U.S. Department
of Transportation

Development of Collision Avoidance Data for Light Vehicles:

Near-Crash/Crash Event Data Recorders


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13. ABSTRACT (Maximum 200 words)

This report presents the results of an analysis effort undertaken to address the following research question: What sensor(s) can be cost effectively added to vehicles on a wide scale to significantly improve our understanding and modeling of naturalistic near-crash/pre-crash driver performance?

Current sensor and computer technology allows for the efficient collection and storage of driver and vehicle performance data on board vehicles. Crash data recorders or black boxes exist today on many vehicles though they are limited in number of recorded parameters and storage capacity. However, their capability is increasing. Recent field operational tests of advanced-technology crash avoidance systems and naturalistic driving data collection efforts have employed comprehensive data acquisition systems to characterize driver and vehicle performance as well as the driving environment. These projects gathered data on driver exposure to various environmental factors and on driver encounters with driving conflicts, near-crashes, and actual crashes. Unfortunately, the in-vehicle data acquisition packages in these projects cost over $10,000 per vehicle. It would be advantageous to build and install a very small, inexpensive package under $1,000 in a vehicle fleet of 5,000 or more. The presence of low-cost near-crash/crash event data recorders (EDRs) on thousands of vehicles would enable a more accurate assessment of safety benefits for intelligent vehicle crash avoidance technologies, and would greatly improve the quality of data in national crash databases such as the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) and General Estimates System (GES).

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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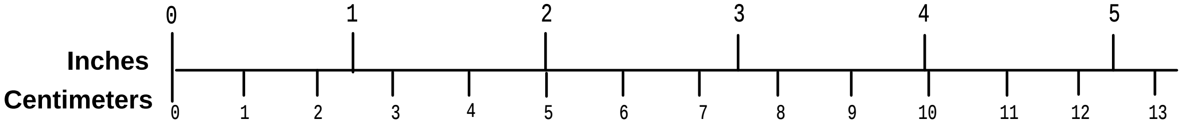

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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LIST OF ACRONYMS

ABS	Anti-lock Braking System
AEDR	Advanced Event Data Recorder
AIRS	Auto Incident Recording System
ANJEL	Automated New Jersey Emergency Locator
ATC	Aberdeen Test Center
BP	Basic Package
CAN	Automated Collision Notification
CDM	Crash Detection Module
CDS	Crashworthiness Data System
CPR	Crash Pulse Recorder
DARR	Digital Accident Research Recorder
DDEC	Detroit Diesel Electronic Control
DMR	Driver Monitoring Recorder
EDR	Event Data Recorder
Evicam	Evidence Camera
FOT	Field Operational Test
FV	Forward View
GES	General Estimates System
GM	General Motors
GPS	Global Positioning System
IAV	Intelligent Adjacent View
IFV	Intelligent Forward View
IRV	Intelligent Rear View
IWI	Independent Witness Incorporated
LD	Lateral Direction
LTAP	Left Turn Across Path
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped
MACBOX	Mobile Accident Camera Box
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
OD	Opposite Direction
OEM	Original Equipment Manufacturer
PCR	Pre-Crash Recorder
RCM	Restraint Control Module
SCI	Special Crash Investigation
SCP	Straight Crossing Paths
SDM	Sensing and Diagnostic Module
SIS	Safety Intelligence Systems
TC	Traction Control
UDS	Unfall Daten Speicher (German for "Accident Data Memory")
VDO	Vereinigte Deutsch… (German for "United German Tachometer Company")
VDOT	Virginia Department of Transportation
VTTI	Virginia Tech Transportation Institute

EXECUTIVE SUMMARY

This report identifies sensors that can be added to motor vehicles on a wide scale in a cost-effective way to significantly improve our understanding and modeling of naturalistic near-crashes, crashes, and pre-crash driver performance. This report first defines general functional requirements of advanced event data recorders (AEDRs) based on the coding structure of national crash databases and crash statistics. These requirements are generated to capture a defined set of dominant pre-crash scenarios and a distribution of known crash causal and contributing factors. Required measures are also proposed to quantify near-crash and pre-crash data needs. The functions, measured parameters, and cost of today's "black boxes" in motor vehicles are collected from a survey of current OEM, aftermarket, and experimental event data recorders (EDRs). OEM EDRs with different complexity are embedded in new vehicles at greater penetration rates. Aftermarket EDRs add more functionality at a higher cost for different applications. Suggested requirements and measures are met by very expensive AEDRs that are currently being used in different field operational tests of crash avoidance systems and in naturalistic driving data collection efforts.

Based on information about crash statistics and current EDR functions and cost, a basic AEDR package and five more advanced packages are proposed as potential in-vehicle near-crash and crash AEDRs. Crash AEDRs would employ similar sensors but less processing and storage capacity than near-crash AEDRs. The basic AEDR package enhances OEM EDRs by adding a positioning sensor, processor, data storage, and camera inside the vehicle to view the driver so as to gain information about causal factors. This package is intended to capture crashes only, not near-crash events. The cost of this basic AEDR package is under $1000 and could be below $500 if the vehicles were equipped with required OEM sensors used for anti-lock brakes and stability control. The incorporation of an intelligent forward view camera in the basic package that measures vehicle position within the lane of travel and the range and range rate to obstacles in the lane ahead proves to be the most efficient in terms of captured events and cost. It is recommended that the capability and limitations of this intelligent camera be characterized under a full spectrum of driving conditions. Moreover, the functional requirements and performance specifications of this enhanced AEDR package need to be defined. Finally, the analysis in this report focuses on the sensory aspect of near-crash and crash AEDRs (front-end analysis); additional analyses must be undertaken to address the processing, storage, and retrieval of data collected by these AEDRs.

1. INTRODUCTION

This report presents the results of an analysis effort that was undertaken to address the following research question:

> *What sensor(s) can be cost-effectively added to vehicles on a wide scale to significantly improve our understanding and modeling of naturalistic near-crashes, crashes, and pre-crash driver performance?*

Crash data recorders, or black boxes, exist today on many vehicle models. Although this type of recorder is very limited in terms of the number of recorded parameters and storage capacity, advanced versions introduced in newer vehicles show promise for use in safety research. To date, field operational tests (FOTs) of advanced-technology crash avoidance systems and naturalistic driving data collection efforts have relied on customized, comprehensive, data acquisition systems to characterize driver and vehicle performance as well as the driving environment. These systems have gathered data on driver exposure to various environmental factors and on driver encounters with driving conflicts, near-crashes, and actual crashes. Unfortunately, the in-vehicle data acquisition packages in these projects were very expensive – over $10,000 per vehicle. That was affordable due to the small size of the test fleet at 100 or less vehicles. For a better understanding of the relationships between crashes and near-crashes and for a more nationally representative sample of data, it would be advantageous to build and install a very small, inexpensive package under $1,000 in a very large vehicle fleet of 5,000 or more vehicles. The presence of such low-cost near-crash/crash *Advanced Event Data Recorders* (AEDRs) on thousands of vehicles would enable a more accurate assessment of safety benefits for various crash countermeasures and intelligent vehicle crash avoidance technologies by creating objective data to better model pre-crash and near-crash events.

This analysis defines general functional requirements of near-crash/crash AEDRs based on an understanding of the most common pre-crash scenarios and causal factors reported in police accident reports and from detailed investigations of specific crashes. The requirements include both the parameters that AEDRs should detect and the measures needed to quantify these parameters. The functionality of current *Event Data Recorders* (EDRs) available from Original Equipment Manufacturers (OEMs), aftermarket products, or built specifically for field trials is then mapped against these requirements to determine what is being measured and at what cost. Moreover, this analysis assesses the performance and cost of vision sensors or other sensors that might have the potential of acquiring the most needed parameters. The development of AEDR devices is envisioned to evolve from the current crash EDR technology to more advanced crash and near-crash data gathering systems using remote sensing capability as shown in Figure 1. A cost/benefit tradeoff study is also conducted to identify the sensors that effectively capture the most pre-crash data at a low cost.

As an outline, this report first describes the pre-crash information of interest to EDR applications, defines AEDR requirements, surveys current EDR products and technology, assesses the cost and benefits of alternative AEDR combinations, and concludes with a summary of major findings.

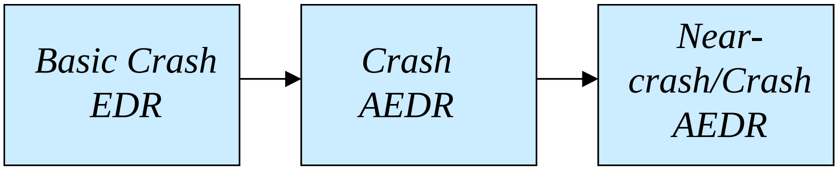


Figure 1. AEDR Development Sequence

2. PRE-CRASH DATA

For a better understanding of intervention opportunities in crash avoidance, it is desirable to obtain qualitative and quantitative knowledge of the events leading to a crash. In particular, there is a need to identify and characterize the dynamically distinct pre-crash scenarios, causal factors, contributing circumstances, and other elements of the driving environment. The *National Automotive Sampling System (NASS)/General Estimates System (GES)* crash database contains a comprehensive list of variables and concomitant codes describing these pre-crash events based on information derived from police accident reports. This type of information will be greatly enhanced by the presence of data recorders on board vehicles that objectively capture data to populate the variables in the GES files. This section presents what is currently known about pre-crash scenarios based on the analysis of GES data and about causal factors obtained from detailed examination of a sample of GES and *Crashworthiness Data System* (CDS) crash files.

2.1. Pre-Crash Scenarios

The NASS/GES and CDS crash databases contain five pre-crash variables that outline the sequence of events leading from a normal driving situation into a collision as shown in Figure 2 [1]. The characterization of the sequence of events leading to collisions is essential to the design of appropriate crash countermeasure systems, the development of their performance specifications and objective test procedures, and the estimation of their safety benefits. The *Movement Prior to Critical Event* variable describes a vehicle's activity prior to the driver's realization of an impending critical event or danger. The *Critical Event* variable identifies the critical event that made the crash imminent (i.e., something occurred that made the collision possible). The combination of these two variables, in conjunction with other variables in the crash database such as the *Accident Type* and *Roadway Geometry* variables, enables the identification of various driving conflicts leading to different crash types. The remaining three pre-crash variables describe the events that follow in response to driving conflicts. The *Corrective Action Attempted* variable describes the actions taken by the driver in response to the impending danger. The *Pre-Crash Vehicle Control* variable assesses the stability of the vehicle during the period immediately prior to the vehicle's initial involvement in the crash sequence. The *Pre-Crash Location* variable identifies the path of the vehicle prior to its first involvement in the crash sequence and further reports the results of the vehicle's pre-crash stability.

