential to expand on-vehicle network/EDR interface.

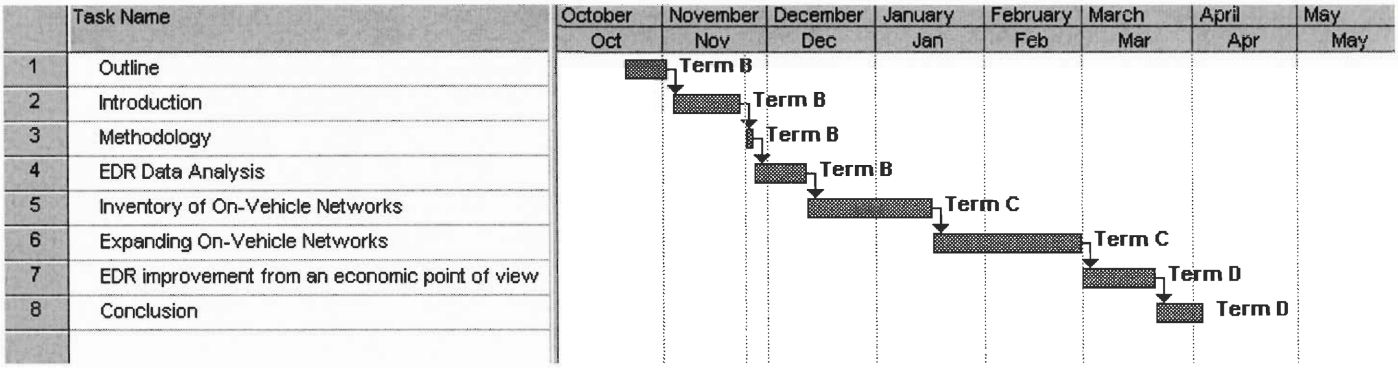
2.5 Cost Analysis

Lastly, it will be imperative to understand this project from an economics point of view. It will be important to look into:

- Cost of production of EDRs,
- Cost to improve EDRs based on our research,

To estimate these costs it will be decisive to look into EDR manufacturing costs. It will also be interesting to see the impact of improved EDRs on the automotive market. This can be analyzed be performing surveys to see if people are willing to pay a little extra for a vehicle with an improved EDR.

The following Gantt Chart shows how I plan to work on this project over three terms.



	Task Name
1	Outline
2	Introduction
3	Methodology
4	EDR Data Analysis
5	Inventory of On-Vehicle Networks
6	Expanding On-Vehicle Networks
7	EDR improvement from an economic point of view
8	Conclusion

3 ANALYZING EDR DATA

Understanding and analyzing the data from an EDR is very important. This chapter discusses a few crash data retrieval system and how the data collected from these systems is used by manufactures to enhance safety measures in vehicles. This chapter also discusses about different crash collecting programs and some statistics collected through them.

3.1 Crash Data Retrieval System

3.1.1 Vetronix Crash Data Retrieval System

The Vetronix Crash Data Retrieval (CDR) System downloads pre- and post-crash data from the vehicle's airbag module. The CDR software is Windows based and in an easy-to-understand format. The airbag module is the vehicle's "computer" that controls airbag deployment. Since 1990, recordable airbag modules were installed in selected GM vehicles. A list of key features of the Vetronix CDR system is shown in the table below.

Pre – Crash Data	**Post – Crash Data**	**Data Summary Table**
• Brake status (on/off) 5 second before impact • Vehicle speed 5 seconds before impact • Engine Speed 5 seconds before impact • Throttle open percent 5 seconds before impact	• User friendly help files with access to on-line technical support • *delta*V vs. time for frontal airbag deployment event.	• State of the warning lamp when event occurred • State of driver's seat belt switch at impact • Pre- and post-crash data displayed in easy-to-read tabular format • Time from vehicle impact to deployment

Figure 4: Key Features of Vetronix CDR System *(13)*

The following figures show some of the graphs generated by the Vetronix CDR System.

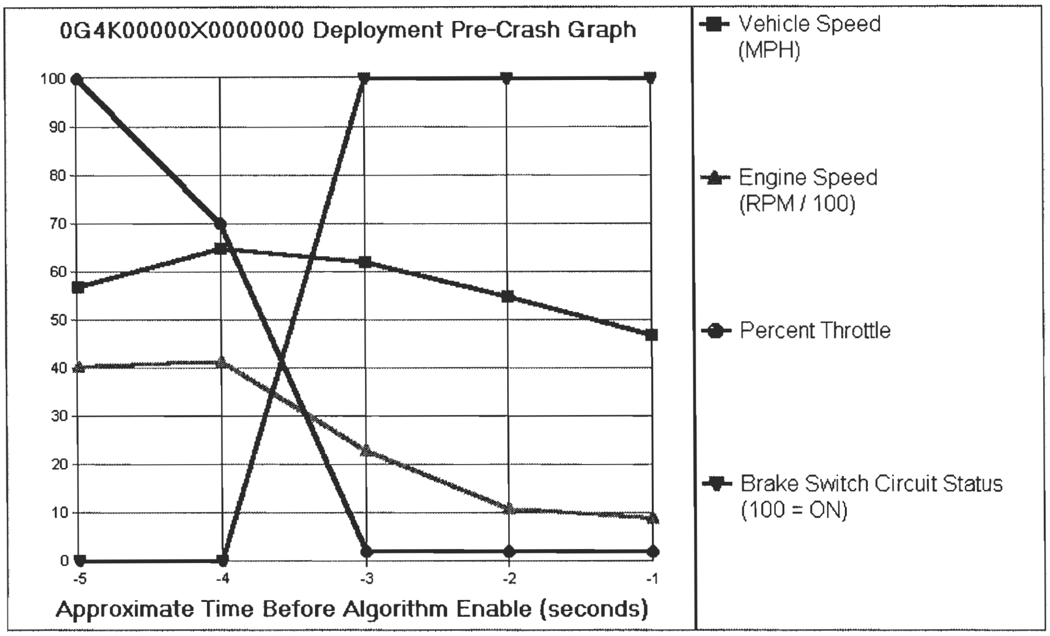


Figure 5: Deployment Pre-Crash Graph *(13)*

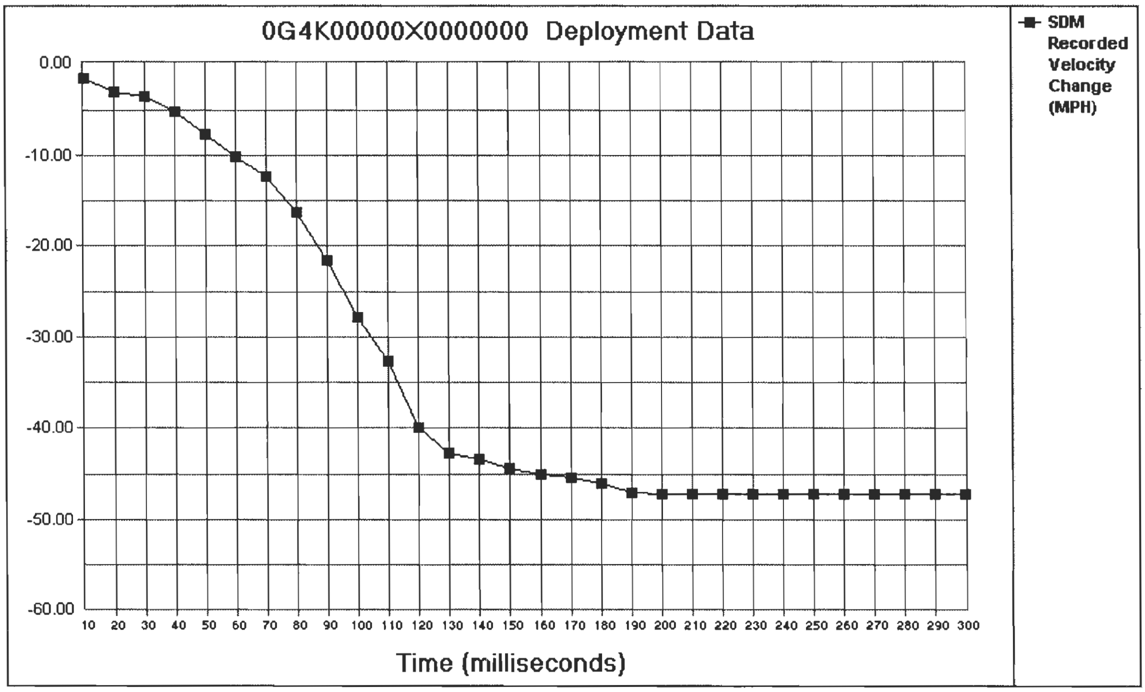
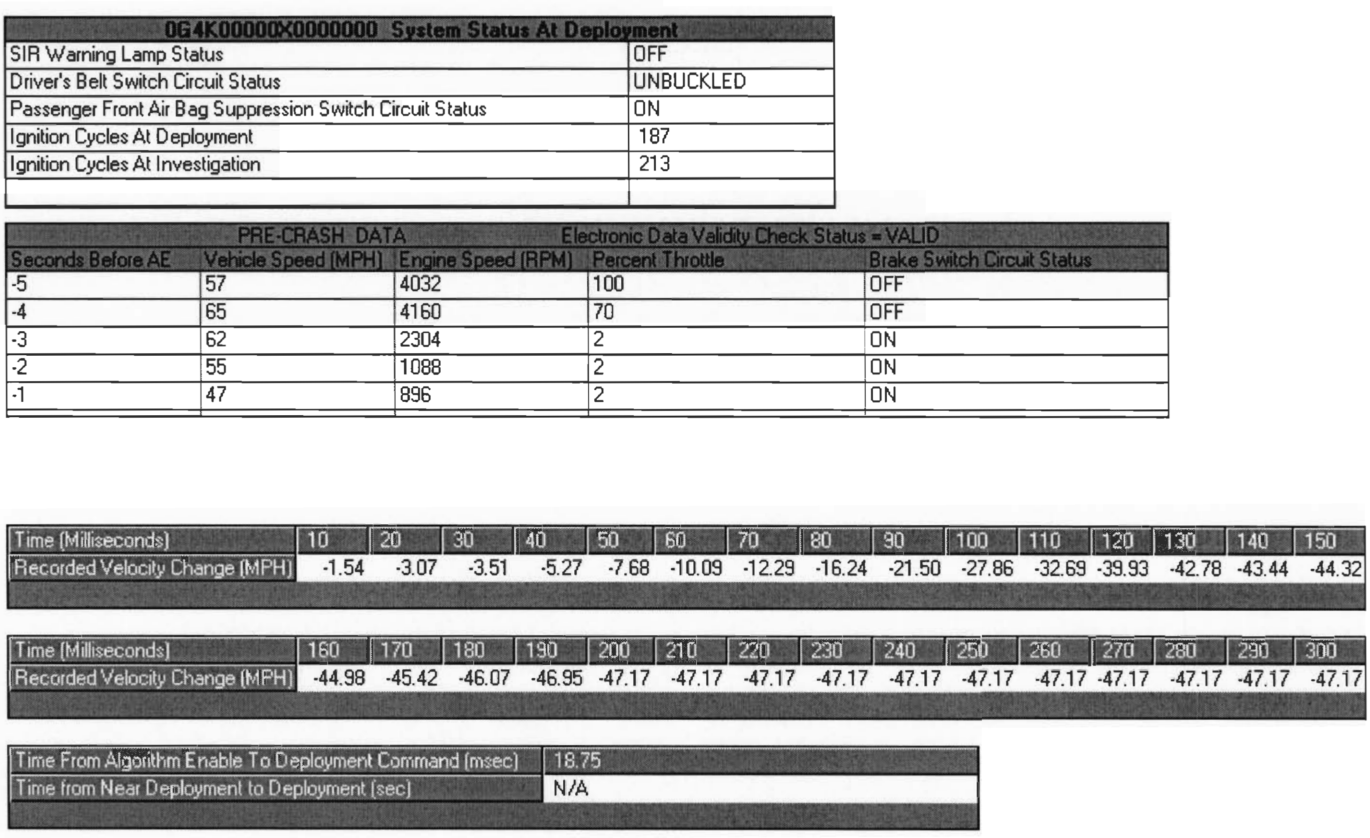


Figure 6: Deployment Data *(13)*



0G4K00000X0000000 System Status At Deployment	
SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Passenger Front Air Bag Suppression Switch Circuit Status	ON
Ignition Cycles At Deployment	187
Ignition Cycles At Investigation	213

PRE-CRASH DATA Electronic Data Validity Check Status = VALID

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	57	4032	100	OFF
-4	65	4160	70	OFF
-3	62	2304	2	ON
-2	55	1088	2	ON
-1	47	896	2	ON

Time (Milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Recorded Velocity Change (MPH)	-1.54	-3.07	-3.51	-5.27	-7.68	-10.09	-12.29	-16.24	-21.50	-27.86	-32.69	-39.93	-42.78	-43.44	-44.32

Time (Milliseconds)	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300
Recorded Velocity Change (MPH)	-44.98	-45.42	-46.07	-46.95	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17	-47.17

Time From Algorithm Enable To Deployment Command (msec)	18.75
Time from Near Deployment to Deployment (sec)	N/A

Figure 7: System Status at Deployment ***(13)***

The following table shows all the GM vehicles that are supported by Vetronix's Crash Data Retrieval System.

1996		1997		1998		1999	
Make	**Model**	**Make**	**Model**	**Make**	**Model**	**Make**	**Model**
Buick	Riviera	Buick	Century	Buick	Century	Buick	Century
Buick	Skylark	Buick	LeSabre	Buick	LeSabre	Buick	LeSabre
Chevrolet	Astro	Buick	ParkAvenue	Buick	ParkAvenue	Buick	ParkAvenue
Chevrolet	Camaro	Buick	Regal	Buick	Regal	Buick	Regal
Chevrolet	Cavalier	Buick	Riviera	Buick	Riviera	Buick	Riviera
Chevrolet	Express	Buick	Skylark	Buick	Skylark	Cadillac	Commercial
GMC	Safari	Cadillac	Commercial	Cadillac	Commercial		Special
GMC	Savana	Cadillac	Special		Special	Cadillac	Deville
Oldsmobile	Achieva	Cadillac	Deville	Cadillac	Deville	Cadillac	Eldorado
Oldsmobile	Aurora	Cadillac	Eldorado	Cadillac	Eldorado	Cadillac	Seville
Pontiac	Firebird	Chevrolet	Seville	Cadillac	Seville	Cadillac	Escalade
Pontiac	GrandAM	Chevrolet	Astro	Chevrolet	Astro	Chevrolet	Astro
Pontiac	Sunfire	Chevrolet	Camaro	Chevrolet	Blazer	Chevrolet	Blazer
Saturn	All models	Chevrolet	Cavalier	Chevrolet	Camaro	Chevrolet	Camaro
		Chevrolet	Corvette	Chevrolet	Cavalier	Chevrolet	Cavalier
		Chevrolet	Express	Chevrolet	Corvette	Chevrolet	Corvette
		Chevrolet	Lumina	Chevrolet	Express	Chevrolet	Express
		Chevrolet	Malibu	Chevrolet	Lumina	Chevrolet	Lumina
		Chevrolet	MonteCarlo	Chevrolet	S10	Chevrolet	S10
		Chevrolet	Silverado	Chevrolet	S10 Electric	Chevrolet	S10 Electric
		Chevrolet	Suburban	Chevrolet	Silverado	Chevrolet	Silverado
		Chevrolet	Tahoe	Chevrolet	Suburban	Chevrolet	Suburban
		GM	Venture EV1	Chevrolet	Tahoe	Chevrolet	Tahoe
		GMC	Safari	Chevrolet	Malibu	Chevrolet	Malibu
		GMC	Savana	Chevrolet	MonteCarlo	Chevrolet	MonteCarlo
		GMC	Sierra	GMC	Jimmy	GM	EV1
		GMC	Yukon	GMC	Safari	GMC	Jimmy
		Oldsmobile	Achieva	GMC	Savana	GMC	Safari
		Oldsmobile	Aurora	GMC	Sierra	GMC	Savana
		Oldsmobile	Cutlass	GMC	Yukon	GMC	Sierra
		Oldsmobile	EightyEight	GMC	Sonoma	GMC	Yukon
		Oldsmobile	Regency	Oldsmobile	Achieva	GMC	Sonoma
		Oldsmobile	Silhouette	Oldsmobile	Aurora	Oldsmobile	Alero
		Pontiac	Bonneville	Oldsmobile	Cutlass	Oldsmobile	Aurora
		Pontiac	Firebird	Oldsmobile	EightyEight	Oldsmobile	Cutlass
		Pontiac	Grand AM	Oldsmobile	Bravada	Oldsmobile	EightyEight
		Pontiac	Grand Prix	Oldsmobile	Intrigue	Oldsmobile	Bravada
		Pontiac	Sunfire	Pontiac	Bonneville	Oldsmobile	Intrigue
		Pontiac	Trans Sport	Pontiac	Firebird	Pontiac	Bonneville
		Saturn	All models	Pontiac	Grand AM	Pontiac	Firebird
				Pontiac	Grand Prix	Pontiac	Grand AM
				Pontiac	Sunfire	Pontiac	Grand Prix
				Saturn	All models	Pontiac	Sunfire
						Saturn	All models

2000		2001		2002	
Make	**Model**	**Make**	**Model**	**Make**	**Model**
Buick	Century	Buick	Century	Buick	Century
Buick	LeSabre	Buick	LeSabre	Buick	LeSabre
Buick	Park Avenue	Buick	Park Avenue	Buick	Park Avenue
Buick	Regal	Buick	Regal	Buick	Regal
Cadillac	Commercial Special	Buick	Rendezvous	Buick	Rendezvous
Cadillac	Deville	Cadillac	Commercial Special	Cadillac	Eldorado
Cadillac	Eldorado	Cadillac	Deville	Cadillac	Seville
Cadillac	Seville	Cadillac	Eldorado	Cadillac	Escalade
Cadillac	Escalade Astro	Cadillac	Seville	Chevrolet	Avalanche
Chevrolet	Blazer	Cadillac	Escalade Astro	Chevrolet	Astro
Chevrolet	Camaro	Chevrolet	Blazer	Chevrolet	Blazer
Chevrolet	Cavalier	Chevrolet	Camaro	Chevrolet	Camaro
Chevrolet	Corvette	Chevrolet	Cavalier	Chevrolet	Cavalier
Chevrolet	Express	Chevrolet	Corvette	Chevrolet	Corvette
Chevrolet	Impala	Chevrolet	Express	Chevrolet	Express
Chevrolet	Lumina	Chevrolet	Impala	Chevrolet	Impala
Chevrolet	S10	Chevrolet	Malibu	Chevrolet	Malibu
Chevrolet	Silverado	Chevrolet	S10	Chevrolet	S10
Chevrolet	Silverado	Chevrolet	Silverado	Chevrolet	Silverado
Chevrolet	Suburban	Chevrolet	Suburban	Chevrolet	Suburban
Chevrolet	Suburban	Chevrolet	Tahoe	Chevrolet	Tahoe
Chevrolet	Tahoe	Chevrolet	Trailblazer	Chevrolet	Trailblazer
Chevrolet	Tahoe	Chevrolet	Lumina	GMC	Envoy
Chevrolet	Malibu	Chevrolet	Venture	GMC	Safari
Chevrolet	MonteCarlo	Chevrolet	Jimmy	GMC	Savana
Chevrolet	Venture	GMC	Safari	GMC	Sierra
Chevrolet	Jimmy	GMC	Savana	GMC	Yukon
GMC	Safari	GMC	Sierra	GMC	Sonoma
GMC	Savana	GMC	Yukon	Isuzu	Hombre
GMC	Sierra	GMC	Sonoma	Oldsmobile	Alero
GMC	Sierra	GMC	Hombre	Oldsmobile	Aurora
GMC	Yukon	Isuzu	Alero	Oldsmobile	Bravada
GMC	Sonoma	Oldsmobile	Aurora	Oldsmobile	Intrigue
GMC	Yukon	Oldsmobile	Bravada	Pontiac	Aztek
GMC	Hombre	Oldsmobile	Intrigue	Pontiac	Bonneville
Isuzu	Alero	Oldsmobile	Silhouette	Pontiac	Firebird Grand
Oldsmobile	Bravada	Oldsmobile	Aztek	Pontiac	AM Grand Prix
Oldsmobile	Intrigue	Pontiac	Bonneville	Pontiac	Sunfire
Oldsmobile	Silhouette	Pontiac	Firebird Grand	Pontiac	All but LS
Oldsmobile	Firebird Grand	Pontiac	AM Grand Prix	Saturn	
Pontiac	AM Grand Prix	Pontiac	Sunfire		
Pontiac	Sunfire	Pontiac	Montana		
Pontiac	Montana	Pontiac	All but LS		
Pontiac	All but LS	Pontiac			
Pontiac		Saturn			
Saturn					

Figure 8: GM Vehicle Supported by Vetronix Crash Data Retrieval Tool *(13)*

3.1.2 Ford Data Retrieval System

The Ford system is different from the Vetronix CDR tool. The system allows the user to connect directly between a computer notebook and the vehicles diagnostic connector. The Ford tool cannot be connected directly to the RCM because it cannot simulate on-board bus or sensors. The RCM system is reusable. Unlike the GM system, the Ford RCM does not store the information in a permanent or incorruptible file. This software provides only a hexadecimal file which can be interpreted by the manufacturer only. In cases where the electrical system of the car has been damaged, the EDR box is removed and sent to Ford for downloading. *(14)* The Ford output provides crash pulse for both longitudinal and lateral axis. Figures 9 and 10 shows some sample data collected from Ford cars.

Longitudinal Cumulative Delta-V

Time (ms)	0	10	20	30	40	50	60	70	78
Delta-V (MPH)	-0.4	-2.3	-4.3	-5.9	-7.4	-10.3	-14.1	-16.2	-19.5

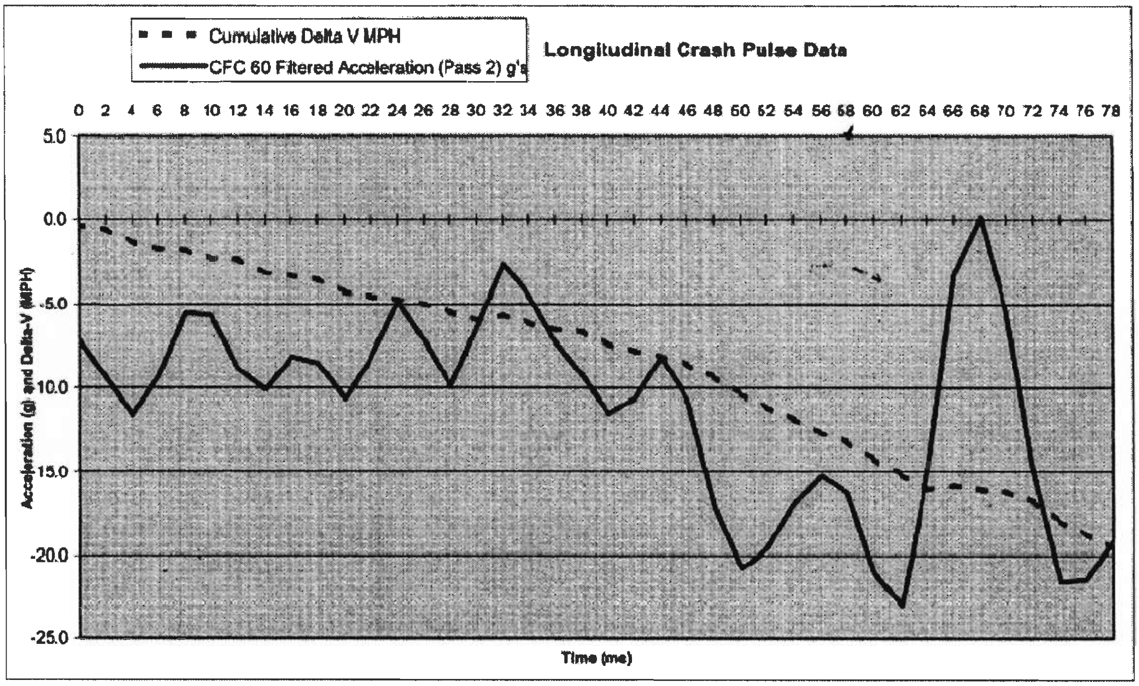
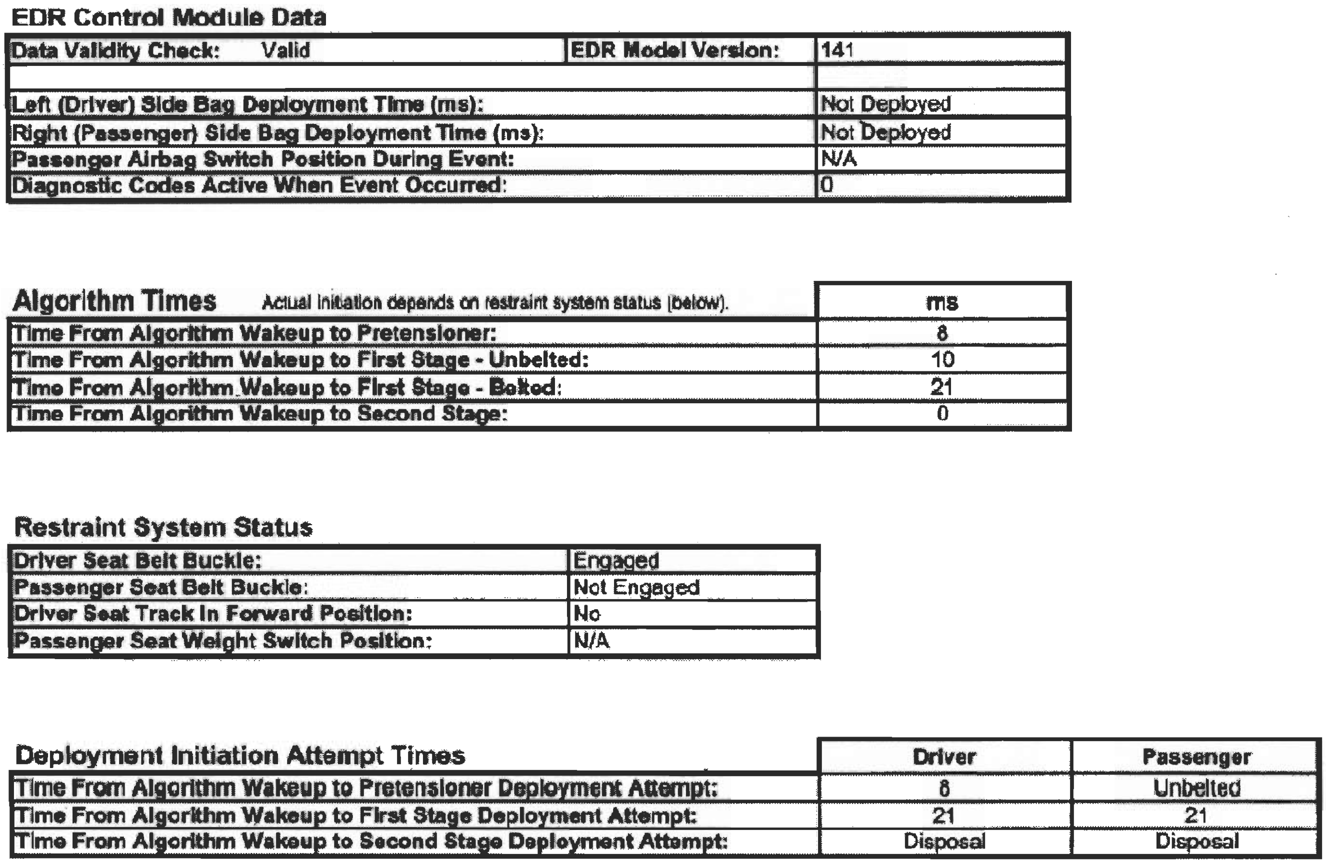


Figure 9: Longitudinal Crash Pulse Data *(14)*



EDR Control Module Data

Data Validity Check:	Valid	**EDR Model Version:**	141
Left (Driver) Side Bag Deployment Time (ms):			Not Deployed
Right (Passenger) Side Bag Deployment Time (ms):			Not Deployed
Passenger Airbag Switch Position During Event:			N/A
Diagnostic Codes Active When Event Occurred:			0

Algorithm Times Actual initiation depends on restraint system status (below).	ms
Time From Algorithm Wakeup to Pretensioner:	8
Time From Algorithm Wakeup to First Stage - Unbelted:	10
Time From Algorithm Wakeup to First Stage - Belted:	21
Time From Algorithm Wakeup to Second Stage:	0

Restraint System Status

Driver Seat Belt Buckle:	Engaged
Passenger Seat Belt Buckle:	Not Engaged
Driver Seat Track In Forward Position:	No
Passenger Seat Weight Switch Position:	N/A

Deployment Initiation Attempt Times	Driver	Passenger
Time From Algorithm Wakeup to Pretensioner Deployment Attempt:	8	Unbelted
Time From Algorithm Wakeup to First Stage Deployment Attempt:	21	21
Time From Algorithm Wakeup to Second Stage Deployment Attempt:	Disposal	Disposal

Figure 10: EDR Control Module Data *(14)*

3.2 Other Data Retrieval Tools

Aftermarket manufactures of the EDR technology include data retrieval systems as a part of their product. The output of the retrieval system is usually an industry accepted standard. Some aftermarket manufactures of data retrieval systems are: *(15)*

- Independent Witness Incorporated (IWI),
- DriveCam,
- Safety Intelligence Systems (SIS), and
- VDO – UDS.

3.2.1 Independent Witness Incorporated

The data stored by the IWI can be accessed immediately for verification at the scene of crash with the use of a notebook computer and required IWI interface tools. Once the data is retrieved, the information is downloaded to the internet and is accessible from the IWI website. *(15)* Some of the data elements that can be obtained by the IWI are: *(15)*

- Acceleration in three dimensions,
- G-force rating of the collision, and
- Delta V.

3.2.2 DriveCam

DriveCam is video event data recorder that can be mounted behind the rear view mirror. It continuously monitors driving activity by recording video, audio and four directions of G-forces into a digital looping memory. These elements can be played on a television or camcorder and can be recorded on videotapes or computer hard drive. *(17)*

Figure 11 shows the actual DriveCam unit. Some of the features of this unit are: *(17)*

- Digital memory,
- Adjustable sensors,
- Automatic and manually activated recordings,
- Full color video, and
- Tamperproof security key.

Figure 11: DriveCam Unit

3.2.3 Safety Intelligence Systems

The SIS MACBOX transmits the encrypted crash data over a digital wireless network. This data is then decoded and stored on a secure data storage facility. Data can be downloaded manually also from the vehicle incase of failure in transmission. *(15)* Some of the data elements of the MACBOX are: *(15)*

- Time,
- Data,
- Latitude,
- Longitude,
- Speed,
- Heading,
- Acceleration,
- Drivers seatbelt status (on/off),
- Brake status (on/off),
- Windshield wiper status (on/off),
- Cellular phone detection (on/off), and
- RS232 connection for headway measurement device of OBD connection.

3.2.4 VDO UDS

The UDS System documents the events before, during, and after an accident. VDO's UDS System records accident data and provides a precise and objective basis for reconstructing traffic accidents. *(19)* The VDO UDS system registers the following data elements: *(19)*

- Vehicle speed,
- Longitudinal acceleration,
- Length of operation of ignition,
- Length of operation of brakes,
- Length of operation of lights,
- Length of operation of brakes,
- Use of sirens and flashing lights (for emergency vehicles)

The UDS records data continuously when in operation. In the event of a crash, the system automatically and permanently stores 45 seconds of data: 30 seconds before and 15 seconds after the accident. When the crash is recognized, the device emits a signal that can also be used in other applications such as signalling the vehicle's logistics system or incorporating in emergency signal management. *(19)*

3.3 Using EDR Data

Presently there are only a few vehicle manufactures which use EDRs. Some of these manufactures are GM, Ford, DCX, Honda, Toyota, and Volkswagen. NHTSA uses the data recorded from these EDRs to improve the following: *(20)*

- Accident,
- Reconstruction,
- Emergency response,
- Biomechanics research,
- Highway design,
- Threshold, and
- Crash causation.

The activation of EDR function data is different for each of the manufactures. The table below shows when the EDR function is activated for the vehicles by manufactures mentioned above.

GM	Ford	DCX	Honda	Toyota	Volkswagen
Frontal – "Algorithm Enable" started by "Near deployment" predetermined Delta-V	Frontal algorithm activated events will be recorded when a minimum velocity change is achieved.	Pyrotechnic deployment due to front, side or rear impact.	Frontal "Algorithm Enable" started by "Near Deployment".	Trig: G>=2.0 Hold: deployment	Wake up of airbag ECU algorithm

Figure 12: Activation of EDR Function *(20)*

At present GM is the leading in the development of EDR technology and majority of the GM vehicles are equipped with EDRs. The Vetronix CDR kit is compatible with just GM at present. All OEM companies have incorporated their recording devices into the airbag controller. There are a wide variety of EDR systems in the market at present.

These systems range from simple acceleration collection devices to video collecting devices, to devices capable of collecting pre-crash, crash, and post crash data. Table below shows different data elements collected by various manufactures:

Data Item	Use of data	GM	Ford	DCX	Honda	Toyota	Volkswagen
Airbag Type Deployed	Crash reconstruction, biomechanics research	Yes	Yes	Yes	Yes	Yes	Yes
Ignition Cycle Counter	Accident reconstruction	Yes	Yes	Yes	Yes	Yes, during the warning lamp ignition	Yes
Seat Belt Status for front occupants (with buckle switch inputs)	Accident reconstruction, biomechanics research	Yes (driver only)	Yes	Yes	Yes	Yes	Yes
Occupant Sensing Status	Accident reconstruction, biomechanics research	No	Yes	Yes	Yes, if applied	Yes, if applied	Yes
Airbag Disable Switch Status	Accident reconstruction	Yes	Yes	Yes	Yes, recorded in manual cut-off switch itself	Yes, recorded in manual cut-off switch itself	Yes
Airbag Warning Lamp Status	Accident reconstruction	Yes	Yes	Yes	Yes	Yes	Yes
System Voltage	Accident reconstruction	No	Yes	To be determined	No	No	Yes
VIN and EDR ID	Accident reconstruction	No	EDR ID, not vehicle VIN	Yes	No	No	Yes
Vehicle Mileage	Accident	No	No	Yes	No	No	?

	reconstruction						
Engine Lamp Status	Accident reconstruction	No	No	To be determined	No	No	?
Cruise Control On/Off/ Engaged Status	Accident reconstruction, Crash causation	No	To be determined	To be determined	No	No	To be determined
Engine RPM	Accident reconstruction, Crash causation	Yes (5 seconds before impact)	To be determined	To be determined	No	Some cars	Yes
Throttle Position	Accident reconstruction, Crash causation	Yes (5 seconds prior to impact)	To be determined	To be determined	No	Some cars	Yes
Brake Applied	Accident reconstruction, Crash causation	Yes (5 seconds prior to impact)	To be determined	To be determined	No	Some cars	Yes
ABS Activated	Accident reconstruction, Crash causation	No	To be determined	To be determined	No	No	Yes
Vehicle Speed	Accident reconstruction, Crash causation	Yes (5 seconds prior to impact)	To be determined	To be determined	No	Some cars	Due to high privacy issues recording would be owners choice at new car purchase or by dealer programming
Adaptive Cruise Control and	Accident reconstruction,	No	To be determined	To be determined	No	No	To be determined

other driver assistance systems	Crash causation						
ESP (stability control)	Accident reconstruction (verify ETC), Crash causation	No	To be determined	To be determined	No	To be determined	To be determined
Crash Pulse Information	Accident reconstruction, emergency response, biomechanics research, threshold	Calculated (from deceleration Pulse) Delta Velocity at 10ms intervals	Actual deceleration pulse at 1ms intervals	No	Partial Delta Velocity	Every 10ms Delta Velocity	Deceleration; rate and duration depending on direction of pulse and available storage capacity
Location, Time, Date – likely available from Telematics system, if equipped	Highway design, accident reconstruction	No	No	No	No	No	No
Automatic Collision Notification (ACN) Data Record sent to Telematics Provider-Time, Data, Location, Number of	Emergency response	No	No	No	No	No	No

occupants							
Environmental Conditions	Emergency response, highway design	No	No	No	No	No	No

Figure 13: NHTSA Working Group Findings for EDR Data Items *(20)*

The data mentioned in table 2 was collected from the NHTSA EDR working group. *(20)* One finding that was revealed from the research conducted by the NHTSA EDR working group was that there are no standards associated with EDRs. Each manufacturer defines how they will collect data. This is of concern as common data definitions can help towards improving the existing technology.