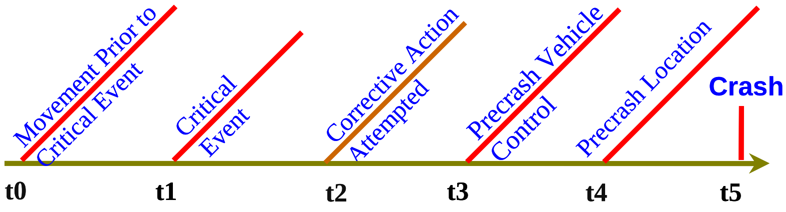


Figure 2. NASS Pre-Crash Variables: Time-to-Crash Sequence of Events

The first pre-crash variable, *Movement Prior to Critical Event*, combines vehicle state with vehicle maneuver as illustrated in Figure 3. The two are drawn separately because each combination provides a unique description of a dynamically distinct pre-crash scenario. Figure 4 breaks down the *Critical Event* variable into five distinct events: two single-vehicle events and three vehicle-obstacle events. The lane crossing single-vehicle event would lead to an encroachment vehicle-vehicle event if there were another vehicle in the adjacent lane. The third pre-crash variable captures driver response to the driving conflict as described by the first two pre-crash variables. Figure 5 identifies the corrective actions that might be taken by the driver, which also include a combination of these actions such as braking and steering.

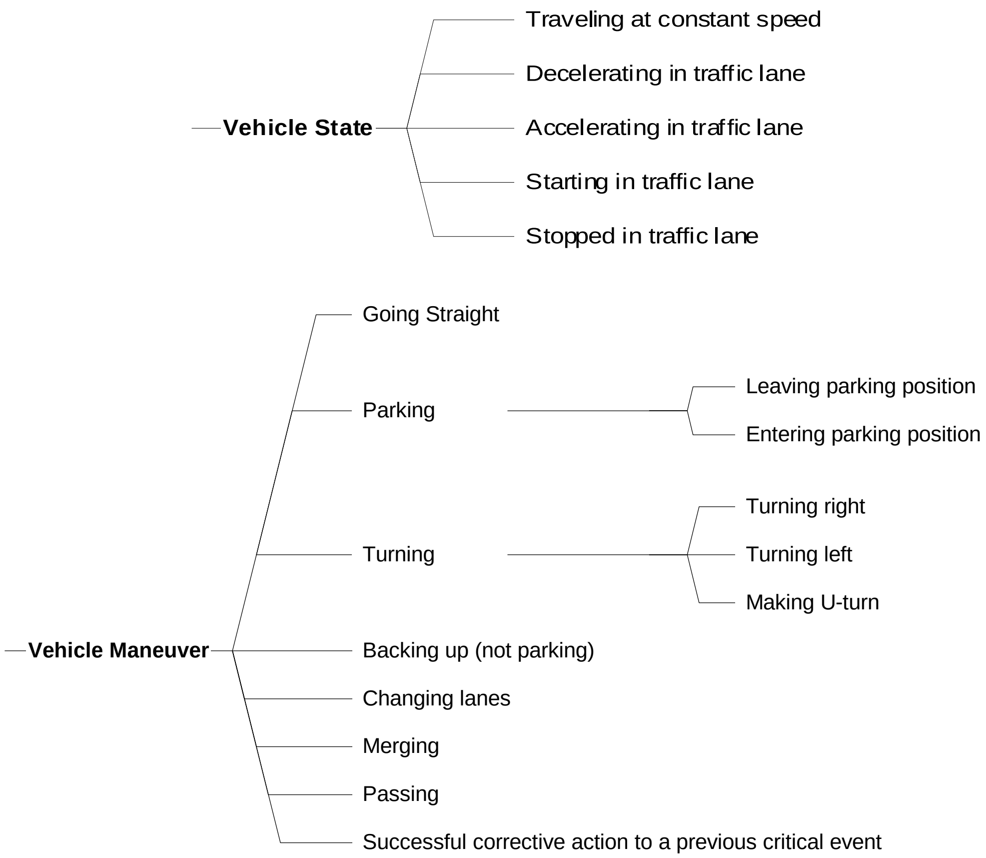


Figure 3. Vehicle States and Maneuvers Represented by GES *Movement Prior to Critical Event* Variable

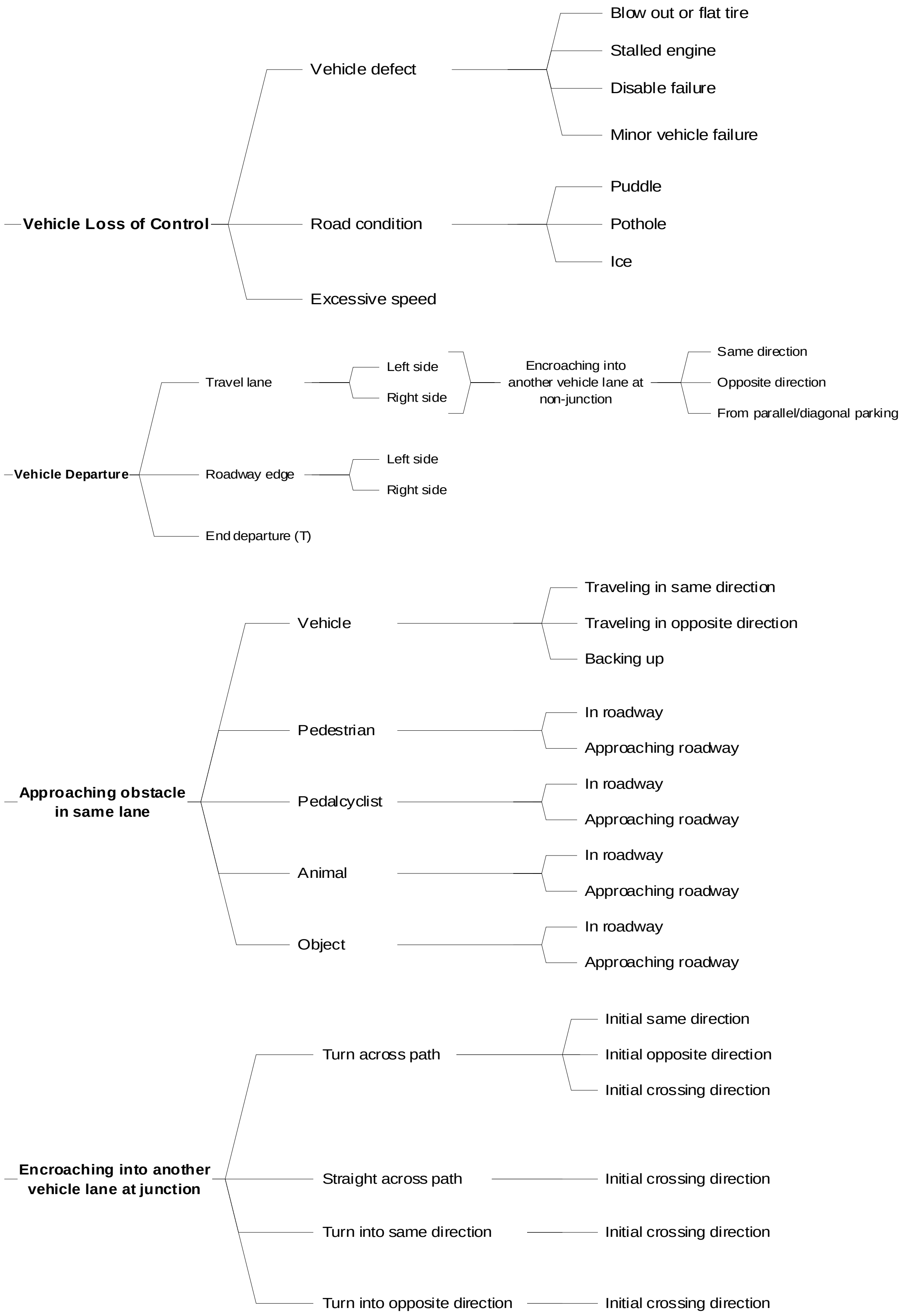


Figure 4. Taxonomy of Critical Events Represented by GES *Critical Event* Variable

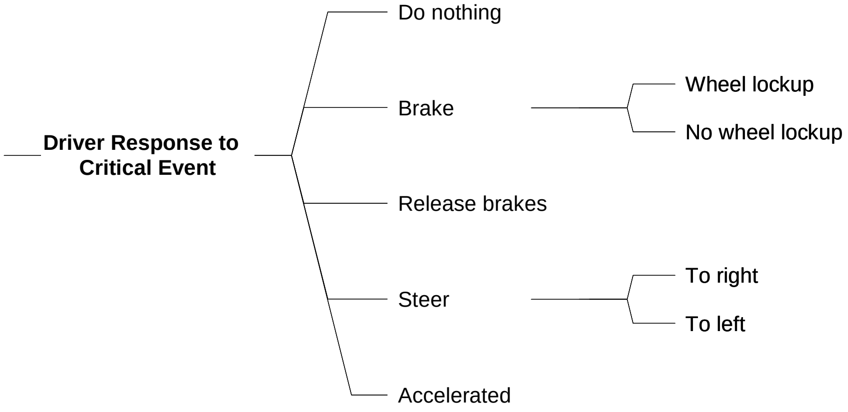


Figure 5. Driver Response to Critical Events Represented by GES *Corrective Action Attempted* Variable

A recent analysis of the 2000 GES database identified 46 pre-crash scenarios that involved at least one light vehicle (passenger vehicle, sports utility vehicle, van, minivan, and light truck). Table 1 lists these scenarios across eight major crash types and indicates their annual frequency. In total, these scenarios were reported to occur immediately prior to about 5,296,000 police-reported crashes in 2000 [2]. The identification of these scenarios was primarily based on the combination of the first two pre-crash variables. The third pre-crash variable characterizes the driver response to the driving conflict imposed by the scenario. Therefore, at a minimum, it would be recommended that near-crash/crash AEDRs capture the first three pre-crash variables.

2.2. Causal Factors

A detailed or clinical analysis was conducted on a large sample of crash files (≈ 1,600) drawn from the 1991-1995 GES and CDS crash cases [3]. As a result, a taxonomy of most common crash causes was created as shown in Figure 6. This taxonomy documents five major categories that were caused by the driver (driving task errors and physiological impairment), the vehicle (defects), and the environment (low-friction road surface and reduced visibility). Figure 7 displays the relative frequency distribution of these categories as derived from the clinical analysis. Weighing crashes associated with each of the five categories in the analysis sample by severity produced this distribution.

2.3. Pre-Crash Data Needs

Based on crash statistics presented above, there is a need to gain a better understanding of driver exposure to most common pre-crash or near-crash scenarios in the driving environment. There is also the need to identify the factors that may have caused the driver to get involved in these scenarios. From Table 1, the following eleven scenarios appear to account for most of the pre-crash scenarios or about 82% of the light vehicle crashes:

1. Lead vehicle stopped (LVS): 895,000 (17%)
2. Straight crossing paths (SCP): 566,000 (11%)

3. Vehicle control loss: 437,000 (8%)
4. Left turn across path/opposite direction (LTAP/OD): 425,000 (8%)
5. Drifting: 621,000 (12%)
6. Lead vehicle decelerating (LVD): 401,000 (8%)
7. LTAP/lateral direction (LTAP/LD): 306,000 (6%)
8. Changing lanes/passing: 247,000 (5%)
9. Animal/pedestrian in road: 283,000 (5%)
10. Lead vehicle moving at lower constant speed (LVM): 144,000 (3%)
11. Vehicle failure leading to control loss: 33,000 (1%)

Table 1. Frequency of Pre-Crash Scenarios by Crash Type Based on 2000 GES

Pre-Crash Scenario	Crash Type								Total, All Crash Types
	Rear-End	Crossing Paths	Single Vehicle Run-Off-Road	Lane Change	Animal	Opposite Direction	Pedalcyclist	Pedestrian	
Lead vehicle stopped (LVS)	895,000								895,000
Straight crossing paths (SCP)		545,000					21,000		566,000
Left turn across path/opposite direction (LTAP/OD)		425,000							425,000
Lead vehicle decelerating (LVD)	401,000								401,000
Going straight - drifting			281,000	38,000		74,000			393,000
Other		93,000	87,000	142,000	6,000	12,000	3,000	6,000	349,000
Left turn across path/lateral direction (LTAP/LD)		306,000							306,000
Going straight - animal in roadway					232,000				232,000
Vehicle changing lanes	30,000			190,000					220,000
Going straight - control loss			220,000						220,000
Negotiating a curve - drifting			110,000	4,000		60,000			174,000
Negotiating a curve - control loss			165,000						165,000
Lead vehicle moving at constant speed (LVM)	144,000								144,000
Avoidance maneuver			118,000						118,000
Left turn into path		94,000							94,000
Right turn into path		93,000							93,000
Turning - parallel paths				76,000					76,000
Initiating a maneuver - departed road edge			54,000						54,000
Initiating a maneuver - control loss			48,000						48,000
Right turn across path		34,000							34,000
Vehicle failure			32,000			1,000			33,000
Passing a turning vehicle				32,000					32,000
Passing				22,000		5,000			27,000
Lead vehicle changing lanes	25,000								25,000
Going straight - pedestrian crossing road								25,000	25,000
Both going straight but another vehicle in same lane				21,000					21,000
One vehicle going straight and another leaving parked position				20,000					20,000
Lead vehicle accelerating	17,000								17,000
Going straight - pedestrian darting onto road								15,000	15,000
Negotiating a curve - animal in roadway					9,000				9,000
Other - departed road edge			8,000						8,000
Going straight - in lane						7,000			7,000
Turning left - pedestrian crossing road								7,000	7,000
Going straight - parallel paths							7,000		7,000
Turning right - crossing paths							5,000		5,000
Turning right - pedestrian crossing road								4,000	4,000
Other - control loss			3,000			1,000			4,000
Negotiating a curve - in lane						3,000			3,000
Going straight - pedestrian doing "other"								3,000	3,000
Turning right - parallel paths							3,000		3,000
Turning left - crossing paths							3,000		3,000
Starting in traffic - crossing paths							3,000		3,000
Going straight - pedestrian walking along road								2,000	2,000
Going straight - pedestrian playing/working in road								2,000	2,000
Backing								2,000	2,000
Turning left - parallel paths							2,000		2,000
Total	1,512,000	1,590,000	1,126,000	545,000	247,000	163,000	47,000	66,000	5,296,000

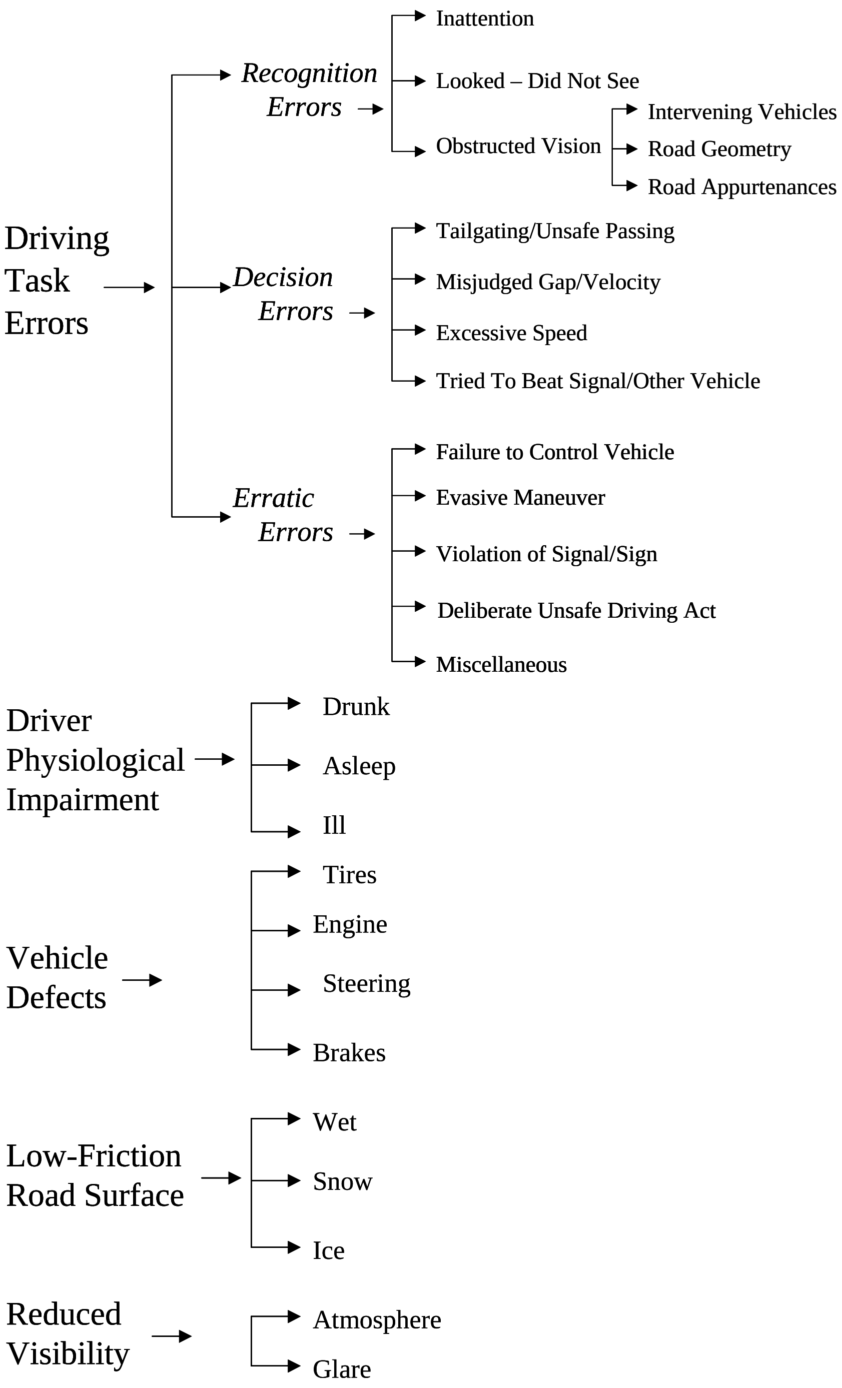


Figure 6. Taxonomy of Crash Causal Factors

In addition to the list of eleven scenarios, the following driver factors dominate the primary causes of crashes:

- Inattention, looked but did not see, and obstructed vision (recognition errors: 44% of crashes)

- Tailgating/unsafe passing, misjudged gap/velocity, excessive speed, and sign/signal violation (decision errors and erratic actions: 32% of crashes)
- Drowsy (8% of crashes)
- Drunk (6% of crashes)

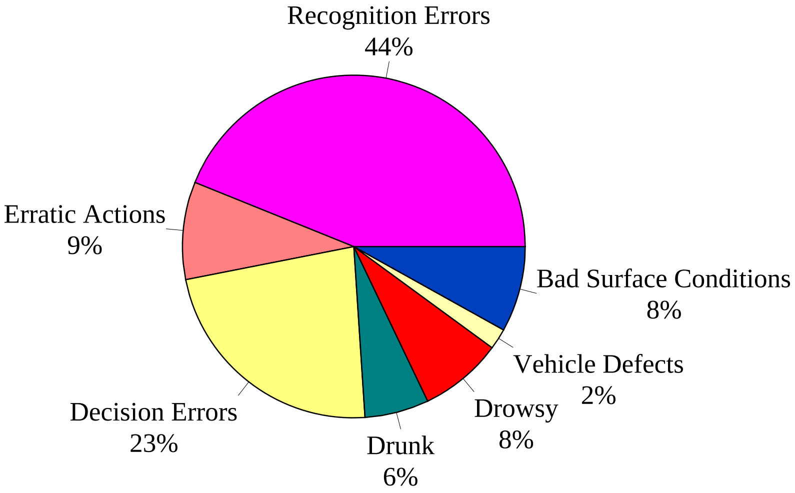


Figure 7. Distribution of Crash Causes Based on Clinical Analysis of a Crash Sample

Other causal factors of interest are the environmental conditions such as low-friction roadway surface condition (8% of crashes) and reduced visibility due to atmospheric and lighting conditions. Even though the relative frequency of crashes caused by reduced visibility is negligible in Figure 6 (0.5% of crashes), the crash analysts might have had difficulty identifying this causal factor from the crash files. Other research has shown that reduced visibility is the primary cause in multiple-vehicle crashes.

3. FUNCTIONAL REQUIREMENTS OF NEAR-CRASH/CRASH AEDR

An EDR consists of four main components as represented by the block diagram in Figure 8. The sensory component picks up the data that meet the needs of the EDR. For a near-crash/crash AEDR, this sensory suite includes OEM sensors and other added sensors. Processing of the sensory data may be conducted on-line in the AEDR device or off-line after the data have been retrieved. The data-sampling rate is an important parameter to consider in AEDR design. The required storage capacity (time and size) impacts the complexity and cost of AEDRs. Current OEM crash EDRs only store few seconds of data prior to and during the collision event. The last EDR component entails the retrieval of stored data, which can be achieved either by a wire-plug or wireless connection. Wire-plugs are used today to extract data from OEM EDRs only after the occurrence of a crash. Periodic downloads of data would have to be scheduled to retrieve information on near-crashes. This report concentrates on the sensory component of EDRs and defines functional requirements in terms of the measures that quantify the needs of near-crash/crash AEDRs. The measures were delineated separately for the host vehicle and for the driving environment in close proximity to the host vehicle.

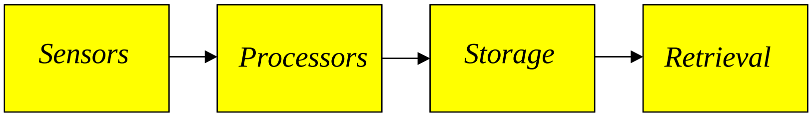


Figure 8. Block Diagram of a Typical Event Data Recorder

3.1. AEDR Needs and GES/CDS Codes

GES and CDS coding would benefit greatly from the measurements of near-crash/crash AEDRs. These measurements would provide better accuracy, more reliability, and quantification to many GES and CDS codes that describe the pre-crash situation. Table 2 maps the needs of near-crash/crash AEDRs against the applicable GES variables and codes that would be enhanced by the measured data. It should be noted that the CDS has many variables similar to the GES but with different numbers and names. Some GES/CDS variables are less reliable than others due to the large number of "unknown" present in the database or miscoded information. Moreover, some GES/CDS variables do not contain specific enough information that might add more insight into the understanding of the pre-crash situation. Data collection would benefit many variables such as GES *Travel Speed* (V11), *Movement Prior to Critical Event* (V21), *Critical Event* (V26), *Corrective Action Attempted* (V27), *Pre-Crash Vehicle Control* (V28), *Pr-Crash Location* (V29), *Driver's Vision Obscured by* (D4), *Driver Maneuvered to Avoid* (D6), *Driver Distracted by* (D7), *Restraint System Used* (P15), *Person's Physical Impairment* (P18), and *Non-Motorist Action* (P19). As seen in Table 2, there are some driver (tailgating/unsafe passing and misjudged gap/velocity) and driving environment (traffic state) AEDR needs that are not currently coded by the GES and the CDS.