3.4 Crash Data Collecting Programs

NHTSA has three main crash data collecting programs:

- National Automotive Sampling System — Crashworthiness Data System (NASS CDS)
- Special Crash Investigations (SCI)
- Crash Injury Research and Engineering Network (CIREN)

3.4.1 National Automotive Sampling System - Crashworthiness Data System

The National Automotive Sampling System — Crashworthiness Data System (NASS - CDS) has been in operation 1978. In 1980's the NASS program was re-evaluated and some changes were implemented by the National Highway Traffic Safety Administration (NHTSA) in January 1988. NASS now has two major operating components: *(21)*

- The General Estimates System (GES) which collects data on an annual sample of approximately 55,000 police traffic crash reports; and

- The Crashworthiness Data System (CDS) which collects additional detailed information on an annual sample of approximately 5,000 police reported traffic crashes involving a towed passenger car, van or truck that is less than or equal to 10,000 pounds GVW

NASS collects crash data to help government scientists and engineers analyze motor vehicle crashes and injuries. It collects detailed data on a representative, random sample of hundreds of thousands of minor, serious and fatal crashes involving passenger cars, pickup trucks, vans, large trucks, motorcycles, and pedestrians. *(22)*

3.4.2 Special Crash Investigations

The purpose of SCI is to examine the safety impact of new, emerging, and rapidly changing technology (such as air bags and alternative fuel systems) and explore alleged or potential vehicle defects. The data collected by SCI ranges from basic data maintained in routine police and insurance crash reports to comprehensive data from special reports by professional crash investigation teams. Hundreds of data elements relevant to the vehicle, occupants, injury mechanisms, roadway, and safety systems involved are collected for each of the over 200 crashes designated for study annually.

The SCI program investigates any new emerging technologies related to automotive safety. A number of incidents involving alternative fuel vehicles, passenger side air bag deployments, vehicle-to-pedestrian impacts, and child safety restraints have been investigated. *(23)* These investigations are used to understand the real world performance of these state-of-the-art systems so that they can be used to make improvements to these new technologies.

3.4.3 Crash Injury Research and Engineering Network

CIREN is a collaboration of research on crashes and injuries at ten Level 1 Trauma Centers linked by a computer network. Researchers can review data and share expertise, which could lead to the design of safer vehicles. Seven of these Centers are funded by NHTSA, one by Mercedes-Benz, and one by Ford. The Froedtert Hospital & Medical College of Wisconsin CIREN Center is self-funded. *(24)* The mission of CIREN is to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries and to reduce deaths, disabilities, and human and economic costs. The following figure shows all the 14 CIREN centers in US.

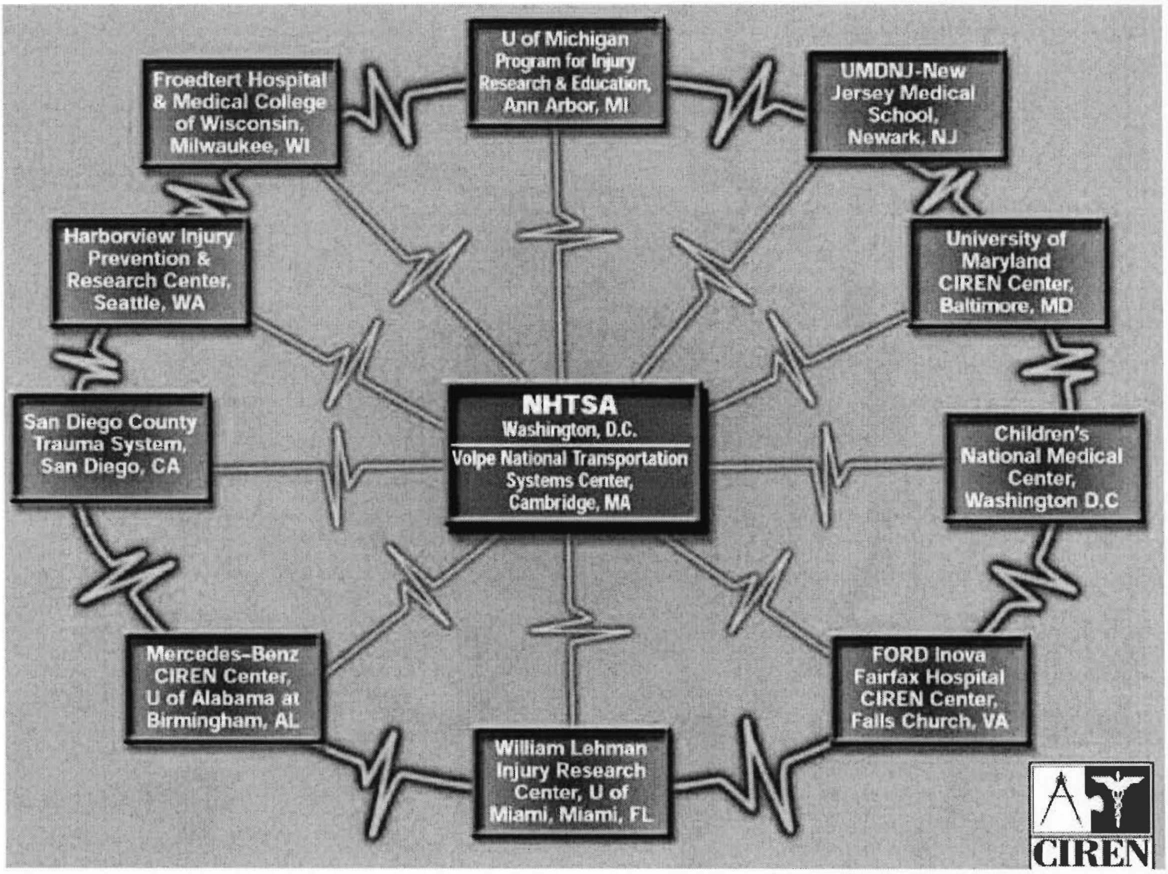


Figure 14: CIREN Computer Communications Network and Database *(11)*

CIREN research helps advance the development, testing, and evaluation of new technologies for the prevention of injuries and new techniques for more effective emergency medical transport and treatment of crash injured people.

The CIREN database consists of the NASS CDS data set plus additional medical and injury variables. The NASS CDS data set contains variables that describe an automotive crash including (but not limited to): *(24)*

- Crash Type
- Vehicle Make, Models, and Body Types
- Crash deformation classification (CDC)
- Crush Profiles
- Delta Vs
- Intrusions
- Occupant Contacts

The CIREN medical and injury data elements include:

- Co-morbidity
- Diagnostic Procedures
- Complications
- Operative Procedures
- Medical Images
- Disability Measurements
- Emergency Medical Response
- Emergency Medical Treatment
- Vital Signs
- Physiologic Measurements
- Injury Location
- Ventilation Periods
- Intensive Care Unit Stays

3.4.4 Collection of EDR Data

NHTSA began collecting crash data from EDRs in the mid 1990's. Most of these early cases were low speed air bag related fatalities that could not be accurately reconstructed by the WINMASH algorithm (this was prior to the Vetronix CDR tool). NHTSA has equipped its crash investigating teams (NASS – CDS, SCI, and CIREN) with Vetronix tools. Ford has also provided SCI and NASS with five proprietary readers. These teams were trained to use these tools properly and collect EDR data on routinely basis. The NHTSA crash teams have investigated over a 100 crashes where an EDR was read. Since 2000, all the three teams have been using Electronic Data Collecting System (EDCS) as their common database for collecting EDR data. Some data collected by SCI and NASS are mentioned in the table below. This data is collected till January 1, 2001. *(14)*

Program	**GM**		**Ford**		**Total**	
	Attempted	**Completed**	**Attempted**	**Completed**	**Attempted**	**Completed**
SCI	7[18]*	7[18]	28	28	53	53
NASS	41[1]	34[1]	6	5	48	41
Total	48[19]	41[19]	34	33	101	94

* The number in the bracket are the counts of data collected by GM

Figure 15: EDR Downloaded by Manufactures and Crash Programs *(14)*

3.4.5 Major Shortcomings

Based of the investigations by SCI and NASS, some major short comings with crash data retrieval data systems were revealed. Some of the systems with which potential problems were found are: GM's SDM and Ford's Crash Data Retrieval System. *(14)*

- SDM – G is the sensing diagnostic module used in the 1999 and few 2000 year GM models. The problem with this system is that if the vehicle's electrical system is compromised during the crash, then the driver's seatbelt switch may incorrectly report the status. It may report the switch to be unbuckled even if it was buckled.

- Another drawback was found with the Ford system. In the case of a complete electrical failure in the 2000 Ford Tarus/Sable, an incomplete file was written from the EDR. This resulted is lost data in most of the sever crashes.

4 INVENTORY OF ON-VEHICLE NETWORK SYSTEMS

Electronics and computer-aided data networks are becoming an integral part of the structure of today's vehicles. Earlier electronic components were used primarily to perform functions that could not be carried out mechanically. Today, computer-aided data networks have opened a new world of opportunities. Data buses that link a variety of electrical and electronic components via just one line are replacing the traditional cable harnesses. Electronic equipment accounts for 30% of the value for some luxury cars. Most modern cars have more computing power on-board than that of the Apollo spacecraft which put the first men on the moon. The on-vehicle network technology cuts costs while enhancing reliability and safety. Ideally, it also extends the vehicle's service life indefinitely.

4.1 Crash Data Retrieval System

Controlled Area Network (CAN) is a serial bus system with multi-master capabilities. Digitized data is sent via a single cable and is made available to different control units simultaneously. In CAN networks there is no addressing of subscribers or stations in the conventional sense, but instead, prioritize messages are transmitted. A transmitter sends a message to all CAN nodes. Each node decides on the basis of the identifier received whether it should process the message or not. The identifier also determines the priority of the message for bus access. It is important to ensure that messages that have been dispatched arrive at the correct receiver. Thus each message is sent with a tool that decodes it according to its significance for individual control units and prioritizes them according to urgency. When the line is free the other stations send their own messages.

However, if several pieces of information are being sent at the same time, those that have higher priority are given precedence. The other stations will then repeat their attempt to transmit their messages as soon as the line is free. *(25)*

One of the outstanding features of the CAN protocol is its high transmission reliability. The CAN controller registers a stations error and evaluates it statistically in order to take appropriate measures. This may result in disconnecting the CAN node producing the errors. Each CAN message can transmit from 0 to 8 bytes of user information. Longer data can be transmitted too by using segmentation. The maximum transmission rate is specified as 1M bit/s. This value applies to networks up to 40m. For longer distances the data rate must be reduced: for distances up to 500m a speed of 125k bit/s is possible, and for transmissions up to 1km a data rate of 50k bit/s is permitted. *(26)*

The relative simplicity of the CAN protocol results in very little cost and requires much less effort on personal training. The CAN chips interfaces make applications programming relatively simple. Introductory courses, function libraries, starter kits, host interfaces, I/O modules and tools are available from a variety of vendors permitting low-cost implementation of CAN networks. The spread of CAN networking shows opportunity for cutting costs. The use of Electronic Brake System (EBS) is one example of this. The pressure control modules have integrated electronic systems fitted to the wheel brake cylinders and axles. These are connected to the core piece and central control unit in the cab with a CAN data bus. These modules also receive the set nominal value from the bus. In future, the driveline control units, retarder, automatic gearbox, running gear control, electronic air preparation system and electronic brake will all be connected to a vehicle master computer (FFR) and vehicle control unit in a similar way.

The will then receive their set-point values, general processing information and sensor values (measured at other points) as well as have the option of transmitting their own values or requirements to it. The electronic injection system is as close to the engine as possible. It receives its set-point values from the FFR via an engine CAN bus. The FFR processes this information centrally depending on operating conditions and the driver's request and then calculates the necessary set-point variables. These include the required gear or requested driving and braking torques that are regulated, via CAN, by locally installed electronic systems. Such an example shows that great emphasis will be placed on CAN networking in order to enhance reliability and vehicle availability. *(25)* Mercedes-Benz was the first manufacturer to implement CAN. Most of the other European automobile manufacturers implemented a CAN high-speed network (e.g. 500k bit/s) in their power-engine systems. Mercedes-Benz has been using CAN in their upper-class passenger cars since 1992. The first step involved connecting all electronic control units taking, that take care of the engine management, via a CAN bus. The second step, the control units needed for body electronics followed. These two separate CAN systems were connected through gateways. Other car manufactures who now implement two CAN networks are: *(26)*

- Volvo,
- Saab,
- Volkswagen,
- BMW,
- Audi,
- Renault and
- Fiat

Volvo uses a CAN high-speed network for engine management and a CAN low-speed network for engine management. Volkswagen has implemented a low-speed CAN network for the door control units.

4.1.1 Some other CAN Benefits

CAN bus technology is not restricted to the driveline and its periphery. It has brought about changes in the traditional electrics and bodywork electronics. Functions previously performed with relay and cabling technology in conjunction with miniature electronics will eventually be amalgamated in a central, on-board computer. Some passenger cars are equipped with CAN-based multiplex systems connecting body electronic ECUs. These networks running at lower data-rates, e.g. 125k bit/s. Most of them are using not the high-speed transceivers compliant with ISO 11898-2, but fault-tolerant transceivers compliant with ISO 11898-3. These multiplex networks link door and roof control units as well as lighting control units and seat control units. *(26)* Some other systems that can be integrated into the computer economically are: *(25)*

- Lighting control,
- Headlight beam regulation,
- Flame starter control,
- Wipe/wash control,
- Headlight cleaning,
- Sensor monitoring,
- Comfortable interior space management and so on.

Figure 16 shows some of the different features controlled by CAN network in a car.

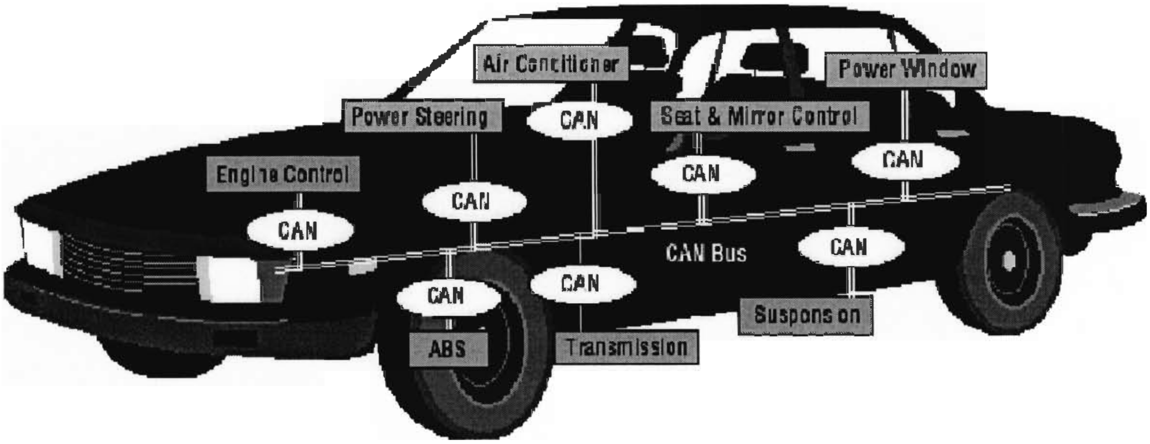


Figure 16: CAN Network in a Car *(27)*

Another purpose of CAN networks in cars is connecting entertainment devices. Figure 17 shows the CAN-based MCNet transmission protocol by Bosch supports connection-oriented communication. The first MCNet compatible devices from Blaupunkt (automotive radio variants and CD-changer) have been commercially available since the middle 1996. *(28)*

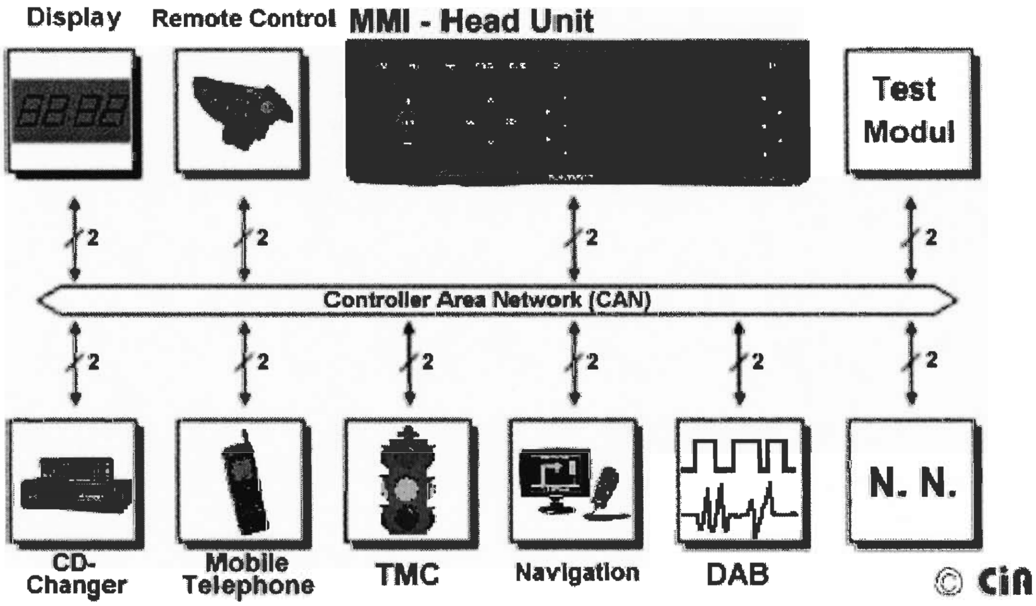


Figure 17: Entertainment in Motor Vehicles *(28)*

4.2 Local Interconnect Network

Car manufactures are very conscious of the cost and are working towards bringing the features of luxury cars to an average family car at affordable cost. At present CAN is the most popular car network standard. LIN is a new low cost serial communication system intended to be used for distributed electronic systems in vehicles. LIN is used to connect clusters of electronic devices within very small areas such a single door or a single seat. *(29)* Figure 18 below show some applications of CAN and LIN networks in a car.