Table 2. AEDR Needs and Applicable GES Variables/Codes

Needs	Applicable 2002 GES Variables/Codes*
Vehicle	
LVS detection	V21, V23, V26
SCP detection	V21, V23, V26
Control Loss detection	V21, V23, V26
LTAP/OD detection	V21, V23, V26
Drifting detection	V21, V23, V26
LVD detection	V21, V23, V26
LTAP/LD detection	V21, V23, V26
Changing Lanes	V21, V23, V26
Object in road (animal/pedestrian…)	A6-21/22/24, A24, V20-21/22/24, V23, V26-80 thru 92, D06-1/3/5, M_D06-1/3/5
LV constant speed detection	V21, V23, V26
Vehicle defect (tires, brakes, steering, engine)	V12, V26-1 thru 4, M_V12
Driver	
Inattention	D07-97, M_D07-97
Looked - Did not see	D07-1, M_D07-1
Obstructed vision	D04, M_D04
Tailgating/Unsafe passing	
Misjudged gap/velocity	
Excessive speed	V26-6, D02-2/3, D09, M_D02-3
Sign/Signal violation	D02-6/7, M_D02-6/7
Drowsy/Sleeping	D07-11, M_D07-11, P18-2, M_P18-2
Drunk	A92, V92, D02-1/3, M_D02-1, P11
Environment	
Posted speed limit	A18, V_A18
Roadway surface condition (dry/wet)	A15, V_A15
Roadway geometry (alignment and profile)	A13, A14, V_A13, V_A14
Traffic state	
Atmospheric conditions	A20
Lighting	A19
Relation to Junction	A09, P13
Traffic Control Device	A16, V_A16, MV_A16

*****: See Appendix A for definition of GES variables.

3.2. AEDR Needs and Corresponding Measures

Tables 3 and 4 provide the measures that quantify the needs of near-crash/crash AEDRs respectively for the host vehicle and its close proximity environment. These tables extend the needs of the dynamic pre-crash scenarios to each of the vehicles involved (i.e., following and lead vehicles in rear-end pre-crash scenarios). Moreover, the needs of the driving environment encompass information that conveys near-crash/crash contributing factors and circumstances. The contributing factors include bad surface condition (roadway surface condition), reduced visibility due to geometric roadway layout (roadway geometry), and reduced visibility due to atmospheric conditions (atmospheric/weather conditions and lighting). Other information needs such as posted speed limit, traffic state, relation to junction, and traffic control device have been added because they provide invaluable insight into the understanding of the pre-crash and crash situations.

The measures in Tables 3 and 4 have been arranged by visual and numerical measures. This emphasizes the need to capture images of the inside of vehicles and of the driving environment surrounding the host vehicle. In fact, many AEDR needs can only be satisfied by examining the visual scene.

3.3. AEDR Measures and Potential Sensors

Table 5 lists some sensors that can potentially measure the various parameters of near-crash/crash AEDRs. In some cases, a single sensor may provide multiple measures. For instance, a yaw rate sensor directly measures the yaw rate of the host vehicle and indirectly provides an estimate of the roadway curvature. The *Global Positioning System* (GPS) sensor produces location coordinates of the host vehicle and must be used in conjunction with digital maps to obtain the characteristics of the surrounding driving environment. Many host vehicle sensors are currently embedded in today's safety systems such as *Anti-lock Braking Systems* (ABSs), *Traction Control* (TC), and advanced stability control systems. Both ABS and TC employ wheel speed sensors at each wheel, while stability control utilizes a suite of sensors that measure steering wheel angle, yaw rate, lateral acceleration, accelerator pedal position, and throttle valve opening. Thus, near-crash/crash AEDRs could tap into many existing sensors on board today's vehicles.

Table 3. AEDR Needs and Corresponding Measures of Host Vehicle

Needs		**Visual**		**Numerical**									
		Driver Face	**Dash-board**	**Travel Speed**	**Long. Accel.**	**Lat. Accel.**	**Yaw Rate**	**Tire Pressure**	**Steering Input**	**Brake Input**	**Engine RPM**	**Throttle Position**	**BAC Level**
Vehicle													
LVS detection	Following Vehicle			X	X								
	Lead Vehicle			X	X								
SCP detection	Vehicle 1												
	Vehicle 2												
Control Loss detection	Single vehicle	X		X	X	X	X						
LTAP/OD detection	Vehicle GS												
	Vehicle LTAP/OD												
Drifting detection	Single vehicle	X											
LVD detection	Following Vehicle			X	X								
	Lead Vehicle			X	X								
LTAP/LD detection	Vehicle GS												
	Vehicle LTAP/LD												
Changing Lanes	Vehicle GS	X											
	Vehicle changing lanes	X											
Object in road	Single vehicle	X											
LV constant speed detection	Following Vehicle			X	X								
	Lead Vehicle			X	X								
Vehicle defect	Single vehicle				X	X		X	X	X	X	X	
Driver													
Inattention		X	X										
Looked - Did not see		X											
Obstructed vision		X											
Tailgating/Unsafe passing				X	X								
Misjudged gap/velocity		X		X									
Excessive speed				X									
Sign/Signal violation													
Drowsy/Sleeping		X											
Drunk		X											X
Environment													
Posted speed limit													
Roadway surface condition													
Roadway geometry													
Traffic state													
Atmospheric conditions													
Lighting													
Relation to Junction													
Traffic Control Device													

Table 4. AEDR Needs and Corresponding Measures of Driving Environment

Needs		Visual				Numerical											
		Forward	Rear	Left Side	Right Side	Location	Position in Lane	Range			Range Rate			Road Curvature	Road Grade	Lighting	Ambient Temp.
								FT*	ST*	AT*	FT*	ST*	AT*				
Vehicle																	
LVS detection	Following vehicle	X						X			X						
	Lead vehicle		X														
SCP detection	Vehicle 1	X		X	X				X			X					
	Vehicle 2	X		X	X				X			X					
Control Loss detection	Single vehicle	X					X										
LTAP/OD detection	Vehicle going straight	X						X			X						
	Vehicle LTAP/OD	X			X			X	X		X	X					
Drifting detection	Single vehicle	X					X	X		X	X		X				
LVD detection	Following vehicle	X						X			X						
	Lead vehicle		X														
LTAP/LD detection	Vehicle going straight	X						X			X						
	Vehicle LTAP/LD	X		X					X			X					
Changing Lanes	Vehicle going straight			X	X		X			X			X				
	Vehicle changing lanes			X	X		X			X			X				
Object in road	Single vehicle	X						X			X						
LV constant speed detection	Following vehicle	X						X			X						
	Lead vehicle		X														
Vehicle defect	Single vehicle																
Driver																	
Inattention		X															
Looked - Did not see		X															
Obstructed vision		X															
Tailgating/Unsafe passing		X					X	X			X			X	X		
Misjudged gap/velocity		X		X	X		X	X			X						
Excessive speed						X											
Sign/Signal violation		X															
Drowsy/Sleeping																	
Drunk							X										
Environment																	
Posted speed limit						X											
Roadway surface condition		X															
Roadway geometry		X				X								X	X		
Traffic state		X															
Atmospheric conditions		X														X	X
Lighting		X														X	
Relation to Junction		X				X											
Traffic Control Device		X				X											

*: FT≡ forward target, ST≡ side target, and AT≡ adjacent target.

Table 5. Needed Measures and Applicable Sensors

Measures	Sensors																	
	Video Camera	GPS	Lane Track.	Radar	Laser	Steer. Angle	2-axis Accel.	Yaw Rate	Tire Press.	Photo-electric	Wheel Speed	Throt. Pos.	Brake Pedal	Speed-ometer	Tach-ometer	Breath-alizer	Thermo meter	Wind. Wipers
Forward View	░																	
Rearward View	░																	
Left Side View	░																	
Right Side View	░																	
Driver Face View	░																	
Location		░																
Position in Lane			░															
Travel Speed														░				
Range - Forward Target*		░ **		▓	█													
Range - Side Target*		░ **		▓	█													
Range Rate - Forward Target*		░ **		▓	█													
Range Rate - Side Target*		░ **		▓	█													
Range Rate - Adjacent Target*		░ **		▓	█													
Acceleration - Longitudinal							░											
Acceleration - Lateral							░											
Yaw Rate								░										
Road Curvature*	░	▓				█		░						█				
Road Grade*	░	▓																
Tire Pressure									░									
Steering Input						░												
Range - Adjacent Target*		░ **		▓	█													
Brake Input													░					
Engine RPM															░			
Throttle Position												░						
Lighting *	░									▓								
BAC Level																░		
Ambient Temperature																	░	
Adverse Weather																		░

*More than one combination of sensors may address this measure. Combinations (per row) are color-coded.

░ **: Sensors have to be installed in every vehicle involved

4. ASSESSMENT OF EDR TECHNOLOGY

A survey of EDR technology was conducted to assess the functionality of state-of-the-art prototypes and products. Currently, there is an abundance of EDR technology being developed and supplied by the OEMs and aftermarket suppliers. Moreover, recent projects by the Intelligent Vehicle Initiative, such as FOTs and naturalistic driving data collection, have built advanced EDRs that capture driver, vehicle, and driving environment data. This section reviews OEM, aftermarket, and experimental EDR products to determine their measures and assess their extent in meeting the general functional requirements of near-crash/crash AEDRs.

4.1. OEM EDRs

The OEMs currently supply two types of automotive EDRs: airbag module and *Automated Collision Notification* (ACN). Airbag modules, also known as "black boxes," control the deployment of the airbags. These modules have the ability to record data on certain vehicle parameters, which have been traditionally used by the OEMs for research purposes. A typical airbag module, or black box, is pictured in Figure 9. On the other hand, ACN usually records less information and is primarily utilized for alerting emergency personnel in the event of a crash via GPS and cellular technologies.

Figure 9. Typical Airbag Module

4.1.1. General Motors (GM)

GM has been at the forefront of vehicle EDR technology since 1974 when it introduced the first vehicle EDR on select vehicle models. Today, most new GM models are equipped with EDRs in the form of a *Sensing and Diagnostic Module* (SDM) [4]. The SDM is the airbag module that controls airbag deployment. Its primary purpose is to deploy the airbags but it also has the capability to store some vehicle data. When the module's algorithm becomes enabled, triggered by parameters reaching a specific threshold, the SDM can start recording data. The SDM has the ability to record data on a crash event in which the airbags were actually deployed and on a near-deployment event in which the algorithm was enabled but the airbags were not fired [5]. Table 6 lists the parameters that GM EDRs store per EDR type [6].

Table 6. Vehicle Parameters Stored by Select GM Airbag Systems

Parameter	**1990 DERM**	**1994 SDM**	**1999 SDM**
State of Warning Indicator when event occurred (On/Off)	X	X	X
Length of time the warning lamp was illuminated	X	X	X
Crash-sensing activation times or sensing criteria met	X	X	X
Time from vehicle impact to deployment	X	X	X
Diagnostic Trouble Codes present at the time of the event	X	X	X
Ignition cycle count at event time	X	X	X
Maximum DeltaV for near-deployment event		X	X
DeltaV vs. time for frontal airbag deployment event		X	X
Time from vehicle impact to time of maximum DeltaV		X	X
State of driver's seat belt switch		X	X
Time between near-deploy and deploy event (if within 5 seconds)		X	X
Passenger's airbag enabled or disabled state			X
Engine speed (5 sec before impact)			X
Vehicle Speed (5 sec before impact)			X
Brake status (5 sec before impact)			X
Throttle position (5 sec before impact)			X

The 1999 SDM version has the added capability to store certain vehicle parameters such as speed and brake status for five seconds preceding a deployment or near-deployment event, as well as up to 300 milliseconds of the crash pulse. In a near-deployment event (the vehicle experiences a DeltaV significant enough to alert the sensing computer but not high enough to trigger deployment), the 1999 and later SDM data recorders will record:

- Pre-impact vehicle speed
- Engine RPM
- % Throttle
- Brake switch (on/off)
- Driver's seatbelt use (fastened or unfastened)
- DeltaV if it is higher than the last DeltaV

Near-deployment event data are automatically cleared after 250 engine cycles (or 250 times turning the engine on/off) that represent approximately 60 days of driving [7].

4.1.2. OnStar

GM provides the OnStar service that functions as an ACN among other things. The vehicle sends a signal to the OnStar Center upon airbag deployment. In response, an OnStar operator contacts the vehicle's occupants via a cellular telephone in the vehicle to ascertain the extent of the emergency. If emergency services are needed, the operator then would notify the appropriate authorities and give them the vehicle's location based on GPS coordinates. The OnStar system can also be manually activated via a button on the rear-view mirror [8]. It should be noted that the OnStar system is powered by the vehicle's battery and will not function if the battery is damaged or disconnected [9].

4.1.3. ATX Technologies

ATX Technologies is a privately held company that provides telematics service to the OEMs. This company is currently marketing an ACN system, which is available in the Lincoln, Mercedes, Jaguar, BMW, and Infinity under different names. Similar to OnStar, the ACN contacts the Response Center if the airbag is deployed or the emergency tensioning restraint in the seatbelt harness is activated. The Center then establishes a voice connection with the vehicle (cell phone) if possible and provides the appropriate emergency personnel with vital information including the location of the vehicle and data on the occupants as well as the vehicle. The system can also be manually activated from within the vehicle [10].

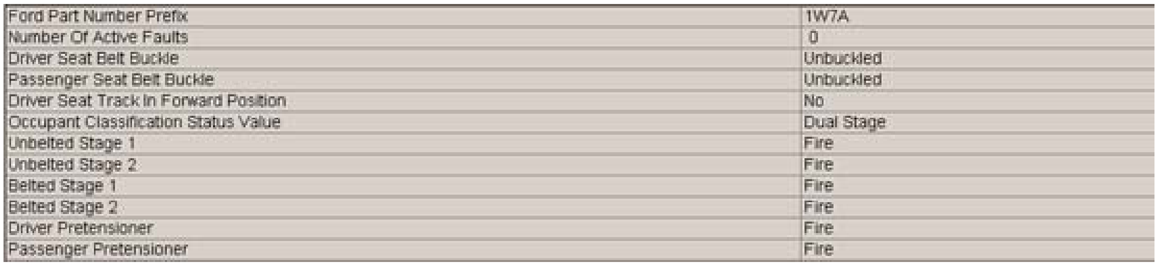
4.1.4. Ford

Ford is currently installing EDRs, known as *Restraint Control Modules* (RCMs), in all of their vehicle models. RCMs collect data on slightly different parameters than the GM EDRs and over a smaller period of time, recording up to only 80 milliseconds of the crash pulse [11]. Ford products equipped with EDRs also have pre-tensioners on the front seatbelts and sensors to determine if a person is wearing the seatbelt and if the driver seat is fully forward. The airbag(s) can fire in stages, and the firing of those bags and of the pre-tensioners depends on seatbelt usage and seat placement with respect to the steering wheel [12]. Table 7 lists the parameters stored on the RCM. Ford's EDRs also contain other data as shown in Tables 8 and 9.

Table 7. Data Stored on Ford's RCM

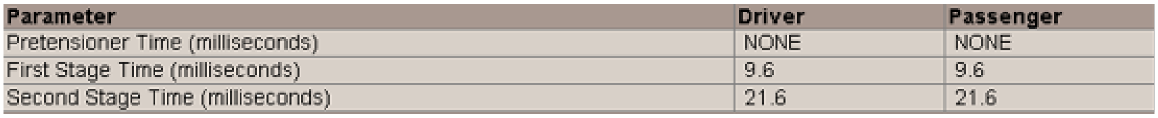
Parameters
Longitudinal acceleration
Lateral acceleration
DeltaV
Time from side safing decision to left (driver) side bag deployment
Time from side safing decision to right (passenger) side bag deployment
Passenger airbag switch position during event
Diagnostic codes active when event occurred
Time from algorithm wakeup to pretensioner
Time from algorithm wakeup to first stage - unbelted
Time from algorithm wakeup to first stage - belted
Time from algorithm wakeup to second stage
Driver seat belt buckle
Passenger seat belt buckle
Driver seat track in forward position
Passenger seat weight switch position
Time from algorithm wakeup to pretensioner deployment attempt
Time from algorithm wakeup to first stage deployment attempt
Time from algorithm wakeup to second stage deployment attempt

Table 8. Ford EDR – Status Table



Ford Part Number Prefix	1W7A
Number Of Active Faults	0
Driver Seat Belt Buckle	Unbuckled
Passenger Seat Belt Buckle	Unbuckled
Driver Seat Track In Forward Position	No
Occupant Classification Status Value	Dual Stage
Unbelted Stage 1	Fire
Unbelted Stage 2	Fire
Belted Stage 1	Fire
Belted Stage 2	Fire
Driver Pretensioner	Fire
Passenger Pretensioner	Fire

Table 9. Ford EDR – Parameter Table



Parameter	Driver	Passenger
Pretensioner Time (milliseconds)	NONE	NONE
First Stage Time (milliseconds)	9.6	9.6
Second Stage Time (milliseconds)	21.6	21.6

4.1.5. Volvo

Volvo vehicles have been equipped with *Digital Accident Research Recorder*s (DARRs) since 1994. The DARR records roughly 60 longitudinal deceleration values over the 180-millisecond period immediately following front airbag deployment. Volvo is also developing a *Pre-Crash Recorder* (PCR) that collects data on 31 selected parameters starting five seconds before a crash in 500-millisecond intervals [13]. The *Special Crash Investigations* (SCI) program of the *National Highway Traffic Safety Administration* (NHTSA) is currently working with Volvo to supply EDR data for crash cases under investigation [14]. Table 10 lists some of Volvo's PCR parameters.

Table 10. Data Stored on Volvo's PCR

Parameters	
Outdoor temperature	AYC function
Global time	ABS function
Time from ignition on	TC function
Steering wheel angle	EBD function
Latitudinal acceleration	RSC function
Roll rate	STC/DSTC manually on/off
Vehicle speed	Driving direction
Longitudinal acceleration	Brake pedal position
Driver requested torque	Clutch pedal position
Engine torque	SC control mode
Actual yaw rate	AYC control mode
Engine speed	ABS control mode
Engine speed quality factor	TC control mode
BCM voltage supply	EBD control mode
Engine torque quality factor	RSC control mode
SC function	

4.1.6. Toyota

Toyota is currently developing and testing enhanced EDRs [15]. There are EDRs installed on select models since 2001.

4.1.7. Mercedes

It has been reported that Mercedes has developed a "super-EDR technology" but has yet to install them in any production vehicles [15].

4.1.8. Saab

Saab employs a form of EDRs to collect crash pulses and uses the data for research purposes [16]. No more information is available about this effort.

4.1.9. Hyundai

According to an article appearing in the May 19, 1999 issue of *Global News Korea* [17], Hyundai has developed a type of EDR and has plans to start installing it on select vehicles in 2003. The device is said to memorize outside shock and how the driver operates the steering wheel, brakes and accelerator, among other driving conditions.

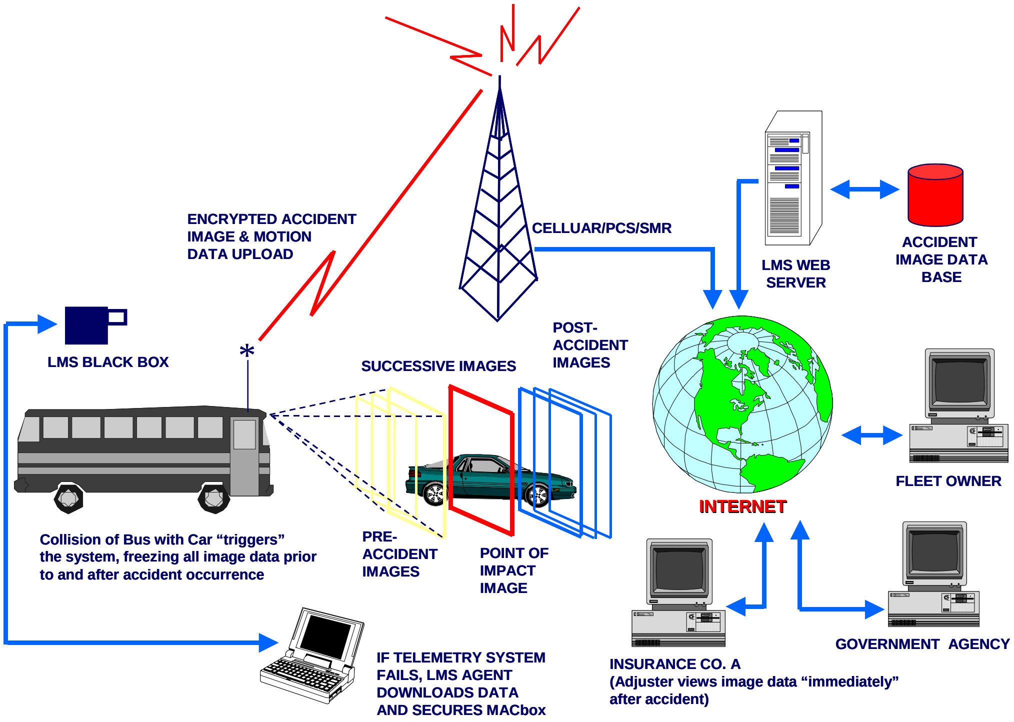
4.1.10. Other OEMs

No information is available on EDR technology from other OEMs such as Honda, Volkswagen, Acura, Mazda, Lexus, BMW, Jaguar, and Land Rover. NHTSA's SCI program is currently working with these OEMs to obtain EDR data from their vehicles under SCI crash investigation [14].