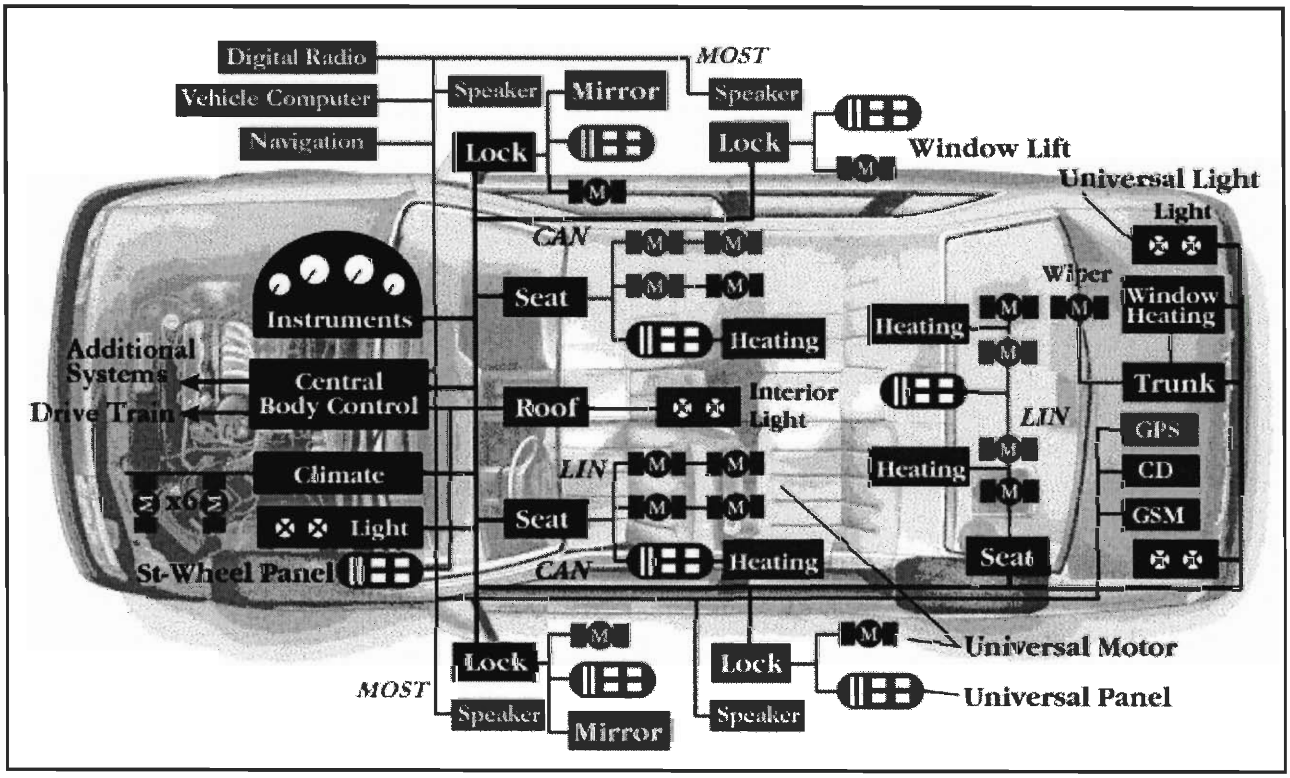


Figure 18: Various Car Networking Applications ***(29)***

LIN is a holistic communication concept for local interconnecting networks in vehicles. At present there is no automotive standard in low end multiplex communication. The LIN consortium has been developed to standardize a concept of a serial low cost communication concept that enables the car manufacturers and their suppliers to create, implement, and handle complex hierarchical multiplex systems in a very cost competitive way. The members of the LIN consortium are:

- Audi,
- BMW,
- Daimler Chrysler,
- Volvo,
- Volkswagen,
- Motorola and
- Volcano Communication Technology.

Figure 19 shows the relative communication cost per node for various in-vehicle networks. It can be seen from the figure that LIN nodes are least expensive.

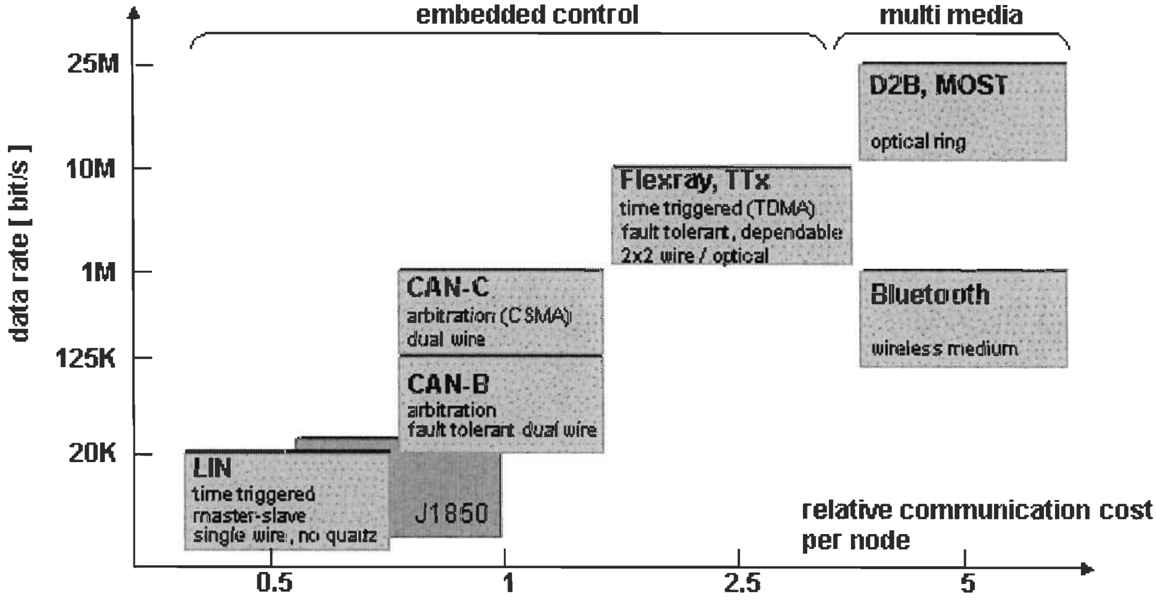


Figure 19: Communication Costs and Data Rates for In-Vehicle Networks *(30)*

LIN is used for simple ON/OFF devices such as:

- Door control (window lifter, seat control, mirror),
- Roof control (light/rain sensor),
- Steering column control (switches, climate),
- Seat control (motors),
- Climate control (motors, sensors),
- Intelligent wiper motor,
- RF-receiver for remote control,
- Intelligent alternators, and
- Switch panels.

The following figure shows a block level diagram of the door module of the car. The door module is controlled by sub LIN buses which combine with the CAN buses.

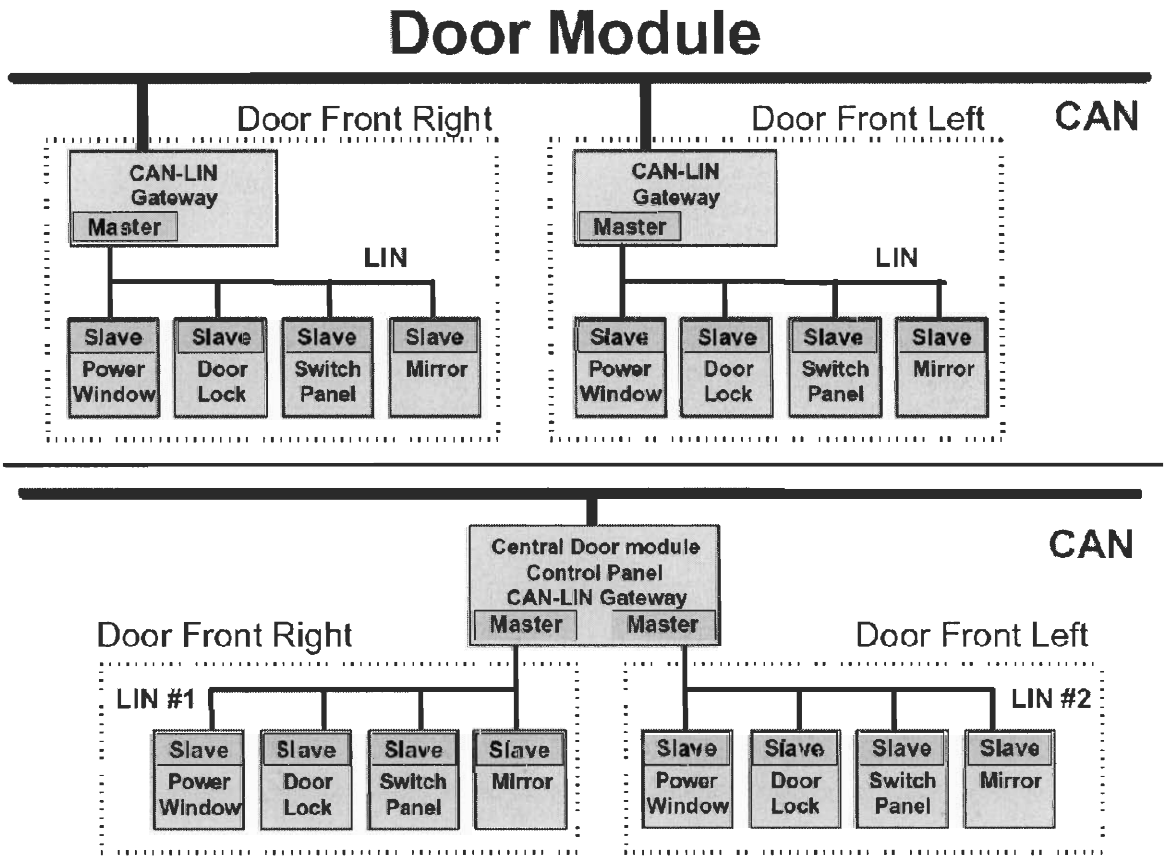


Figure 20: Door Module using CAN and LIN *(31)*

The LIN network consists of one master node and one or more slave nodes. All nodes include a slave communication task that is split into transmit and a receive tasks. The master node includes an additional master transmit task which always initiate the communication in an active LIN network. The master sends out a message header which contains the synchronization byte and the message identifier. Exactly one slave task is activated upon reception and filtering of the identifier and starts the transmission of the message response. The response comprises two, four, or eight data bytes and one checksum byte. The header and the response part form one message frame. The identifier of a message denotes the content of a message but not the destination. This communication concept enables the exchange of data in various ways: from the master node to one or more slave nodes, and from one slave node to the master node and/or other slave nodes. It is possible to communicate signals directly from slave to slave without routing through the master node, or broadcasting messages from the master to all nodes in a network. *(30)*

LIN is becoming more common in today's networks. Some of its key features are: *(30)*

- Low cost single-wire implementation,
- Enhanced ISO 9141, V_{BAT}-Based,
- Speed up to 20Kbit/s,
- Acceptable speed for many applications (limited for EMI-reasons),
- Single Master / Multiple Slave Concept,
- No arbitration necessary,
- Low cost silicon implementation based on common UART/SCI interface hardware,
- Almost any microcontroller has necessary hardware on chip,
- Self synchronization in the slave nodes without crystal or ceramics resonator,
- Significant cost reduction of hardware platform,
- Guaranteed latency times for signal transmission and
- Predictable systems possible.

Although CAN protocol represents a cost-efficient technology and has become a standard for in-vehicle networking in the automotive industry, there are some applications which do not need the performance of CAN and require a lower cost solution. This can be achieved using LIN which is much more cost-effective for some simple and smaller networks.

4.3 On – Board Diagnostic Systems

In 1970, the Congress passed the Clean Air Act and established the Environmental Protection Agency (EPA). This started a series of graduated emission standards and requirements for maintenance of vehicles for extended periods of time. To meet these standards, manufacturers turned to electronically controlled systems. Sensors measured engine performance and adjusted the systems to provide minimum pollution. These sensors were also accessed to provide early diagnostic assistance. On – Board Diagnostic systems were introduced primarily to meet EPA (Environmental Protection Agency) emission standards. OBD-II is an expanded set of standards and practices developed by SAE (Society of Automotive Engineers) and adopted by the EPA and CARB (California Air Resources Board) for implementation by January 1, 1996. *(32)*

OBD is a computer based system that detects operational malfunctions or failures of the engine and emissions related components. OBD uses sensors and software to compare expected and actual signals from the engine to trace faults that can lead to excessive vehicle emissions. For example oxygen sensors are used to check the air/fuel ratios and detect any emission control failure. If such a failure is found the system automatically illuminates a Malfunction Indicator (MIL) in the dashboard display to alert the driver of the problem and the need for repair. MIL shows three different types of signals. Occasional flashes show momentary malfunctions. It stays on if the problem is of a more serious nature, affecting the emissions output or safety of the vehicle. A constantly flashing MIL is a sign of a major problem which can cause serious damage if the engine is not stopped immediately. In all cases a "freeze frame" of all sensor readings at the time is recorded in the central computer of the vehicle. *(33)*

The figure below shows the OBD network to illuminate Malfunctioning Indicator.

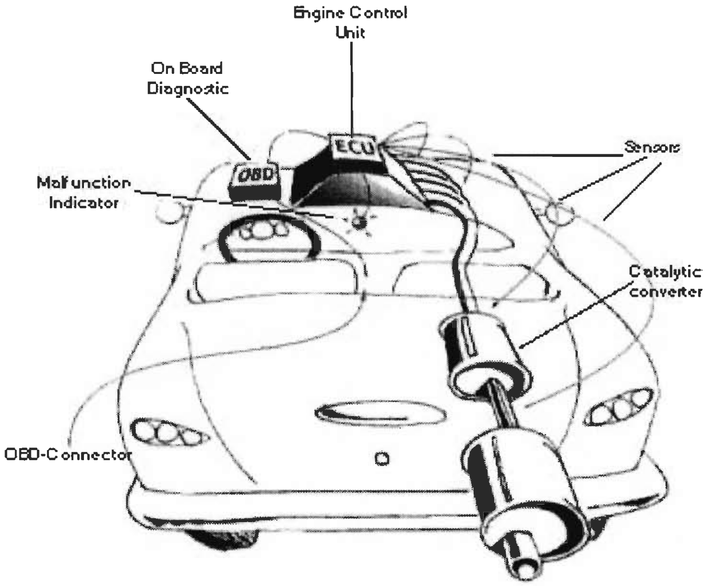


Figure 21: Applications of OBD *(33)*

It is required to have access to the engine control computer, the OBD Command Software and to Fault Codes (records and stores the status of the engine and emission control systems) to identify and repair any fault. For this standardized scan tools are required. These tools can connect with the vehicle's OBD system, be able to read and erase the relevant fault codes, and have all other relevant repair information. *(33)*

4.4 Next Generation In-Vehicle Networks

4.4.1 Next Generation Car Network by Altera Corporation

Cars have various networks running through them to control different features. An example of the of the next generation car network provided by Altera can be seen in figure 22.

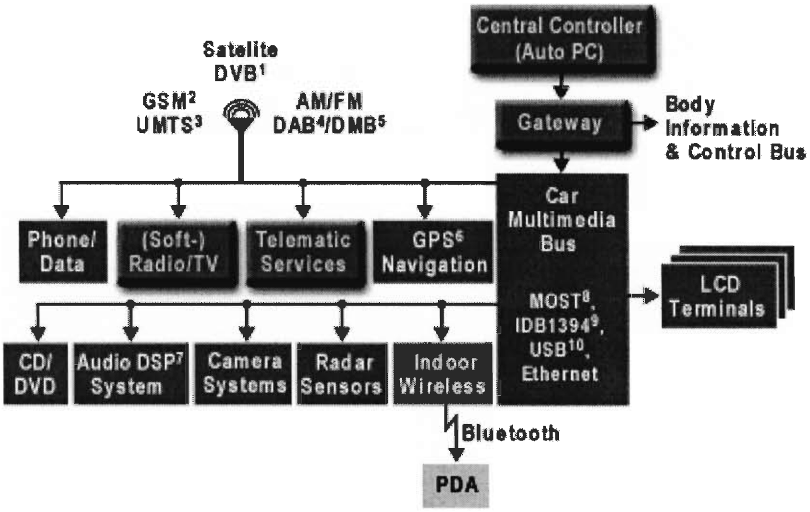


Figure 22: Next-Generation Car Network *(34)*

Car networks are usually divided into body and power train controls, telematics and multimedia sub-networks. The core of the automotive system is the central controller (known as an "Auto PC" in Europe). The central controller serves as the control for both the segments of the vehicle through a gateway. The main task of the central controller is to control the user interaction with the system and serve as a front-end for many electronic control units. The gateway controller acts as a router between the different electrical and optical buses in a car. The communication between the ECU's on the body and the power train branches are carried by CAN and LIN networks. In future, FlexRay or a timing-triggered CAN will be used to combine multiple sensors and ECU's, and requires a high data rate and communication capability. *(34)*

A typical car network for next generation can be seen below in figure 23.

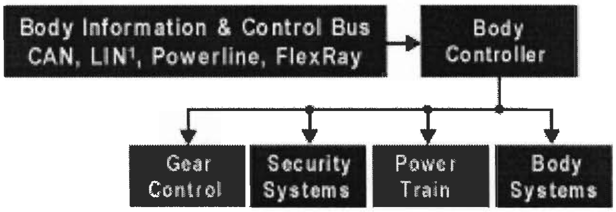


Figure 23: Typical Next Generation Car Network *(34)*

Altera and Cyclone provide cost-effective in-vehicle network systems which meet the demands of advanced vehicle information and safety features.

4.4.2 Wireless Road Interface Module by Vetronix Corporation

Vetronix's "next generation" telematics solution that is capable of interfacing directly with the vehicle's electronic and on-board computer based systems. This capability offers remote monitoring, telemetry and control of many vehicle engineering, location and operational parameters. Vetronix's "next generation" solution is based around Vetronix's patented bi-directional control gateway. *(35)* This Wireless Road Interface Module (WRIM), is capable of monitoring a wide range of data elements, but is not limited to the ones listed below: *(35)*

- ABS Event and Data
- Air Bag Deployment and Crash Data
- Air Bag Near Deployment and Data
- Anti-Theft and Alarm Status and Control
- Application-Specific Inputs
- Brake Switch Status
- Current Gear

- Diagnostic Trouble Codes
- Door Lock/Unlock Control
- Emissions Status
- Engine Coolant Temperature
- Engine Oil Level
- Engine Speed
- Fuel Level
- Headlight and Parking Light On/Off Control
- Horn On/Off Control
- Odometer
- Shift Lever Position
- Throttle Angle
- Tire Air Pressure
- Transmission Fluid Temperature
- Vehicle Speed

WRIM unit also has an internal expansion slot for addition of future protocols. WRIM also includes an external RS232 channel for communication with peripheral devices. WRIM's embedded software can be reprogrammed wirelessly in order to add functions in the field without removing WRIM from the vehicle. *(35)* The following figure shows the internal architecture of WRIM.