4.2. Aftermarket Suppliers

4.2.1. Safety Intelligence Systems (SIS)

SIS has developed an enhanced EDR, called the *Mobile Accident Camera Box* (MACBOX), which stores data as well as compressed digital video of the events immediately prior to, during, and following a crash [6]. The MACBOX records video data from the driver's point of view as well as longitudinal and lateral accelerations at 2,000 Hz [18]. As illustrated in Figure 10, the system transmits a Mayday message to the Public Safety Access Point (911) once a crash has occurred. The system also sends stored data to a central data vault through a cellular transceiver. The data can then be disseminated to the appropriate entities for analysis. Table 11 lists the MACBOX stored parameters.



LMS= Long Message Service

Figure 10. MACBOX Architecture

Table 11. Stored Parameters on MACBOX

Parameters	
Date	Windshield wiper status
Time	GPS status indicators
Latitude	Longitudinal acceleration
Longitude	Lateral acceleration
Speed	Vertical Acceleration
Heading	DeltaV (calculated)
Acceleration	Direction of force (calculated)
Seatbelt status	Rollover (calculated)
Brake status	

4.2.2. Independent Witness Incorporated (IWI)

IWI has developed an EDR system that records the date, time, direction of movement (three-dimensional), impact severity, acceleration profiles, and DeltaV (the change of velocity that occurs between impact and within less than a millisecond following) associated with a vehicular crash [19]. The primary purpose of this data is to substantiate or disprove insurance claims.

4.2.3. VDO North America

Siemens automotive VDO developed an EDR referred to as the UDS (translated to *Accident Data Memory*), which registers the vehicle's speed, transversal and longitudinal accelerations, and changes in direction at the rate of 500 times per second as well as other parameters as shown in Table 12 [20]. In the event of a crash, the system automatically stores 45 seconds of data: 30 seconds before and 15 seconds after the event. The UDS device has the capability to emit a signal that can be used in other applications such as an ACN system. The driver can also manually activate it to record near-crash events.

Table 12. Siemens VDO UDS Parameters

Parameters	
Vehicle speed	Time from ignition on
Longitudinal acceleration	Brake duration
Transversal acceleration	Indicators duration
Direction change rate	Lights duration

4.2.4. DriveCam

The DriveCam EDR is a palm-sized video recorder that mounts behind a vehicle's rearview mirror. It monitors driving activity by continuously recording video, audio, and longitudinal and lateral accelerations into a digital looping memory [21]. Hard braking, acceleration, harsh cornering, or actual crashes trigger the DriveCam EDR to save the 30 seconds before, during, and after the driving event. The driver can also manually activate DriveCam at any time. Table 13 lists the recorded parameters of DriveCam.

Table 13. DriveCam's Recorded Parameters

Parameters	
Time before/after impact	Video - forward view
Longitudinal acceleration	Audio
Lateral acceleration	

4.2.5. Accident Prevention Plus

Accident Prevention Plus sells the AP+ line of onboard computer recording systems primarily for commercial vehicle fleets. The company actively markets three models, each recording a slightly different set of parameters as shown in Table 14. Each model can be expanded on due to the availability of extra input channels as seen in the last row of Table 14 [22]. Thus, these models have the ability to monitor, record, and retrieve numerous types of data [23].

4.2.6. Road Safety International

This company sells a series of EDRs ranging from the RS-1000 series targeting teenage drivers to the RS-3000 series for emergency vehicle fleets. The basic function of these EDRs is to issue an audible warning to the driver immediately after an unsafe driving condition such as high speed or hard braking is detected. These EDRs also generate reports and graphs that can be downloaded to a personal computer [24]. Table 15 lists the parameters that are stored on Road Safety International's RS-3000 Series.

Table 14. Parameters Stored on Accident Prevention Plus Systems

Parameter	Series Model		
	APP1000	APP2000	APP3000
Distance/Speed	X	X	X
Engine RPM	X	X	X
Fuel consumpsion		X	X
Foot brake	X	X	X
Lights	X	X	X
Reverse gear	X	X	X
Power off	X	X	X
Longitudinal acceleration	n.a.	n.a.	X
Lateral acceleration	n.a.	n.a.	X
Gear position	X	X	X
Additional & Customizable Inputs	2	14	13

Table 15. Data Stored on Road Safety International RS-3000 Series

Parameters	
Date	Hard Accelerations
Time	Hard Decelerations
Location (GPS add-on)	Daily distance
Vehicle Speed	Seatbelt use
Longitudinal acceleration	Turn signals
Lateral acceleration	Brakes
Engine RPM	Doors
Vehicle stops	Warning lamps
Excess idle time	Excessive G-forces
Over speeds	Ambient Temperature
Over RPM's	Throttle position

4.2.7. MobilEye

This company launched an aftermarket system in 2004 with a wide range of warning capabilities including forward collision, lane departure, pedestrian protection, and cut-in. The system, consisting of a forward view video camera and a black-box-type vehicle detection module, will be capable of recording forward view video and parameters listed in Table 16 [25].

Table 16. MobilEye Parameters

Parameters	
Range (to lead vehicle)	Lane Position
Range Rate (to lead vehicle)	Lane Assignment of Other Vehicles
Azimuth to vehicle (angle)	Lane Typing
Road Curvature	Vehicle Classification
Pedestrian - Range, Range Rate, Azimuth, lateral speed	

4.2.8. Folksam Research

Folksam is a very large Swedish insurance company. Its research arm conducts safety tests on vehicles for insurance purposes. In cooperation with the Swedish National Road Administration, Folksam has been installing one-dimensional *Crash Pulse Recorders* (CPRs) since 1992 in thousands of vehicles registered in Sweden [16]. These CPRs are mounted under the driver or passenger seat and record the crash pulse during such an event onto photographic film. These CPRs only store longitudinal acceleration (DeltaV can be extracted from this information).

4.2.9. Evicam International

This company develops advanced EDRs for transportation and insurance areas [26]. Its main product, Evicam ("evidence camera"), is a multi-camera digital video recording system designed to record the events leading up to and following a crash. Evicam records both forward and rear video as well as speed, turn signals, brake lights, and headlight activation. This crash-proof system is capable of accepting up to 20 inputs (six analog and 14 digital) and four video camera feeds for a maximum storage of three minutes. The data are embedded into the video frames, encrypted, and can only be accessed by authorized users. The system, while still in the latter stages of testing, is slated for production in April 2004 [27].

4.2.10. Detroit Diesel Corporation

This company developed the *Detroit Diesel Electronic Controls* (DDEC) for heavy-duty truck engines. The DDEC records engine as well as vehicle operating information including hard brake incidents and can generate reports [26].

4.2.11. Mitsubishi

Mitsubishi has developed the *Auto Incident Recording System* (AIRS), also known as Crash Cam, for roadway intersections. It consists of a pole-mounted video camera, microphone, and controller with a video recorder. The AIRS monitors the intersection and saves onto videotape 3.6 seconds of data before and after (7.2 seconds total) a crash when detected by its sensors. The system has already been deployed in Japan and Australia [28].

4.2.12. Other Aftermarket Products

Yazaki of Japan focuses on *Driving Monitoring Recorder*s (DMRs) for trucks, taxis, and other commercial vehicles [29]. Although required by law in Japan for certain types of vehicles, these DMRs record very little information. They usually record only speed, mileage, and driving time. Further efforts have been made by at least two other Japanese companies to expand DMRs into *Accident Data Recorder*s (ADRs), but no information was available on their progress [30].

4.3. Experimental EDRs

4.3.1. MicroDAS

NHTSA has been developing portable data collection systems for crash avoidance research since the early 1990s [31]. The latest version, called MicroDAS, uses off-the-shelf technology at a cost under $10,000. This system is capable of recording a wide array of data and can be tailored for specific needs.

4.3.2. Rowan University EDR/ACN System

Rowan University, sponsored by the New Jersey Department of Transportation, has developed an EDR/ACN system called the *Automated New Jersey Emergency Loca*tor (ANJEL). The system detects a crash and sends an emergency signal along with the crash pulse to a base station, which in turn notifies the responsible authorities [6]. Table 17 shows the parameters stored by the system.

Table 17. Rowan University's EDR/ACN System Parameters

Parameters	
GPS location	Lateral acceleration
Longitudinal acceleration	DeltaV (calculated)

4.3.3. General Dynamics Advanced Information Systems (GDAIS)

Formerly Veridian, GDAIS has developed an ACN system that automatically reports crash data to the appropriate emergency dispatch centers [32]. System components include crash sensors, a patented crash detection algorithm, wireless communications, GPS, and automated map displays [33]. The system has been integrated into various FOT's, including one sponsored by NHTSA that involved almost 4,000 vehicles and was completed in 2000. Table 18 lists the ACN parameters.

Table 18. General Dynamics' ACN Parameters

Parameters	
GPS location (lat/long)	Velocity
3-D Acceleration	Heading
DeltaV (calculated)	

As an improvement to the ACN, GDAIS has developed the *Crash Detection Module* (CDM) that is currently being field-tested on Ford vehicles [33]. This system records a few more parameters than the ACN as shown in Table 19 and contains spare digital input/output (I/O) pins that can be used to read on/off types of switches (wipers, door locks) and other devices. The CDM system also incorporates an infrared digital camera that records occupant location.

Table 19. General Dynamics' CDM Parameters

Parameters	
GPS location (lat/long)	Heading
3-D Acceleration	Seat belt status
DeltaV (calculated)	Occupancy
Velocity	In-vehicle camera

4.3.4. ATC

The U.S. Army's *Aberdeen Test Center* (ATC) has developed a range of data acquisition systems for in-house vehicle testing. ATC integrated data acquisition systems along with sensors onto 100 Volvo trucks that were involved in an FOT sponsored by the U.S. DOT and Volvo from 2000 through 2003 [34]. Table 20 lists the parameters recorded in the Volvo truck FOT. It should be noted that ATC built the data acquisition system with expandability in mind to record much more data than needed for the Volvo FOT.

Table 20. ATC's Volvo FOT Data Acquisition System Parameters

Parameters	
Following distance	DDU light (CWS)
Road speed	DDU audio (CWS)
Relative velocity	Longitudinal acceleration
Relative acceleration	Lateral acceleration
Azimuth	Following interval
Steering position	Time-to-collision
Accel pedal %	Video data
Brake Pressure	

4.3.5. Naturalistic Driving Data Acquisition System

Virginia Tech Transportation Institute (VTTI), sponsored by NHTSA and the *Virginia Department of Transportation* (VDOT), has conducted the "100 Car Naturalistic Driving Study" with the aim of obtaining real-world driving data [35]. A one-year pilot test involving about 100 thoroughly instrumented vehicles commenced in March of 2003. Data collection was performed on a continuous basis and was not triggered by any pre-defined event. Table 21 shows some of the collected parameters.