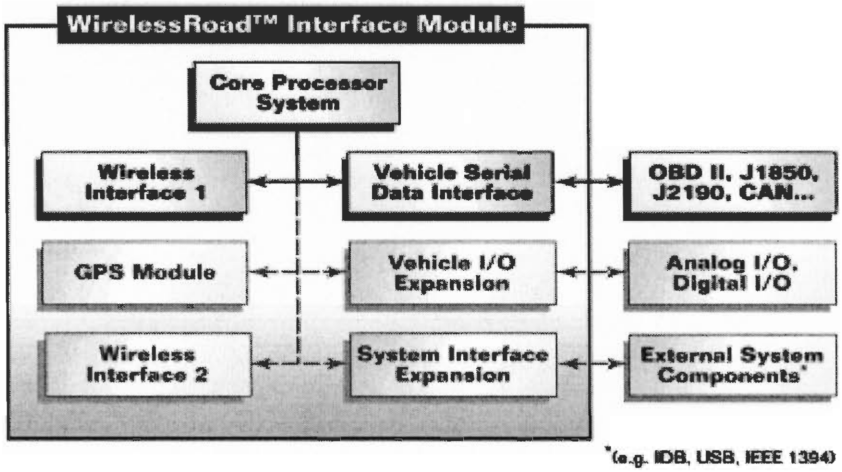
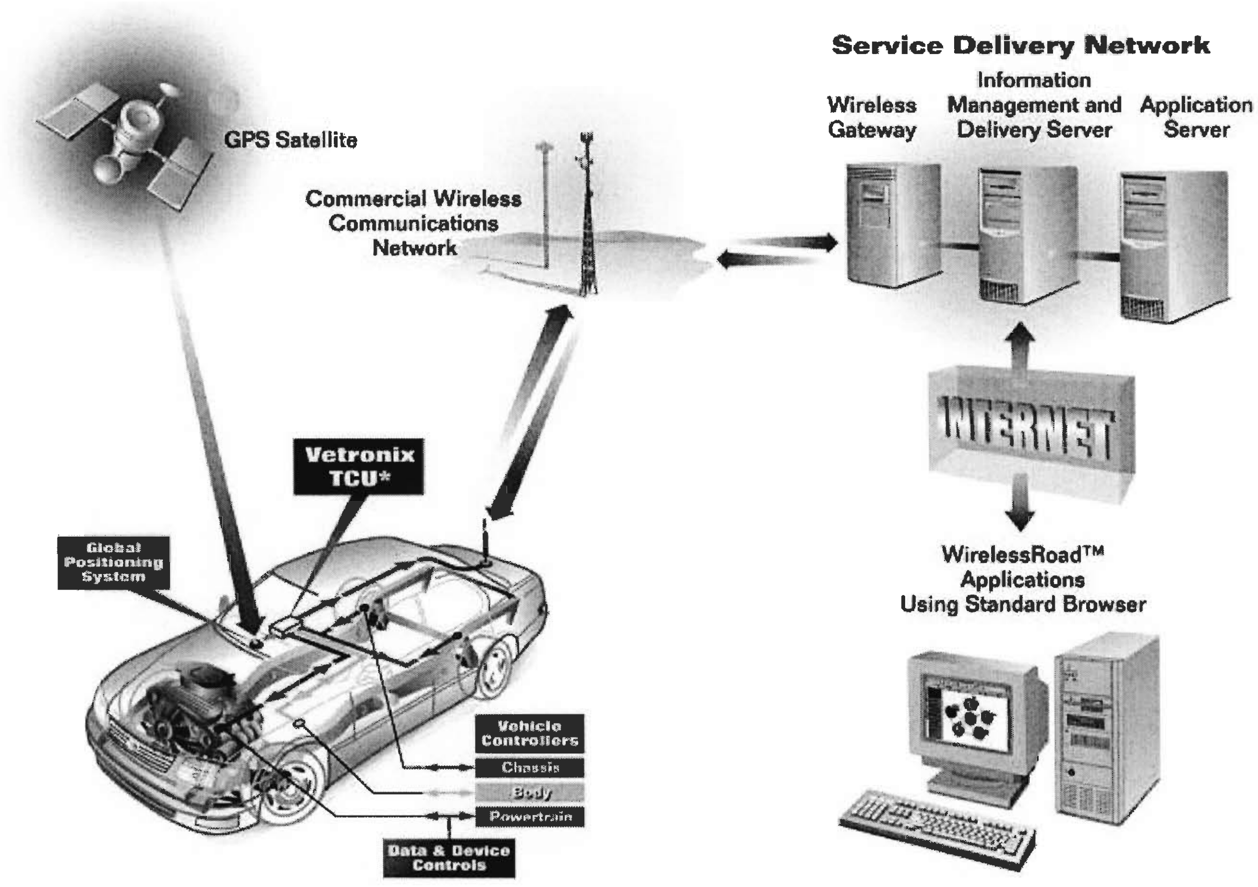


Figure 24: Internal Architecture of Wireless Road Interface Module *(35)*

The following figure shows a brief proposed working of Vetronix's WRIM system.



***Telematics Control Unit**

Figure 25: Vetronix's Wireless Road Interface Module *(35)*

4.4.3 Bluetooth in Automotive Applications

Bluetooth was initially developed for two big markets; telephone and PC. Bluetooth can also be extended to another market; cars. Some of the possible services include locking and unlocking of the car using a mobile phone, using mobile phone settings to adjust seat and climate, etc. There are endless numbers of possible services. This is possible if Bluetooth is made suitable for CAN. *(27)* The main advantage of Bluetooth is the wireless connection and it can be used for car production and service.

Bluetooth in Car Production

A Bluetooth base station is connected to the production field bus. When the car on line gets connected to Bluetooth, it uploads the serial number of the car. The production computer downloads the software for that particular car via the field bus to the base station, which in turns transmits that data to the car.

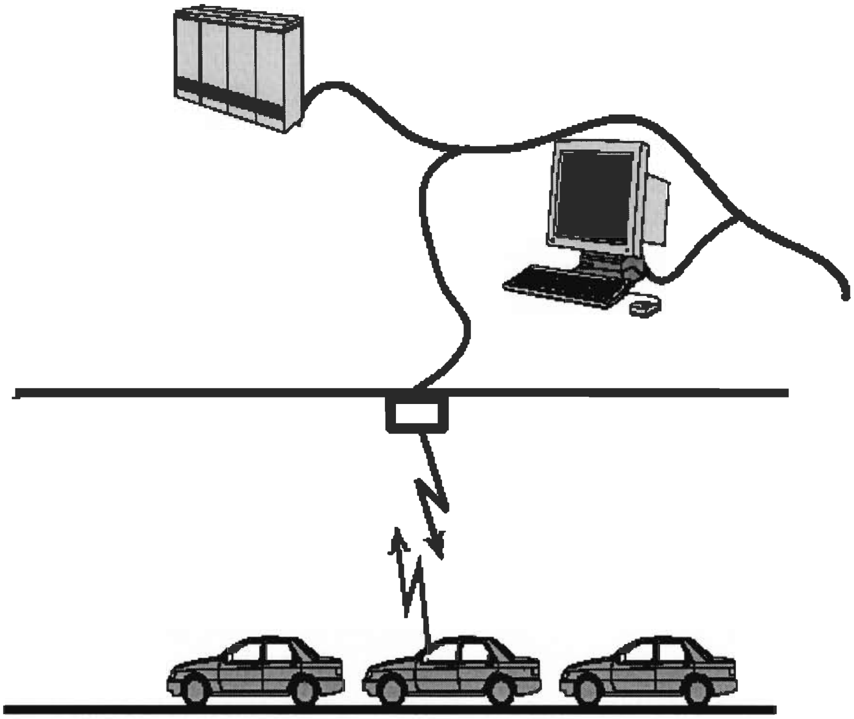


Figure 26: Bluetooth in Car Production Line *(27)*

Bluetooth in Car Service

Another application of Bluetooth can be in car services. For instance, when a car enters the service station, its Bluetooth station contacts the service stations main computer. This has previously exchanged information with the car computer via the cell phone. The service man at the service station establishes a contact with the car and downloads any information needed. While servicing the car, the service man can control various features through his PC, for instance, lights, windows, climate control, engine parameters, etc. The service man can also download any new software required to any ECU.

The figure below shows a CAN/Bluetooth Network in a car.

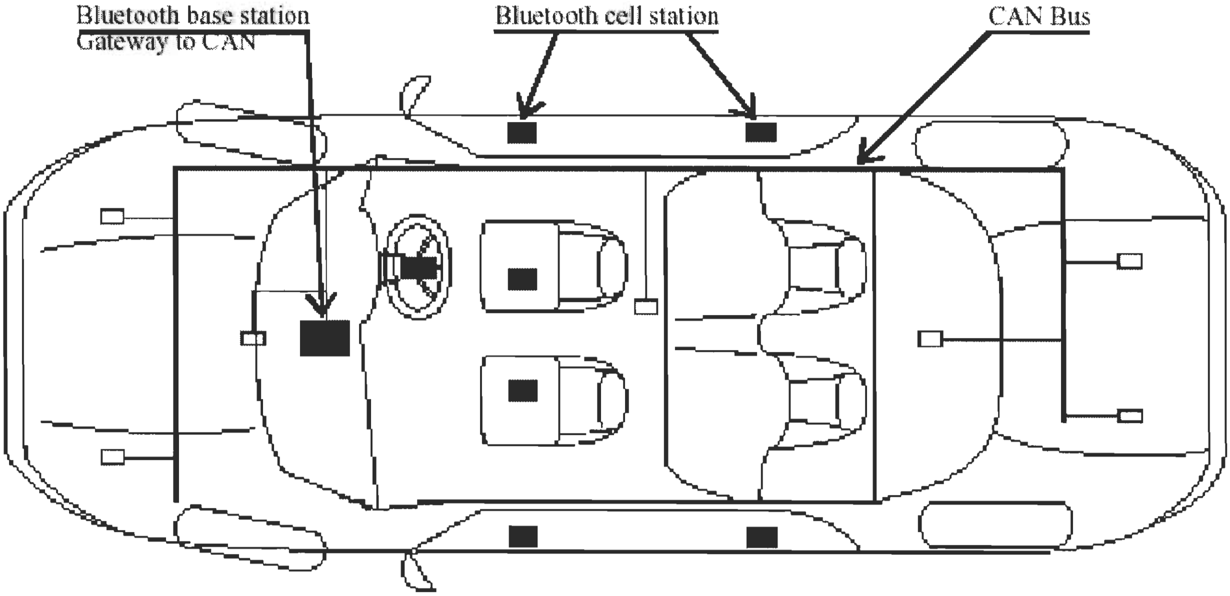


Figure 27: CAN/Bluetooth Network in a Car *(27)*

5 Expanding On-Vehicle Networks

An EDR combines information from multiple systems, such as engine, transmission, and anti-lock brakes. An EDR provides important data from an accident reconstruction, equipment failure, maintenance and diagnostic standpoint. An event data recorder collects information from multiple vehicle areas with a memory capacity greater than that of a single electronic module. The advanced event recorders store vehicle speed, engine speed, throttle position, and brake use — at one second intervals — taken just prior to a crash.

A new product which is expected to enter the market in model year 2002 is a sensor that disarms the battery in event of a collision eliminates the possibility of arc-originated fire. Although the battery cut-off sensor package is electronics-void, the sensor permits continued operation of must-have vehicle electronics. For instance during an accident you'd want your in-vehicle communications system to work, and your power doors to open. *(36)*

Another electronics/sensor application is a single-point, light plane sensor package from Novi, MI-based Prospects, Corp. This sensor automatically senses if a hand, or finger, or piece of paper is in the power window and stops the window instantaneously. Another similar system in production is by General Motors. GM is planning to use an infrared sensor that detects a person through heat signature and motion readings in its Automatic Trunk Detection and Opener System. This system senses both movement and temperature and opens the car trunk if it detects a temperature differential — such as the heat signature of mammals — and motion. The system is active only when the car's transmission is in park. *(36)*

5.1 Sensors Used in Vehicles

The networks in a vehicle link various sensors to actuators and the control system of the vehicle to enable various functions. Some of these sensors are used by the EDR system to provide information about a crash scenario later. There are about 40-50 sensors in a vehicle. Some of these sensors can be clustered together into multi-sensor modules.

Some of the common sensors used in a vehicle are: *(37)*

- Pressure sensor
- Side Air-bag sensor
- Micro-safing sensor
- Sensing system discrimination sensor
- Variable reluctance sensor
- Polymer PTC sensor
- Thick film oxygen sensor
- Contact less angle measurement sensor
- Catalyst temperature sensor
- Distance sensing sensor
- Hall Effect Sensor
- Occupant weight sensor
- Pressure sensor
- Temperature measurement sensor
- Rotary sensor

A brief description on the working and use of some of these sensors is given below.

Pressure Sensor

Pressure sensors are used in various automotive applications such as dynamic control (VDC), gasoline direct fuel injection, common rail diesel fuel injection, and other emerging systems. *(37)*

Side Airbag Sensor

The side airbag systems measure the acceleration within a time frame of less than 3 ms to inflate the side airbag in time. The circuit includes amplification, temperature coefficient compensation, two-wire unidirectional current interface, and a zero-offset compensation. The sensing element for the measurement of acceleration is a surface micro-machined accelerometer. When the power is turned on, an internal self-test is performed and the result is transmitted to the airbag control unit. The sensor measures the real acceleration value. This analog signal is amplified and filtered and then converted into a digital signal and transmitted to the airbag control unit. *(37)*

Micro-safing Sensor

Control systems such as ABS and airbags (frontal and side airbags) are dependent on sensors. The purpose of the safing sensors is to prevent malfunctioning. These sensors are integrated into airbag systems to detect an impact from collision simultaneously with the main acceleration sensor in the deployment of the airbag. In a side collision the deployment of the airbag must be quicker than in a head-on collision because in a side collision the crushable zone is smaller. Therefore, analog sensors are used for the side airbags because mechanical lead-switch type safing sensors, used mainly for front collision sensors, have a slow response time. *(37)*

Sensing System Discrimination Sensor

Sensing systems are packaged in the vehicle's interior on the center tunnel or other internal location. The sensing system is typically a single electronic control unit which uses internal accelerometers to measure the severity of the impact and provide deployment signals to the appropriate squibs. The vehicle body structure transfers the force from the crush zone to the ECU mounting location in time for the ECU to make the deployment decisions. The ECUs predict the severity of the impact prior to deployment based on the acceleration data obtained. The ability to differentiate between moderately severe and severe event yields improved discrimination between the events. *(37)*

Variable Reluctance Sensors

Variable reluctance speed and position sensors are very commonly used in the automotive industry. Unlike other sensors, these sensors are self excited and do not need external voltage supply. *(37)*

Polymer PTC Sensor

A wide range of motors in the automotive interior require over-current or over-temperature protection. These motors include the ones for power seats, power door locks, and window lifts. There is recent interest in protecting underhood cooling fan motors also, which can get blocked with snow in the winter. The Positive Temperature Coefficient (PTC) sensor is obtained from two materials. One is a polyolefin-based conductive material which provides a switch temperature of 125°C and the other is a polyamide based material with a higher temperature of 165°C for applications where the ambient temperature is higher. The purpose of the Polymer PTC sensor is to guard the automotive interior motors from unexpected current flow. *(37)*

Thick Film Oxygen Sensor

Oxygen sensors control air/fuel ration with least amount of delay. This helps in reducing HC emissions during engine cold starts. Thick film-type sensor has a single body of integrated sensing and heating element that helps maintain a good thermal conductivity from the heater to the sensing element. Therefore the heating mass is small and the sensor activates quickly. *(37)*

Catalyst Temperature Sensor

The catalyst temperature sensor is in response OBD-II requirements to reduce exhaust gases. Some of the advantages of the catalyst temperature sensor are: *(37)*

- Wide detection area
- High responsiveness
- High reliability
- High accuracy

Distance Sensing

The distance sensing sensors is a multi-functional sensor. It is used due to the limited space in the vehicle's front and rear region. Smart restraint systems of future generations with reversible actuators require a pre-crash sensor which alerts the restraint ECU of an object coming from front or side into the car several milliseconds before crash occurs. The examination of the vehicle's blind spots and an indicator of the presence and speed of an object within the area not covered by the rear view mirrors will also help the driver during lane-change operation or low speed maneuvering. *(37)*

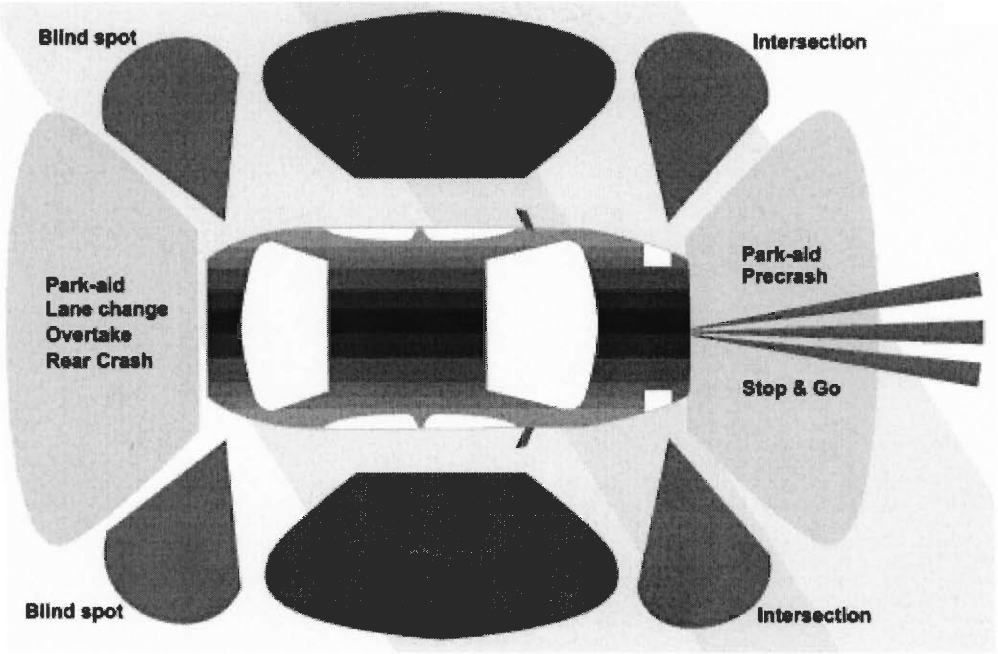


Figure 28: Peripheral Regions *(37)*

Hall Effect Sensor

Hall-effect sensors use a programmable ASIC control chip which provides structure height and position information for dynamic headlight-level adjustment systems. These sensors are used in vehicles equipped with high-intensity discharge headlamps that produce twice the illumination of conventional tungsten bulbs, often blinding the drivers of oncoming vehicles. The headlight-level adjustment system continually monitors the height and angle of the vehicle and adjusts the headlight aim to compensate for changes in the altitude of the vehicle due to road conditions, or passenger and luggage loads. *(37)*

Occupant Weight Sensor

The occupant weight sensor works with the smart airbag control system. The output from the sensor provides the weight and pressure of the occupant which is used in various airbag scenarios. *(37)*

Pressure Sensor

The pressure sensor detects fuel leaks as small as 0.5 mm (0.02 in.) in diameter. The temperature-compensated sensor can withstand exposure to a variety of conditions. It has a temperature storage rating of -40° to +125°C for 1000 hours, high humidity storage at 85% RH for 1000 hours, and a thermal shock rating of -40° to +125°C for 1000 cycles. It also meets the OBD II requirements. *(37)*

Rotary Sensor

The Hall-effect non contact rotary sensor has an accuracy of 2.5%. Some of the applications of the rotary sensor are: *(37)*

- Throttle position,
- Transmission shift position,
- Suspension height,
- Rotary EGR valve position,
- Air intake manifold bypass control damper position, and more.