4.3.6. Other FOTs

There are ongoing FOTs under the Intelligent Vehicle Initiative to evaluate rear-end and run-off-road crash countermeasure systems. These FOTs employ data acquisition systems that monitor the driver, vehicle, and driving environment. In these tests, data collection takes advantage of the sensory (numerical and visual) data provided by the crash countermeasure systems.

Table 21. VTTI's Data Acquisition System Parameters

Parameters	
GPS location	ABS status
Video - forward view	Airbag deployment
Video - driver face	Audio
Video - driver hands/feet	Vehicle speed
Video - rear/left view	ABS (on/off)
Video - right side view	Traction control (on/off)
Brake status (on/off)	Longitudinal acceleration
Throttle position	Lateral acceleration
Turn signal status	Range (forward-facing)
Wheel slip (traction)	Range rate (forward facing)
Traction control activation	Yaw rate
Cruise control status	Lane position
Cruise control set speed	Lane deviation (yes/no)

4.4. Assessment of EDR Functionality

Figure 11 shows the incremental complexity of crash and near-crash AEDRs over the basic crash EDR in terms of sensors, processing power, and storage capacity. Crash AEDRs would have similar sensors as near-crash AEDRs but with less processing and storage capacity. Tables 22 and 23 map the functionality of EDR prototypes and products against the general functional requirements of near-crash/crash AEDRs respectively by host vehicle and driving environment measures. OEM EDRs provide numerical measures only; they do not incorporate any cameras on board the vehicle. Moreover, most of their measures characterize the performance of the host vehicle. On the other hand, some aftermarket EDRs employ cameras to view the driving environment in close proximity to the host vehicle. Unfortunately, there are currently no installed cameras to view the inside of the host vehicle. MobilEye products incorporate cameras with integrated digital image processing that compute range and range rate to targets around the host vehicle. Of course, FOT EDRs perform most of the functions of near-crash/crash AEDRs at a very high cost. The biggest challenge for all these EDR products is to view and measure the range and range rate to targets that are on lateral crossing paths to the host vehicle. This problem would be solved if both vehicles on crossing paths were equipped with onboard GPS receivers. An infrastructure-based data collection system would also measure the kinematics of these vehicles.

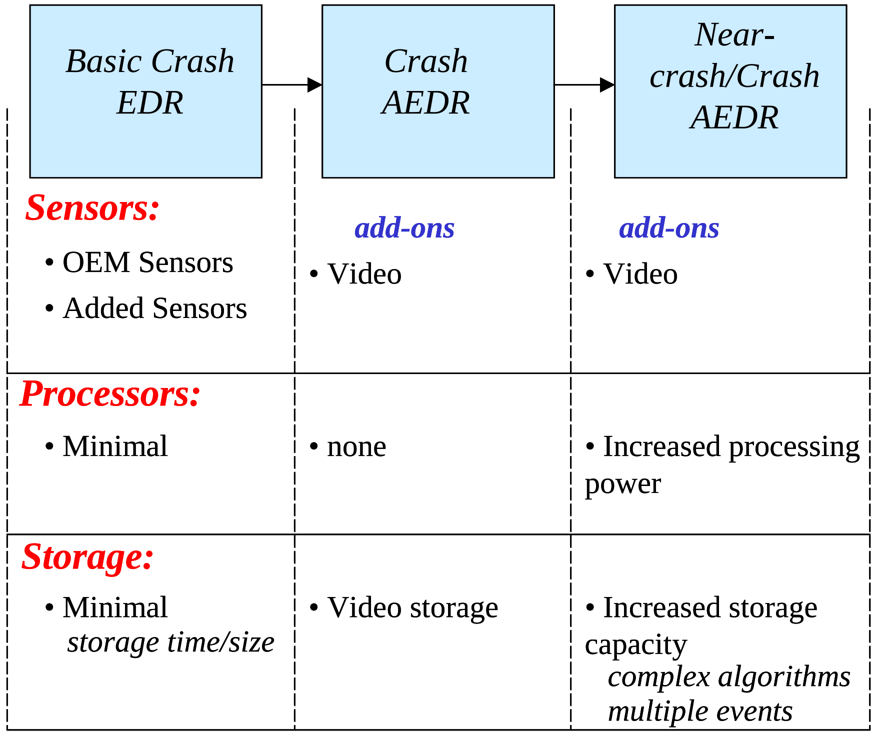


Figure 11. AEDR Add-ons to Basic Crash EDR

Table 22. EDR Products and Host Vehicle Measures

Products	Visual		Numerical									
	Driver Face	Dash-board	Travel Speed	Long. Accel.	Lat. Accel.	Yaw Rate	Tire Pressure	Steering Input	Brake Input	Engine RPM	Throttle Position	BAC Level
OEM												
GM SDM Module			X						X	X	X	
OnStar												
ATX Technologies												
Ford				X	X							
Volvo			X	X	X	X		X	X	X	X	
Aftermarket												
SIS MACBox			X	X	X							
IWI				X	X							
VDO North America			X	X	X							
DriveCam				X	X							
Accident Prevention Plus			X	X	X				X	X		
Road Safety International			X	X	X				X	X	X	
Folksam Research				X								
Evicam International			X									
MobilEye												
FOT												
Rowan University				X	X							
GDAIS	X			X	X							
VTTI Naturalistic Driving	X		X	X	X	X					X	
GM ACAS FOT	X		X	X	X	X	X	X	X	X	X	

Table 23. EDR Products and Driving Environment Measures

Products	Visual				Numerical												
	Forward	Rear	Left Side	Right Side	Loc.	Pos. in Lane	Range			Range Rate			Road Curve	Road Grade	Light.	Amb. Temp.	Adverse Weather
							FT*	ST*	AT*	FT*	ST*	AT*					
OEM																	
GM SDM Module																	
OnStar					X												
ATX Technologies																	
Ford																	
Volvo																X	
Aftermarket																	
SIS MACBox					X												X
IWI																	
VDO North America																	
DriveCam	X																
Accident Prevention Plus																	
Road Safety International					X											X	
Folksam Research																	
Evicam International	X	X															
MobilEye	X					X	X			X			X				X
FOT																	
Rowan University					X												
GDAIS					X												
VTTI Naturalistic Driving	X	X	X	X	X	X	X			X							
GM ACAS FOT	X				X	X	X			X			X		X	X	X

4.5. EDR Product Cost

An attempt was made to obtain the cost or price for all the EDR products and prototypes described above. This turned out to be a difficult task since many manufacturers offer these devices as part of a package deal. Table 24 provides the results of the inquiry into the cost of these EDRs. Depending on the number and type of measured parameters, the price of these devices varies from a low of $280 to a high of $10,000. As seen in Table 24, the cost of many EDRs remains unknown due to unavailability of information from vendors and manufacturers. It should be noted that the price of some vehicle safety systems is included in the table below because they incorporate sensors of interest to near-crash/crash AEDRs.

Table 24. Cost of EDR Prototypes and Products

EDR Product	Cost	Comments
OEM		
GM SDM Module		
Ford		
Volvo		
OnStar (ACN)	$ 695	The Safe & Sound plan costs $199 per year or $16.95 per month
ATX Technologies (ACN)		
Aftermarket		
SIS MACBox	$ 300	On sale by mid-2004 and retail for around $300
IWI		
VDO North America		
DriveCam	$ 700	under $700 as of 2000
Accident Prevention Plus		
Road Safety International	$ 280	For RS-1000 and does not include the optional GPS receiver module
Folksam Research		
Evicam International		
FOT		
Rowan University		
GDAIS		
VTTI Naturalistic Driving		
GM ACAS FOT		
ATC	$5K to $10K	DAS cost from $5K to $10K depending on the configuration, sensors are extra
Other vehicle systems (Sensors)		
ABS	$ 400	Average ABS price based on 6 vehicle models
ESP (ESC)	$ 630	Average ABS price based on 4 vehicle models, SUV's much higher priced than others
Airbag	standard	Standard on all vehicles
Lane Position Sensor - Assistware SafeTRAC	$ 15,000	
MobilEye	$850 - $1,550	Cost ranges from $850 to $1,550 depending on the configuration

5. COST/BENEFIT TRADEOFF

The benefits of various near-crash/crash AEDR packages are evaluated based on the number of near-crashes and pre-crash scenarios (crashes) that they might capture if installed in a vehicle fleet. This analysis assumes that the number of near-crashes in different dynamic scenarios would be proportional to the number of crashes. These benefits are weighed against the cost of each of the various AEDR packages. A basic package (BP) or configuration containing a suite of sensors is proposed as a foundation for near-crash/crash AEDRs. This package records the most essential measurements for a crash-capturing AEDR. Other AEDR configurations with increased functionality, mainly to capture and characterize near-crash events, are then built upon the basic package by incorporating additional sensors. The benefits-to-cost ratio of the various AEDR packages is determined from the relative increase in captured near-crashes or crashes divided by the relative increase in cost of an AEDR configuration in comparison to the basic AEDR package.

5.1. Functionality and Cost of Proposed AEDR Packages

Table 25 describes the functionality of a proposed basic AEDR package in terms of the measures that can be collected. Moreover, five other AEDR configurations are proposed by incorporating additional sensors to capture more measures. The basic package consists of a driver face camera to identify driver contributing or causal factors and a sensor suite that encompasses various devices already available on many vehicles in the vehicle fleet. Many cars today are equipped with a dark sensor to automatically activate headlights (lighting measure), thermometers to display temperature inside and outside the vehicle (ambient temperature), windshield wiper status (adverse weather), and GPS unit for ACN services such as OnStar. More new vehicles come equipped with advanced stability control systems that contain accelerometers, yaw rate sensor, steering wheel sensor, wheel speed sensors, brake pedal status, and throttle opening sensor. Based on a cost survey, it is estimated that the sensors in a stability control system may amount to between $600 and $650. In addition, the prices of a video camera and a GPS unit are estimated respectively at $150 and $125. By including $100 for processor and data storage (low estimate), the basic package might amount to about $1,000. Near-crash AEDRs would cost more than crash AEDRs because they require more processing and data storage capability. It should be noted that this BP could cost under $500 if the vehicles were OEM-equipped with many of the needed sensors.

By adding a forward view (FV) camera to the BP, the BP+FV AEDR can then pick up information about the traffic and roadway ahead including roadway surface conditions. An AEDR could include an intelligent forward view (IFV) camera instead of a basic camera. The IFV is based on the *MobilEye* product that employs a single camera to detect vehicles and lane markers and to measure range, range rate, and azimuth angle to vehicles ahead. As indicated earlier in this report, the *MobilEye* product could cost about $1,500. The addition of an intelligent rear view (IRV) camera, an intelligent adjacent view (IAV) camera, or both cameras would enhance the functionality of the BP+IFV AEDR package. Also, two IAV cameras would be required ($3,000) to cover adjacent lanes on the right and left sides of the host vehicle.

Table 26 lists the cost of each proposed AEDR package under the assumption that most sensors were not already installed in the vehicle. The cost figures for each configuration in this table could be reduced by about $600 if the vehicles were already equipped with electronic stability or traction control. In this case, most BP sensors would already be installed in the vehicle for stability/traction control purposes. It should be noted that configurations above the basic package would require more data processing power and storage capacity. In order for these more advanced packages to detect and record near-crash events, a suite of near-crash detection algorithms would have to be developed and programmed into the processors. Therefore, processor and data storage would become more expensive than in the BP (assumed to be doubled to $200).