5.2 Sensors Used in EDRs

An EDR comprises of various sensors which together work in helping to analyze crash scenario. The following figure shows the main sensors and components of an EDR.

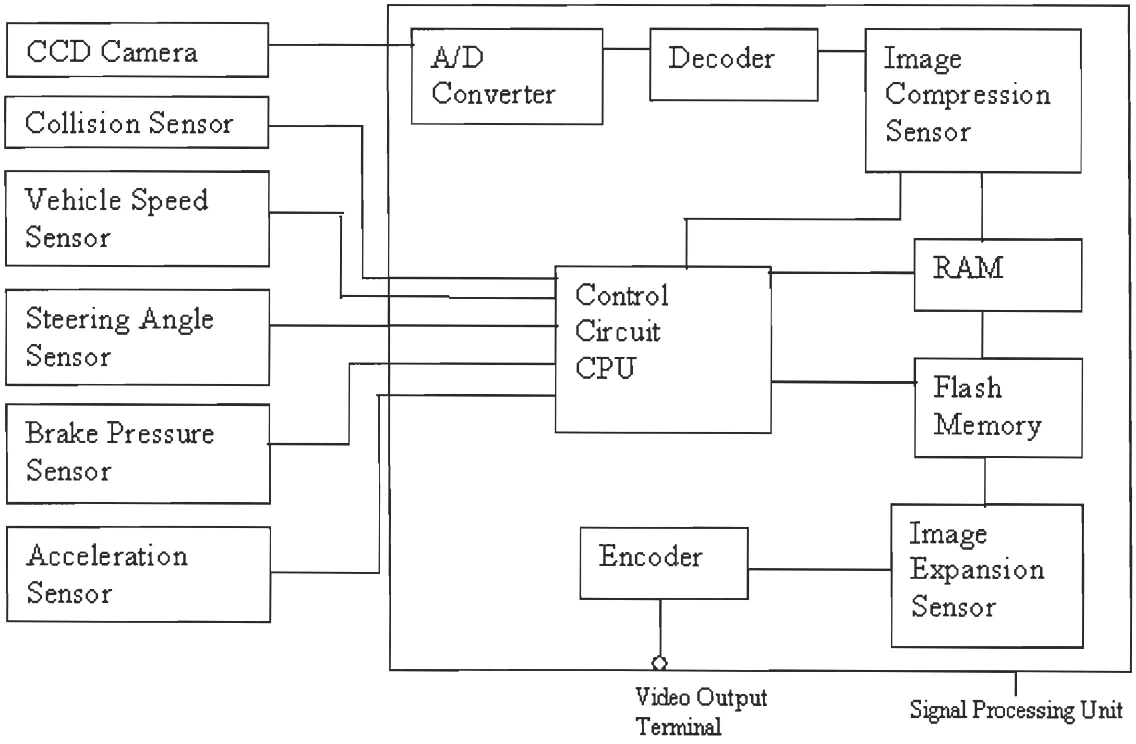


Figure 29: Block Level Design of EDR *(38)*

The figure above shows some of the main sensors used in an EDR. The data obtained from various sensors is stored in memory. This EDR has a CCD camera that records image information immediately before the accident and outputs it through the Video Output Terminal which helps in accurate analysis of the accident. The RAM is controlled by the CPU such that the oldest information is erased when the newest information in recorded. This results in endless recording with recording the newest data each time. The sensor section of the EDR consists of the following sensors:

- Collision Sensor,
- Wheel Speed Sensor,
- Steering Angle Sensor,
- Acceleration Sensor,
- Brake Pressure Sensor,
- Sound Sensor and
- Vehicle Interval Sensor.

A brief purpose of these sensors is mentioned below *(38)*:

Collision Sensor
The collision sensor outputs signal upon the collision of the vehicle.

Wheel Speed Sensor
The wheel speed sensor outputs the signal representing a slip condition of the vehicle.

Steering Angle Sensor
This sensor outputs the signal representing a dangerous abrupt operation of the steering wheel.

Acceleration Sensor
The acceleration outputs an abrupt change in the acceleration or deceleration of the vehicle.

Brake Pressure Sensor
This sensor shows the condition of the brake operation.

Sound Sensor
The sound sensor outputs signal representing a scream with a high frequency band and a collision sounds with a low frequency band.

Vehicle Interval Sensor
The output of this sensor represents the conditions immediately before the collision.

The CPU has a calculation processing section which processes the output signals of the sensors mentioned above. A buzzer (operated by the CPU) generates a warning sound with a short duration for each of the memory operation. Figure 28 shows the operational flowchart of the working of an EDR.

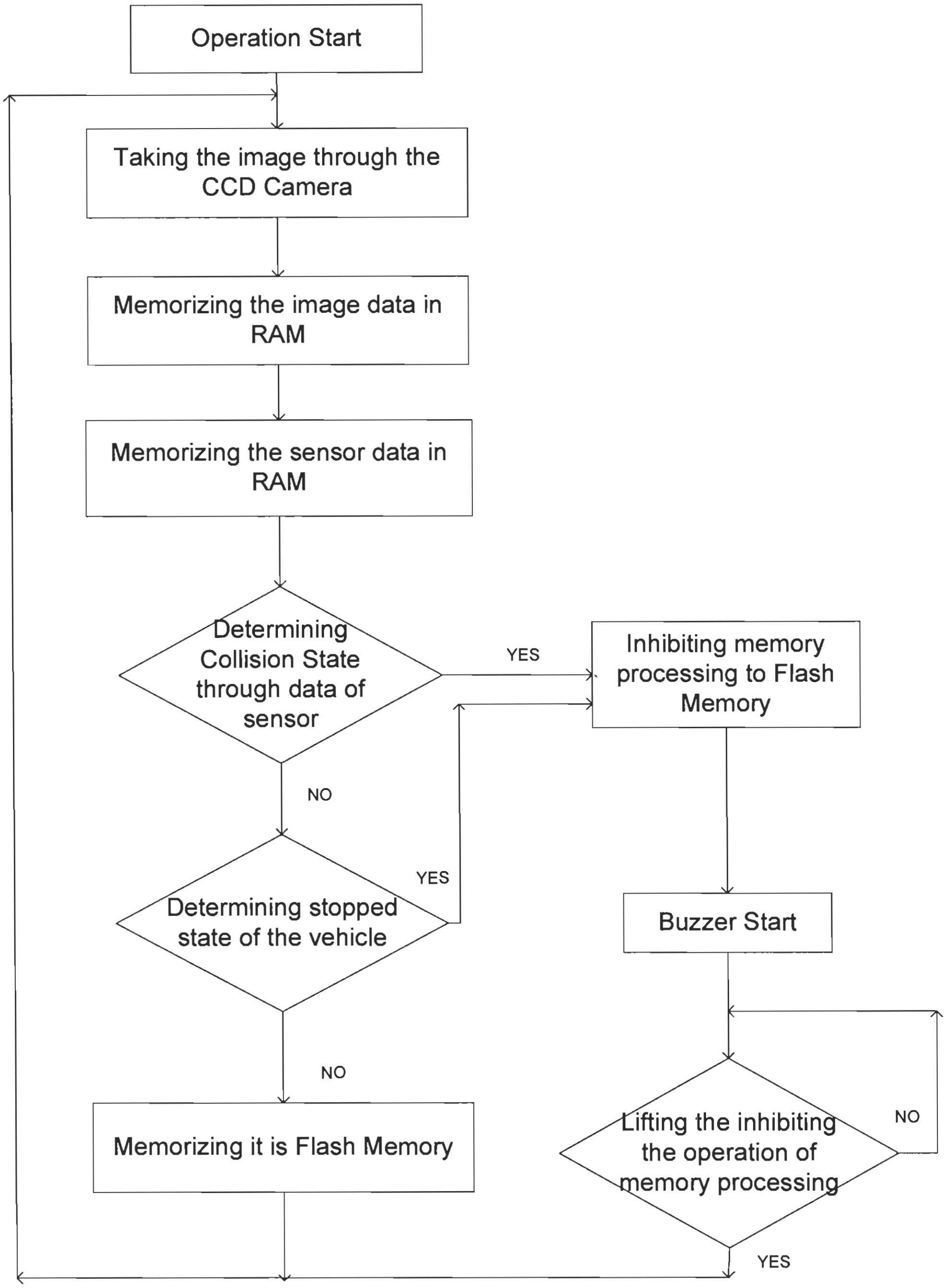


Figure 30: Operational Flowchart of an EDR *(38)*

5.3 Volvo Pre Crash Recorder

Volvo Pre Crash Recorder (PCR) is an extension to the existing Digital Accident Research Recorder (DARR). DARR is a digital crash pulse recorder installed in Volvo cars since 1994. DARR records upto 60 deceleration values in 180ms before the front airbag deployment. The PCR records information from different parts of the car circulating in an internal network. The PCR records 31 selected parameters in 500 ms, starting 5 seconds before the crash and stores them in an EEPROM. *(39)* The 31 selected parameters recorded by PCR are: *(39)*

- Outdoor temperature,
- Global time,
- Time from ignition on,
- Steering wheel angle,
- Latitudinal acceleration,
- Roll rate,
- Vehicle speed,
- Longitudinal acceleration,
- Driver requested torque,
- Engine torque rate,
- Actual Yaw rate,
- Engine speed,
- Engine speed QF,
- Break Control Module (BCM) voltage supply,
- Engine torque QF,
- Stability Control (SC) function,
- Active Yaw Control (AYC) function,
- Anti-lock Break System (ABS) function,
- Traction Control (TC) function,
- Electronic Break Force Distribution (EBD) function,
- Roll Stability Control (RSC) function,
- Stability and Traction Control (STC)/ Dynamic Stability and Traction Control (DSTC) manually ON/OFF,
- Driving direction,
- Brake pedal position,
- Clutch pedal position,
- Stability Control (SC) control mode,
- Active Yaw Control (AYC) control mode,
- Anti-lock Break System (ABS) ABS control mode,
- Traction Control (TC) control mode,
- Electronic Brake Force Distribution (EBD) control mode, and
- Roll Stability Control (RSC) control mode.

A brief description of some of the important parameters is given below.

Steering Wheel Angle

The steering wheel angle determines the angle that the steering wheel is being turned from the "straight forward" position. The resolution is 5.6° in both directions. A (+) sign represents right turn and (-) represents a left turn. *(39)*

Latitudinal and Longitudinal Acceleration

Latitudinal is the acceleration orthogonal to the driving direction. The (+) sign represents forward and right direction and the (-) represents the backward and left direction. Longitudinal acceleration is the acceleration in the driving direction of the car. It is measured by accelerometers placed near the center of the vehicle. *(39)*

Roll Rate

The roll rate describes the rotation speed around a coordinate axis pointing in the direction of the vehicle. The measuring sensors are placed near the center of gravity of the vehicle. *(39)*

Driver Requested Torque

It displays the amount of torque the driver wants to get out of the engine (i.e., to what extent the accelerator is pressed). A modern Volvo engine has a computer-controlled electronic throttle. There is no mechanical connection between the throttle plate and the accelerator. Instead, the pedal has a sensor attached to it which directly communicates with the ECU and delivers the parameter Driver Requested Torque. The electronic throttle system has some advantages. The EDU optimizes the driver input signals which result in smoother operation, lower fuel consumption and lower emissions. It also handles idle speed function and cruise control. *(39)*

Engine Torque

This parameter represents the actual torque the engine is delivering at the sampling moment. This torque differs from the torque delivered by driving wheels. *(39)*

Actual Yaw Rate

The Yaw rate is the angular velocity of the vehicle around the vertical Z axis. This determines how fast the car is changing directions. The Yaw rate sensor is placed near the center of gravity of the vehicle. *(39)*

Engine Speed

This parameter is obtained by sampling the CAN parameter Engine Speed. *(39)*

Engine Speed QF

The engine speed quality factor shows the reliability of the engine speed information in the following way: *(39)*

0 x 01 = accuracy undefined
0 x 02 = data temporary undefined
0 x 03 = accuracy of data not within specification
0 x 04 = data calculated with specified accuracy

BCM Voltage Supply

This parameter indicates the voltage level the Brake Control Module (BCM) is supplied with. A minimum voltage of 8V is required for CAN network and the processors to function. *(39)*

Engine Torque QF

The engine torque quality factor shows the status and reliability of the torque sensors. The four codes which determine this information are: *(39)*

0 x 01 = accuracy undefined
0 x 02 = data temporary undefined
0 x 03 = accuracy of data not within specification
0 x 04 = data calculated with specified accuracy

BCM Functions Enabled/Disabled

BCM is the heart of the PCR. All the crash information is saved here. Many of the comfort and handling improving functions are controlled by the BCM. These include:

- Anti-lock Brake System (ABS),
- Electronic Brake Distribution System (EBD),
- Stability Control (SC),
- Traction Control (TC),
- Active Yaw Rate (AYC), and
- Roll Stability Control (RSC).
-

This parameter records the status of the BCM controlled functions and when the cease to function.*(39)*

STC/DSTC Switch Manually On/Off

Stability and Traction Control (STC) prevents the wheels from spinning when starting and accelerating. It also counteracts wheel spin on slippery spots while driving.

Dynamic Stability and Traction Control (DSTC) is an anti-skid system. DSTC uses several sensors to measure the rotation of the wheels, steering wheel angle, lateral acceleration, and actual yaw rate. BCM uses this information to compare the ideal handling of the vehicle with the present handling. Then, by braking one of more wheels, it automatically corrects or prevents a skid motion. *(39)*

Brake Pedal Position

It determines to what extent the brake pedal is pressed down. A Pedal Travel Sensor (PTS) registers the movement the position of the pin which is pressed when brakes are applied. This is divided into 4 levels: PTS inactive, PTS 0-1 cm, PTS 1-2 cm, and PTS > 2cm. *(39)*

Clutch Pedal

The handling of the clutch pedal is recorded as: position unknown, not pressed down, partly pressed down and fully pressed down. *(39)*

BCM Function Active/Inactive

BCM controls the functions, ABS, EBD, SC, TC, AYR, and RSC. These functions remain inactive as long as the BCM tells them not to go active. The decision to become active is mastered by advanced algorithms in the control unit. The control unit gets information from the various sensors in the car. *(39)*

5.3.1 The Multiplex System in Volvo

The Volvo model S80 consists of different operative modules connected via the CAN network. The network consists of high-speed network for the engine control and a low-speed network for the rest of the car. The figure below shows the high speed and the low speed network. The network in the front of the car in the high speed network and the network running along the second half of the car is the low speed network. *(39)*

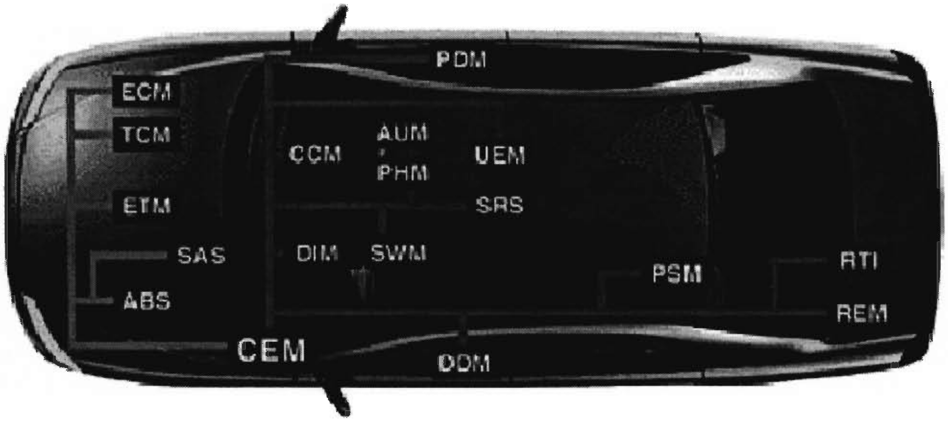


Figure 31: High and Low Speed Network in a Volvo Car *(39)*

The modules are micro computers that are controlled by the Central Electronic Module (CEM). There are about 15 operative modules in an S80 which control almost all of the electrical functions in the car, for instance climate control, ABS, electrical control in the driver's door, etc. Information addressed to different parts of the car circulates simultaneously on the same network cable. The modules recognize and pick up the package meant for them. This is called Multiplexing. *(39)*

5.3.2 Data Recording

The data in the various parts of the car is continuously circulating in the CAN. The main parameters are regularly recorded in the RAM. The data for the last 5 seconds is held in the memory. When a sever collision occurs, the Supplement Restraint System (SRS) sends a signal to the Central Electronic Module (CEM) via the CAN to lock the RAM. This information from the RAM is then transferred to the EEPROM located in the BCM. If an accident is followed by another one, the information about the first accident only is stored in the EEPROM. The readout from the cars is done using a Volvo Standard called D2. *(39)*

5.4 Improving On-Vehicle Networks Interface with EDRs

Understanding the workings of the Volvo's Pre Crash Recorder (PCR), General Motor's Sensing Diagnostic Module (SDM) and the Ford's Restraint Control Module (RCM) make evident that understanding the interface between EDR's and On-Vehicle Networks is one of the key steps towards understanding the working of EDRs. All EDRs reproduce data that has been captured by the On-Vehicle Network. Present day EDRs are technologically advanced and capture a large quantity amount of information which can be useful in understanding specific collision scenarios so that future crashes can be prevented.

5.4.1 Recommendations for Future EDRs

So far in this report we have looked at various features of an EDR and come across different data elements that it can measure. These data elements are very helpful, however there are the data collecting agencies have suggested some additional data elements to assist future EDR hardware and software applications. These additions are in data collection, pre-crash, crash and post crash data. *(4)*

Some proposed recommendations for data collection are: *(4)*

- Lock the deployment record data in EEPROM such that the data cannot be erased, altered, or cleared by service or crash personnel.
- Use SAEJ211 protocol for collecting data.
- Locate the EDR in a crash survivable location while still providing post crash inspection accessibility.
- Ensure sufficient back up power to record the entire crash sequence even when the vehicle electrical system is damaged.
- Employ a single universal crash data retrieval tool for downloading data.
- The universal crash data retrieval tools should be able to be connected directly to the EDR for downloads.
- Record Data for at least two events.

Recommendations for Pre-Crash Data: *(4)*

- Record vehicle speed for 10 seconds before algorithm starts (MPH).
- Record engine speed for 10 seconds before algorithm starts (RPM).
- Record throttle position for 10 seconds before algorithm starts.
- Record the brake switch status for 10 seconds before algorithm enable (on/off).
- Record the actuation of antilock brake system for 10 seconds before algorithm starts (on/off).

Recommendations for Crash Data: *(4)*

- Record the status of the warning lamp (ON/OFF).
- Record the status of the driver and the passenger belt switch (buckled/unbuckled).
- Record the driver and passenger air bag suppression switch status (ON/OFF).
- Record the ignition cycle at deployment and investigation.
- Record the air bag deployment level. (i.e. First stage or second stage deployment.)
- Record the time from algorithm enable to airbag first stage or single stage deployment.
- Record the time from algorithm enable to driver and passenger pretensioner deployment.
- Record the time between two event files if they are in same ignition cycles.
- Record driver and passenger seat position.
- Record the data from the passenger seat weight/position sensor.

Crash Pulse Graphs: *(4)*

- Record at least 300 ms of crash pulse decelerated data.
- Record both longitudinal and lateral axes data.

At the third NHTSA T&B EDR WG meeting help at Florida Atlantic University in Boca Raton, Florida it was agreed that three breakout sessions should be formed to develop a data element list, survivability list, and other EDR related item. These three breakout sessions were from June to September 2001. They were on 27 June 2001, 14 August 2001 and 24 September 2001. The last breakout session was a teleconference. The results of these breakout sessions were proposed a list of data elements. These data elements were grouped in three categories based on their priority. *(40)*

The priority 1 data elements included: *(40)*

- Acceleration, X (Longitudinal)
- Acceleration, Y (Lateral)
- Acceleration, Z (Vertical)
- Acceleration Pedal Position
- Antilock Brake System Status (ABS)
- Automatic Transmission Gear Selection
- Belt Status (driver)
- Brake Status (Service Pedal, Emergency, Trailer)
- Engine RPM
- Identification
- Time/Date
- Vehicle Speed
- Wheel Speeds

The priority 2 data elements included: *(40)*

- Air Bag deploy time
- Air Bag Lamp Status
- Air Bag Status
- Battery Voltage
- Cruise Control (and Auto Distance)
- Heading
- Retarder System Status which determines whether the retarder system is turned on and activated at the time of the crash.
- Steering Wheel Angle

- Traction Control
- Turn Signal/Hazard Operation
- Windshield Wiper Status

The optional data elements included: *(40)*

- Digital Imaging

Based on the findings of NHTSA's Second Working Group, priority 1 data elements are those that should be the core data elements of all EDRs. It was also suggested that the manufactures should be allowed to offer minimum configurations (such as priority 1 data elements) plus additional features. The priority 2 data elements should be very closely considered when designing an EDR as they can help greatly in better crash reconstruction leading to safer highways and possibly fewer deaths and injuries on the highways.

5.4.2 Recommendation for Reliability of EDR Data

The survivability of EDRs raises the doubts about the reliability of EDR data because the EDR data can be lost or questionable due to power loss and sensor problems. For instance, the SDM used in 1999 and few 2000 GM cars were faulty. The problem with this system was that if the vehicle's electrical system is harmed during the crash, then the driver's seatbelt switch may incorrectly report the status. It may report the switch to be unbuckled even if it was buckled. A problem was found with the 2000 Ford Sable/Taurus also where the data stored in the EDR is lost in case of an electrical failure. *(4)*

This is one of the reasons that survivability of EDRs is one of the biggest issues addressed by NHTSA's Working Group. The main purpose of this is to ensure that the EDR memory survives crashes such that recorded data can still be retrieved. *(40)* Some of the factors examined included: *(40)*

- Location,
- Impact Shock,
- Temperature,
- Immersion,
- Fluid Immersion,
- Penetration,
- Static Crush,
- Fire,
- Independent Power and
- Survivability of stored data.

A detailed understanding of these factors is given below which can help us understand how important it is to improve these factors.

Location

The location of the EDR in the vehicle is one of the most important factors. The proper placement of the EDR can minimize survivability requirements and costs. The ideal location of the EDR depends on the type of the vehicle. *(40)*

Impact Shock

It is important to protect the EDR from impact damage. EDRs should be capable of surviving an impact shock of 300g for duration of 50 milliseconds. *(40)*

Temperature

EDRs low temperature tolerance can put the EDR data at risk as vehicles operate on a wide range of temperatures depending on climatic conditions and the engine of the car. Thus, a minimum temperature constraint should be set. The NHTSA working group found that EDRs should have a temperature requirement of 40 degrees for 8 hours. *(40)*

Immersion

For Flight Data Recorders (FDRs), design for a deep sea immersion of 30 days is required. Shallow immersion for a short period of time is important for EDR's. Deep sea immersion is not a concern for EDRs thus there is no requirement set by the working group for deep sea immersion. *(40)*

Fluid Immersion

This feature is slightly different from the previous feature. During a crash, EDRs can be exposed to or immersed in fluids such as water, salt water, fuel and oil. To ensure that exposure to fluids does not damage EDR data, the working group found that EDRs should be able to withstand immersion from such liquids for at least 8 hours. *(40)*

Penetration

Penetration of the EDR during a crash can cause serious damage to the EDR and can result in loss of data. The working group recommended that EDRs should be able to survive 200 pounds dropped from 3 feet with a ½ - inch diameter contact point. *(40)*

Static Crush

During a crash, the memory of the EDR can be severely damaged or ruined due to static crush. The working group suggested that the EDR memory should be able to survive a static crush. *(40)*

Fire

According to highway crash data, a relatively small percentage of crashes result in catastrophic fires but in case of such fires all the EDR data is destroyed. This data can be crucial in understanding crashes such that such crashes can be avoided in future. The working group did not address the fire survivability as a high priority but it is important to readdress this factor such that EDRs can survive fire. *(40)*

Independent Power

Independent power is another very important factor. Independent power can help in saving and recording EDR data in case there is a complete electrical failure of the vehicle. Independent power can be supplied from a device within the EDR or from an external source. The independent power should have sufficient reserve to enable EDR to record data for at least one minute. *(40)*

Survivability of Stored Data

In many cases, the EDR data is not immediately accessed after the crash. Thus, it is important that the EDR data is stored safely after the crash. The working group has suggested that the EDR should be able to save the recorded data safely without an external power supply for 30 days. *(40)*

The 2002 NASS gave some statistics on EDR Data Distribution of un-recovered EDRs. The data from these EDRs could not be recovered due to various reasons, such as: *(41)*

- **Data collection failed/no recording:** The EDRs in this category included cases where the recording device did not record any of the data or the criteria to record were not met in the crash. *(41)*
- **Software issues:** This category consists of cases where issues with the cable or software prevented obtaining data from the EDR. This also included cases with unsuccessful OBD (On Board Diagnostic Systems) attempts. *(41)*
- **OBD unusable (no power, keys, etc), direct connection unspecified:** In these cases, it was impossible to obtain data from the EDR via the vehicles diagnostic system. No attempt to make a direct connection to the recording device was explained. *(41)*
- **Technical/training issues:** This category consists of cases where the crash data was not available due to technical issues such as inability to access the data recording device without causing undue damage to the vehicle, partial inspection of vehicles, etc. *(41)*
- **Crash damage prevented access:** The cases in this category included those where the recording device could not be physically accessed. *(41)*
- **No permission:** Permission was not given to interrogate the EDR. *(41)*

The following figure shows EDR data distribution of the un-recovered EDRs due to various reasons explained above:

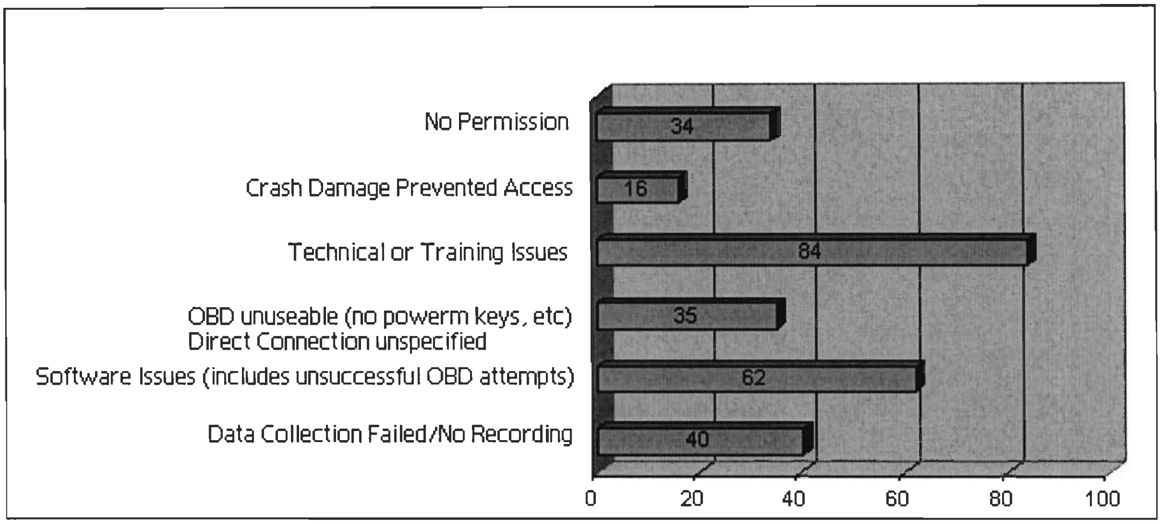


Figure 32: EDR data distribution of the un-recovered EDRs ***(41)***

From this data we can see that to be able to use EDR data to its fullest potential it is essential to improve on some of the EDR factors which hamper the ability to retrieve the data.

6 BENEFITS OF EDRs

The purpose of having EDRs is to be able to reconstruct crash scenarios such that they can help avoid crashes in the future. Some of the other advantages of EDRs are:

- Helps the police in investigating crashes.
- It can help insurance companies in avoiding fraud.
- People may drive more cautiously.
- EDR data helps in improving existing technology.
- Helps locating stolen vehicles using ACN or other technologies using GPS.

Police Investigations

One major use of EDRs is to help police in investigating crashes. For instance, at what speed the vehicle was traveling when the collision happened? Were the seat belts buckled or not? These details help investigators determine the actual details of the crash and assist in determining the cause of the crash.

Insurance Company Fraud

The data from EDRs are used by insurance companies to investigate accidents and injury causation in auto claims. This was formerly not possible without spending thousands of dollars on forensic expert evaluation and waiting for months. EDR data is used for investigating false injury claims for low speed crashes also.

Insurance frauds have been increasing every year. For instance, in 2001 auto insurance frauds cost New Yorkers an average of $200 per driver. *(42)* In total, auto insurance costs New Yorkers $1billion per year and costs Americans over $23 billion per year. *(42)* Another set of data showed that the number of auto insurance fraud cases in New York has doubled in number since 1998 to 1999. *(43)*

EDR provides parameters, such as delta V which can help in determining the actually speed of the vehicle at the time of the crash. These details can help in distinguishing intentional and unintentional crashes.

Cautious Drivers

The presence of a device which records your actions may make drives more cautious and careful while driving. This can reduce the number of crashes as drivers maintain safe speeds and avoid risky behaviors.

Improving Existing Technology

The data collected from the EDRs can help in understanding different modules of the vehicle and how they can be improved. For instance, it can help in improving the airbag module such that there are fewer fatalities due to airbag deployment. Statistics show that from 1990 – 2000 there were approximately 194 air bag related low speed fatalities. Another 50 fatalities were caused due to side air bags. *(44)* A better understanding of the air bag deployment event can help in redesigning air bags such that the fatality and injury rates can be reduced. Some of the life threatening injuries that can be caused from air bag deployment are: *(44)*

- Neck fracture,
- Spinal Cord damage,
- Brain swelling,
- Rib fracture with heart laceration and
- Abruption of placenta and fatal fetus (for pregnant women).

These are only some of the injuries; there are many more serious injuries that can be caused by air bag deployment.

EDRs can provide the insight on the air bag modules which can help in making safer air bags for future. Some vehicle manufactures have already started using “smart air bags” which deploy depending on the body structure, weight and size of the occupant.

Using ACN and Other GPS Based Technologies

ACN (Automatic Collision Notification) technology enables to provide immediate medical assistance by linking the crash site to 9-1-1 and EMS. Cars with ACN have collisions sensors connected to in-vehicle telematics systems that automatically send a wireless alert signal and accident location information to response centers. Over one million cars on the road today already have ACN capabilities -- most are from General Motors and Mercedes Benz. *(45)* Another similar system is the OnStar which uses Global Positioning System (GPS) satellite network and wireless technology to link driver and vehicle to the OnStar Center. OnStar services include: *(46)*

- Automatic notification of air bag deployment,
- Stolen vehicle tracking,
- Emergency services,
- Roadside assistance with location,
- Remote door unlock,
- Remote diagnostics,
- Route support,
- OnStar Concierge and
- Convenience services locator.

OnStar mobile communications services in Honda and Acura vehicles beginning with the 2002 Acura RL luxury sedan sold in the US. *(46)* These systems are like advanced EDRs with additional features. These systems can help in locating stolen vehicles also.

6.1 Costs of an EDR System

The cost of and EDR or more simply an airbag control module varies from vehicle to vehicle. It is hard to estimate the cost of installing the airbag control module during the manufacturing process as it is included in the total cost of the vehicle but an approximate cost range of the airbag control module can be obtained by looking at cost of replacing an airbag after a crash.

Airbag control modules are expensive. Prices of these replacement airbag modules are high, averaging \$500~\$600 dollars per unit in the US after market, even higher in other markets. Today, on a double deployment of an air bag system (driver and passenger) the minimum cost to replace the components is \$1,200 - \$1,500. On some models, this cost can run as high as \$3,000 - \$4,000. *(47)* A typical airbag control system consists of: *(47)*

- The airbag,
- The clockspring that is located in the steering wheel,
- Crash sensors that sense the impact and relay info to the computer modules and
- The computer control modules that monitor and activate the system.

The cost of replacing the airbag module (driver or passenger side airbag) for some vehicle is as follows *(48), (49), (50)*:

Vehicle	**Cost of replacing airbag module**
2000 DeVille (driver airbag)	\$790
2000 S-Class Mercedes (driver airbag)	\$890
Volvo V70 Wagon (driver airbag)	\$982
Volvo V70 Wagon (passenger airbag)	\$1242
1994 Taurus (driver airbag)	\$597
1994 Taurus (passenger airbag)	\$773
1997 Volkswagen GTI VR6 (driver airbag)	\$722
1997 Volkswagen GTI VR6 (passenger airbag)	\$743

Figure 33: Cost of Replacing Airbag

These numbers are only for a few cars and gives cost of replacing the driver or passenger airbags. The replacement of airbags requires more changes also. The two cases mentioned below give details on how much replacing an entire airbag module costs.

Volkswagen GTI VR6 *(49)*

Parts	Cost
Air Bag Driver with tilt	$ 722.00
Air Bag Passenger	$ 743.00
Cover	$ 68.90
Clockspring with tilt	$ 92.70
Control Module	$ 421.85
Bracket	$ 8.55
RT Retractor	$ 55.90
LT Retractor	$ 55.90
Labor	$ 164.10
TOTAL	**$ 2332.90**

1994 Taurus *(50)*

Parts	Part Cost	Bodyshop Labor Cost	Mechnical Labor Cost
Airbag (Driver)	597.00	0	10.00
Airbag (Passenger)	773.00	0	25.00
Sensor Impact, Front	65.00	0	25.00
Sensor Impact, Rear	54.00	0	25.00
Contact, Airbag	93.00	0	60.00
TOTAL $1727			

6.2 Various Costs due to Crashes

A report by NHTSA presents the results of motor vehicle crash costs in 2000. The total economic cost of motor vehicle crashes in 2000 was $230.6 billion. This represents the present value of lifetime costs for 41,821 fatalities, 5.3 million nonfatal injuries, and 28 million damaged vehicles, in both police reported and unreported crashes. Motor vehicle crashes cost the society $4,800 per second. According to NHTSA's study titled "The Economic Impact of Motor Vehicle Crashes 2000," the estimated yearly economic cost of roadway crashes is: *(52)*

- Property damage costs of $59 billion,
- lost market productivity accounted for $61 billion,
- $20.2 billion in lost household productivity,
- medical expenses totaled $32.6 billion,
- $25.6 billion in travel delay costs and
- other costs are $26.6 billion.

The figure below shows the total cost distribution for crashes in 2000.

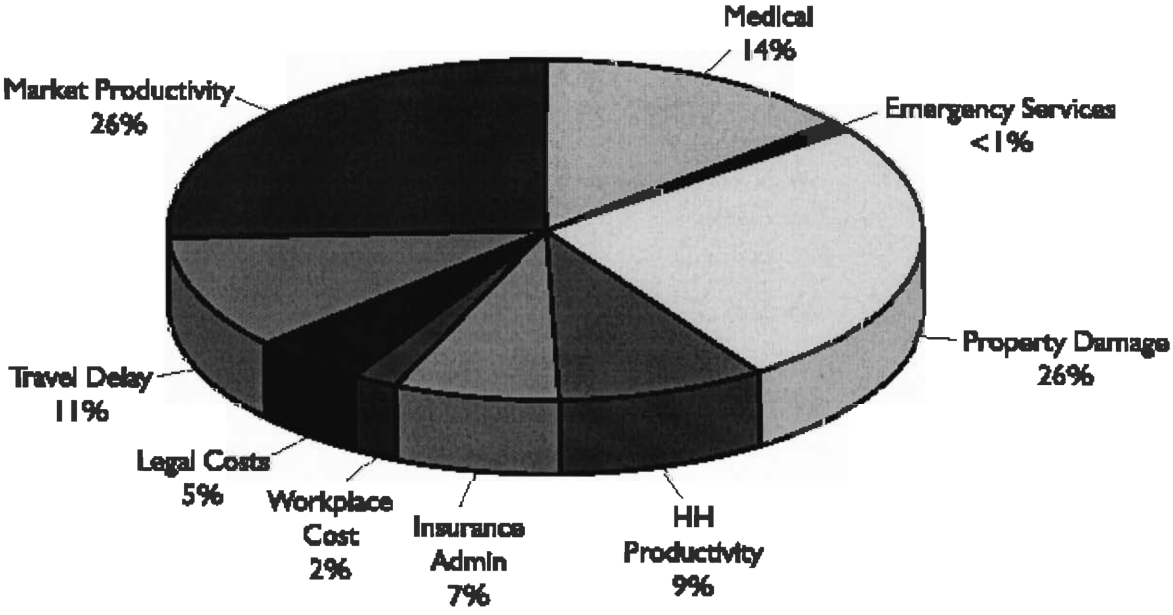


Figure 34: Total Cost of Crashes in 2000 *(52)*

According to this report, each fatality resulted in an average discounted lifetime cost of $977,000. Another Traffic Safety Summit in 2002, showed that the total cost of motor vehicle Crashes in US in 2002 accounted for $230.6 billion. That is $820 for every person in the US. *(52)*

According to CIREN statistics, every year there are approximately: *(53)*

- 42,000 crash deaths,
- 250,000 life threatening injuries,
- 500,000 hospitalization,
- 2,000,000 are disabled by injuries and
- 4,000,000 emergency department visits.

Motor vehicle crashes are responsible for a large number of life threatening diseases.

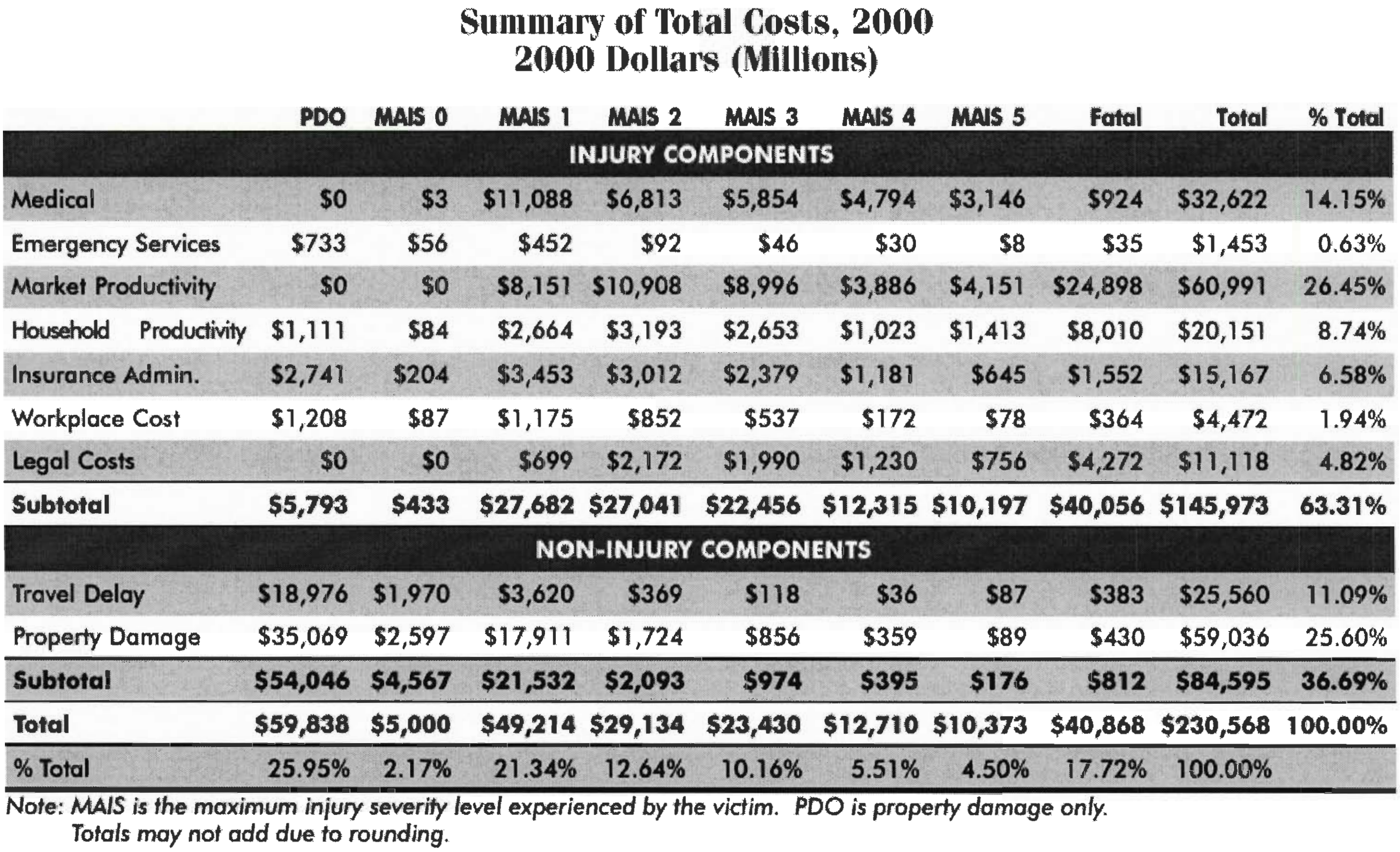
Estimates on the number of serious crash injuries occurring each year in the US are: *(53)*

- 70,000 brain injuries,
- 4,400 neck and spinal cord injuries,
- 80,000 chest and abdominal injuries: Heart, Lungs, Spleen, Liver and Kidney,
- 18,000 hip and pelvic injuries and
- 35,000 leg, ankle and foot injuries.

6.3 Human Capital Costs

Table shown in figure 35 and figure 36 show data collected by NHTSA for the total cost of crashes in the year 2000. The first table shows the various costs for the total number of crashes in the year 2000. The second table shows the unit cost per person for a crash. The data is divided from MAIS 0 to MAIS 5, where MAIS implies Maximum Injury Severity Level. MAIS 0 represents minimal injury and MAIS 5 represents maximum injury level. *(52)*

According to the data shown in the table below, the total cost of a crash ranges from $433 million - $145, 973 million depending on the severity of the crash. The total cost of fatalities can range from $812 million - $40,056 million. The damage to the property can range from $5,793 million - $54,046 million. The total costs are divided in two main parts: costs due to injuries and costs due to non-injury components. The injury components make up for 63.31% of the total cost.



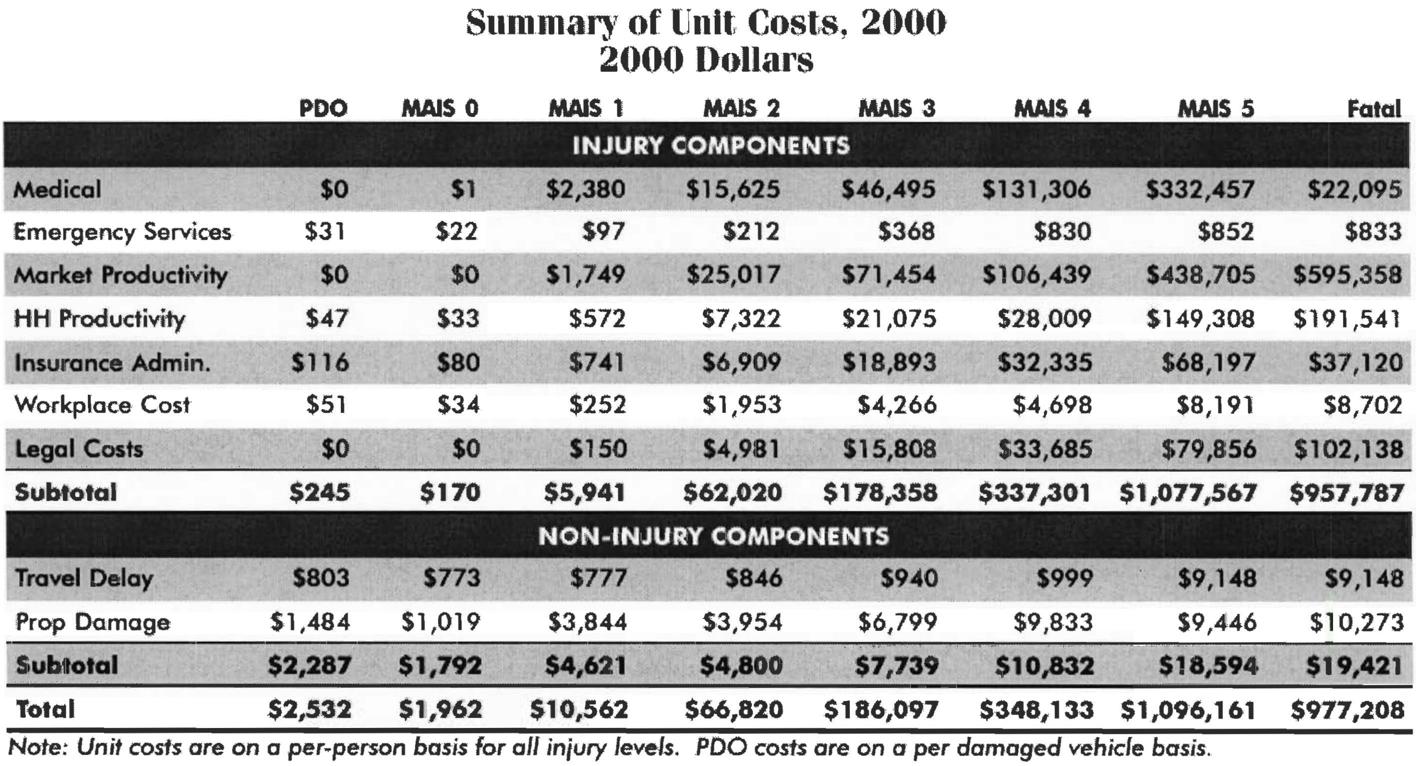
Summary of Total Costs, 2000
2000 Dollars (Millions)

	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total	% Total
INJURY COMPONENTS										
Medical	$0	$3	$11,088	$6,813	$5,854	$4,794	$3,146	$924	$32,622	14.15%
Emergency Services	$733	$56	$452	$92	$46	$30	$8	$35	$1,453	0.63%
Market Productivity	$0	$0	$8,151	$10,908	$8,996	$3,886	$4,151	$24,898	$60,991	26.45%
Household Productivity	$1,111	$84	$2,664	$3,193	$2,653	$1,023	$1,413	$8,010	$20,151	8.74%
Insurance Admin.	$2,741	$204	$3,453	$3,012	$2,379	$1,181	$645	$1,552	$15,167	6.58%
Workplace Cost	$1,208	$87	$1,175	$852	$537	$172	$78	$364	$4,472	1.94%
Legal Costs	$0	$0	$699	$2,172	$1,990	$1,230	$756	$4,272	$11,118	4.82%
Subtotal	**$5,793**	**$433**	**$27,682**	**$27,041**	**$22,456**	**$12,315**	**$10,197**	**$40,056**	**$145,973**	**63.31%**
NON-INJURY COMPONENTS										
Travel Delay	$18,976	$1,970	$3,620	$369	$118	$36	$87	$383	$25,560	11.09%
Property Damage	$35,069	$2,597	$17,911	$1,724	$856	$359	$89	$430	$59,036	25.60%
Subtotal	**$54,046**	**$4,567**	**$21,532**	**$2,093**	**$974**	**$395**	**$176**	**$812**	**$84,595**	**36.69%**
Total	**$59,838**	**$5,000**	**$49,214**	**$29,134**	**$23,430**	**$12,710**	**$10,373**	**$40,868**	**$230,568**	**100.00%**
% Total	25.95%	2.17%	21.34%	12.64%	10.16%	5.51%	4.50%	17.72%	100.00%	

Note: MAIS is the maximum injury severity level experienced by the victim. PDO is property damage only.
Totals may not add due to rounding.

Figure 35: Total Cost Due to Crashes in 2000 *(52)*

According to the data given below, the total cost per person depending on the severity of a crash ranges from $170 - $1,077,567. The total cost due to fatalities can range from $957,787 - $977, 208. Costs of damage per vehicle range from $245 - $2532. The cost per person is also divided in two main categories: injury and non-injury components. The injury components account for most of the total cost.



Summary of Unit Costs, 2000
2000 Dollars

	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
INJURY COMPONENTS								
Medical	$0	$1	$2,380	$15,625	$46,495	$131,306	$332,457	$22,095
Emergency Services	$31	$22	$97	$212	$368	$830	$852	$833
Market Productivity	$0	$0	$1,749	$25,017	$71,454	$106,439	$438,705	$595,358
HH Productivity	$47	$33	$572	$7,322	$21,075	$28,009	$149,308	$191,541
Insurance Admin.	$116	$80	$741	$6,909	$18,893	$32,335	$68,197	$37,120
Workplace Cost	$51	$34	$252	$1,953	$4,266	$4,698	$8,191	$8,702
Legal Costs	$0	$0	$150	$4,981	$15,808	$33,685	$79,856	$102,138
Subtotal	**$245**	**$170**	**$5,941**	**$62,020**	**$178,358**	**$337,301**	**$1,077,567**	**$957,787**
NON-INJURY COMPONENTS								
Travel Delay	$803	$773	$777	$846	$940	$999	$9,148	$9,148
Prop Damage	$1,484	$1,019	$3,844	$3,954	$6,799	$9,833	$9,446	$10,273
Subtotal	**$2,287**	**$1,792**	**$4,621**	**$4,800**	**$7,739**	**$10,832**	**$18,594**	**$19,421**
Total	**$2,532**	**$1,962**	**$10,562**	**$66,820**	**$186,097**	**$348,133**	**$1,096,161**	**$977,208**

Note: Unit costs are on a per-person basis for all injury levels. PDO costs are on a per damaged vehicle basis.

Figure 36: Total Cost per Person Due to Crashes in 2000 *(52)*

6.4 Costs Reduced by Airbag Modules

According to the National Highway Traffic Safety Administration, more than 6200 people are alive as of November 1, 2000 because of airbags. Driver deaths have reduced by about 14 percent. Passenger airbags have reduced deaths by 11 percent. *(51)*

Seat belts have also lowered the number of deaths. In 2000 seat belts prevented 11,900 fatalities and 325,000 serious injuries, saving $50 billion in medical care, lost productivity and other injury related costs. NHTSA estimates that 9,000 of the 42,000 auto-related fatalities in the U.S. in 2001 could have been avoided with the use of seat belts. Combination of an airbag in addition to a lap and shoulder belt reduces the risk of serious head injury by 75 percent, compared with a 38 percent reduction for belts alone. *(52)*

Presently over 134 million (62.6%) of the more than 214 million cars and light trucks on U.S. roads have driver airbags. Over 113 million (52.5%) of these also have passenger airbags. Another 1 million new vehicles with airbags are being sold each month. Crash studies by the National Highway Traffic Safety Administration (NHTSA) show that airbags reduced death fatalities in a direct frontal crash by about 30%. The increasing trend towards requiring airbags in all new cars reflects realization of the airbag's benefits. As more new cars come standardized with airbags, the rate of deaths in high-speed accidents will decrease. *(54)* The following table shows an estimate on the number of deaths that airbags have prevented. These statistics have been collected from various sources. *(55)*

Year	**Lives Saved by Airbags**
1995	600
1996	700
1997	842
1998	1048
2001	1584
1987 – 2001	7,224

Figure 37: Lives Saved by Airbags

According to the cost per person, due to a crash, mentioned in the table in figure 36 we can approximate the amount of money saved with the use of airbags in the past few years. For instance, in 1995 about 600 lives were saved by using airbags. So the amount of money saved in this year was approximately:

$977, 208 x 600 ≈ $586,324,800

The following table shows an approximate amount of money saved in different years due to the use of airbags. These costs are an approximate value and are determined by using the cost of crashes for the year 2000 only. These costs are only for the fatalities avoided with the use of airbags. But there are additional costs due to crashes which are mentioned in figure 35 and figure 36.

Year	**Lives Saved by Airbags**	**Amount of Money Saved**
1995	600	≈ $586,324,800
1996	700	≈ $684,045,600
1997	842	≈ $822,809,136
1998	1048	≈ $1,059,293,472
2001	1584	≈ $1,547,897,472
1987 – 2001	7,224	≈ $7,059,350,592

Based on these statistics we can say that the use of airbags has helped in bringing down the costs of crashes. Usage of seatbelts has also helped in lowering costs of crashes and reducing the number of fatalities and injuries.

6.5 Societal Benefit

The main benefit of an EDR is that it can give data which can help in saving the lives of thousand of other people. The cost effectiveness of an EDR can be evaluated by analyzing the cost of an EDR and comparing it to the total amount of money that is spent due to crashes.

For instance, using the data collected in this report we can estimate the following costs for the year 2000:

Number of cars manufactured in 2000 (all cars produced at present have airbag control modules): *(56)*

1,587,608

Cost of Airbag Control Module in 2000:

Approximately \$500 ~ \$600

This is the cost of replacing the airbag module and not the cost of installing the airbag module while manufacture of the vehicle.

Number of airbag equipped vehicles x **Cost of airbag control module =**

1,587,608 x (\$500 ~ \$600)

Total Cost = \$ 0.794 billion ~ \$0.953 billion

Number of lives saved in 2000 by airbags and seatbelts:

Lives saved by using seatbelts: 11,900

Lives saved by using airbags: 1,584

Total: 13,484

Injuries prevented by seatbelts: 325,000

Injuries prevented by airbags: 182,000

Total: 507,000

Cost per life (fatalities plus injuries) in 2000:

Cost per fatality: $977, 208

Cost due to injuries: $1,962 - $1,096,161

Lowest cost of injury: $1,962

Highest cost of injury: $1,096,161

Cost per life x **Number of lives saved:**

Cost of fatalities: $977,208 x 13,484 = $13.18 billion

Lowest cost of injury: $1,962 x 507,000 = $0.995 billion

Highest cost of injury: $1,096,161 x 507,000 = $ 555.75 billion

Total cost: ($13.18 billion + $0.995 billion) ~ ($13.18 billion + $555.75 billion)

Total Cost: $14.175 billion ~ $568.93 billion

If we compared the total amount of money spend on installing airbag modules in cars to the total amount of money saved due to airbag module, we can see that the amount of money saved by airbag modules is much higher. From the above calculations we can see that, the cost of airbag modules for the year of 2000 was approximately between $ 0.794 billion to $0.953 billion. Where as the amount of money saved with the use of airbags ranged between $14.175 billion to $568.93 billion. This shows us the cost benefit of using airbags and Event Data Recorders is very high and is a very good deal for the society.

Event Data Recorders help us in saving the amount of money that is spend every year due to crashes and also the irreplaceable human lives. Event Data Recorders have proved beneficial to our society in every way and have helped us understand and improve the existing technology for a better and safer tomorrow.

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