Table 25. Configurations of Proposed AEDR Packages

Measures		Packages					
		Basic	BP+FV	BP+IFV	BP+IFV +IRV	BP+IFV +IAV	BP+IFV+ IAV+IRV
Host Vehicle	Driver Face View	X	X	X	X	X	X
	Dashboard View						🟦
	Travel Speed	X	X	X	X	X	X
	Acceleration - Longitudinal	X	X	X	X	X	X
	Acceleration - Lateral	X	X	X	X	X	X
	Yaw Rate	X	X	X	X	X	X
	Tire Pressure	X	X	X	X	X	X
	Steering Input	X	X	X	X	X	X
	Brake Input	X	X	X	X	X	X
	Engine RPM	X	X	X	X	X	X
	Throttle Position	X	X	X	X	X	X
	BAC Level						🟦
Driving Environment	Forward View		X	X	X	X	X
	Rearward View				X		X
	Left Side View					X	X
	Right Side View					X	X
	Location	X	X	X	X	X	X
	Position in Lane			X	X	X	X
	Range - Forward Target			X	X	X	X
	Range - Rear Target				X		X
	Range - Side Target						🟦
	Range - Adjacent Target					X	X
	Range Rate - Forward Target			X	X	X	X
	Range Rate - Rear Target				X		X
	Range Rate - Side Target						🟦
	Range Rate - Adjacent Target					X	X
	Road Curvature	X	X	X	X	X	X
	Road Grade	X	X	X	X	X	X
	Lighting	X	X	X	X	X	X
	Ambient Temperature	X	X	X	X	X	X
	Adverse Weather	X	X	X	X	X	X

Colored cells refer to the additional measures picked up by the more advanced package over the one in the previous column.

Table 26. Cost of Proposed AEDR Packages

Package	Cost
Basic Package	$ 1,000
BP+FV	$ 1,250
BP+IFV	$ 2,600
BP+IFV+IRV	$ 4,100
BP+IFV+IAV	$ 5,600
BP+IFV+IRV+IAV	$ 7,100

5.2. Benefits of Proposed AEDR Packages

Table 27 provides estimates for the relative frequency of crashes (and near-crashes) that can be captured by the various proposed AEDR packages. The basic package has the capability to detect and collect data on vehicle defect and control loss that account for at least 8% of all crashes (near-crashes). The addition of an FV camera enables the identification of bad surface conditions in control loss events, which are estimated at about 15% of all control loss crashes. Instead of a simple FV camera, the installation of an IFV camera offers substantial gains in captured crashes at about 6.7 times the crashes captured by the basic package. The addition of an IRV camera to the BP+IFV EDR package would increase the percentage of captured events by about 27% over the BP+IFV package. On the other hand, the installation of two IAV cameras to the BP+IFV AEDR package would increase the percentage of captured events by only 11%.

Table 27. Percentages of Events Captured by Proposed AEDR Packages

Needs		Packages					
		Basic	BP+FV	BP+IFV	BP+IFV +IRV	BP+IFV +IAV	BP+IFV+ IAV+IRV
LVS detection	Following vehicle			8.5%	8.5%	8.5%	8.5%
	Lead vehicle				8.4%		8.4%
SCP detection	Vehicle 1			5.3%	5.3%	5.3%	5.3%
	Vehicle 2						
Control Loss detection	Single vehicle	7.0%	8.3%	8.3%	8.3%	8.3%	8.3%
LTAP/OD detection	Vehicle going straight			4.0%	4.0%	4.0%	4.0%
	Vehicle LTAP/OD						0.0%
Drifting detection	Single vehicle			10.9%	10.9%	11.7%	11.7%
LVD detection	Following vehicle			3.8%	3.8%	3.8%	3.8%
	Lead vehicle				3.8%		3.8%
LTAP/LD detection	Vehicle going straight			2.9%	2.9%	2.9%	2.9%
	Vehicle LTAP/LD						
Changing Lanes	Vehicle going straight					2.3%	2.3%
	Vehicle changing lanes					2.3%	2.3%
Object in road	Single vehicle			5.3%	5.3%	5.3%	5.3%
LVM detection	Following vehicle			1.4%	1.4%	1.4%	1.4%
	Lead vehicle				1.4%		1.4%
Vehicle defect	Single vehicle	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
	Total	7.6%	8.9%	51.0%	64.6%	56.4%	70.0%

5.3. Benefits-to-Cost Ratio Estimates

Figure 12 illustrates the incremental benefits-to-cost ratios that might be obtained by adding additional sensors and functionality to the BP and the BP+IFV AEDR packages. As seen in Figure 12, the addition of an IFV camera to the BP AEDR yields the highest benefits-to-cost ratio in terms of the increase in relative number of captured events divided by the increase in relative cost of installed AEDRs.

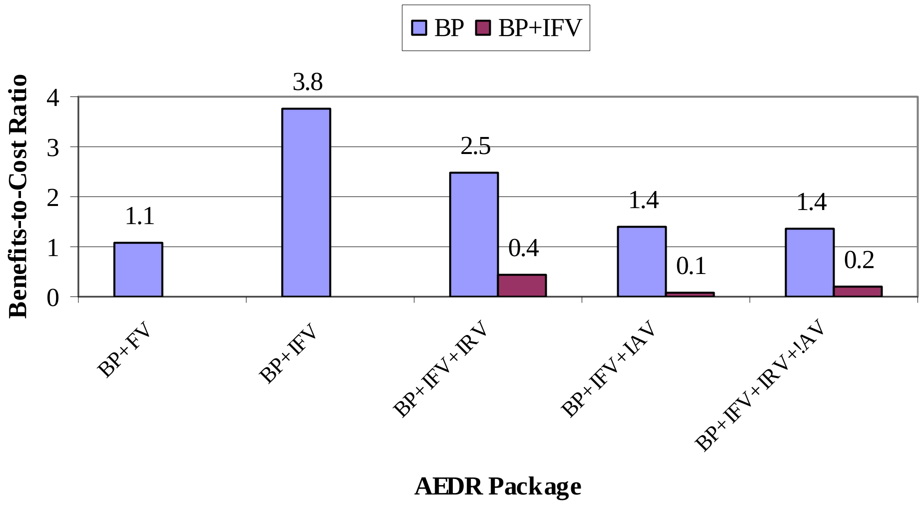


Figure 12. Incremental Benefits-to-Cost Ratios Relative to BP and BP+IFV AEDR Packages

6. CONCLUDING REMARKS

This report defined general functional requirements of near-crash/crash AEDRs based on the code structure of the GES/CDS and crash statistics. These requirements were expressed in terms of the needs to capture a defined set of dominant pre-crash scenarios and a distribution of known crash causal and contributing factors, as well as the measures that are required to quantify the near-crash/pre-crash data needs. Separate EDR functions were defined for the host vehicle and the driving environment in its close proximity. The measures were distinguished by visual and numerical measures.

The results of an EDR survey, which examined the state-of-the-art of current OEM, aftermarket, and experimental EDR prototypes and products, were also presented. The survey identified the functions, measured parameters, and cost of today's EDRs. OEM EDRs with different complexity are embedded in new vehicles at greater penetration rates. Aftermarket EDRs add more functionality at a higher cost for different applications. Advanced EDRs are currently being used in different field operational tests of crash avoidance systems and in data collection efforts of naturalistic driving.

Based on information about crash statistics and current EDR functions and cost, a basic AEDR package and five more advanced packages were proposed as potential in-vehicle near-crash/crash AEDRs. The basic AEDR package enhances OEM EDRs (i.e., sensors are currently available in many new vehicles) by adding a camera inside the vehicle to view the driver so as to gain information about causal factors. This package is intended to capture crashes only, not near-crash events. It is noteworthy that driver factors were cited as the primary cause in 90% of all crashes. An incremental benefits-to-cost ratio analysis was conducted to assess the advantage of adding various sensors (five advanced AEDR packages) to the basic AEDR package. These more complex configurations added the capability of capturing multiple near-crash events. The incorporation of an IFV camera in the basic package that measures vehicle position within the lane of travel and the range and range rate to obstacles in the lane ahead proved to be the most efficient in terms of captured events and cost. The capability of such a camera (e.g., *MobilEye* product) has not been fully characterized. Thus, it is recommended that a test be conducted to describe the capability and limitations of this IFV camera under a full spectrum of driving conditions. Moreover, the functional requirements and performance specifications of the BP+IFV AEDR package as a whole device need to be defined. Finally, the analysis in this report focused on the sensory aspect of near-crash/crash AEDRs (front-end analysis); additional analyses must be undertaken to address the processing, storage, and retrieval of data collected by these AEDRs.

7. REFERENCES

[1] National Center for Statistics and Analysis. *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-1999*. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, 20590.

[2] Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N.. *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System*. DOT HS 809 573, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, February 2003.

[3] Najm, W.G., Mironer, M., Koziol, J., Jr., Wang, J.-S., and Knipling RR.. *Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures*. DOT HS 808 263, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, June 1995.

[4] EDR Vehicle List. http://www.harristechnical.com/cdr2.htm, viewed September 25, 2003.

[5] http://www.mindspring.com/~ralphc/edrcdr.htm, viewed September 22, 2003.

[6] NHTSA EDR Working Group. Summary of Findings. National Highway Traffic Safety Administration. Washington, D.C., August 2001. http://www-nrd.nhtsa.dot.gov/edr-site/uploads/edrs-summary_of_findings.pdf, viewed September 25, 2003.

[7] http://www.wendellhull.com/accident/airbagedr.asp#1, viewed September 30, 2003.

[8] http://www.onstar.com, viewed October 6, 2003.

[9] http://www.onstar.com/us english/jsp/faq/not_faq_main.jsp?topPage=not_faq_techhardware.jsp&id=4&title=Technology+%26amp%3B+Hardware, viewed November 6, 2003.

[10] http://www.cwta.ca/safety/E911/ATX_Presentation_to_CWTA.doc, viewed October 6, 2003.

[11] Chidester, A., and Hinch, J.A. *Real World Experience with Event Data Recorders*, SAE Government and Industry Meeting on Frontal Crash Protection, May 14, 2001. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/SAE/SAE2001/ChipEDR.PDF, viewed September 25, 2003.

[12] http://www.mindspring.com/~ralphc/edrcdr.htm, viewed September 22, 2003.

[13] Engström, Anders. *Methods and Tools for Evaluation of the Volvo Pre Crash Recorder*. Master's thesis performed in Vehicular Systems at Linköping Institute of Technology, Linköping, Sweden, reg. no. LiTH-ISY-EX-3181, May 2001. grouper.ieee.org/groups/1616/ VolvoPreCrashRecorderResearch.pdf, viewed September 26, 2003.

[14] Brophy, J., and Roston, T. *Data Collection on New and Emerging Technologies – NHTSA's Special Crash Investigations (SCI) Program*, SAE Government and Industry Meeting, May 14, 2003. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/SAE/SAE2003/Brophy.pdf, viewed September 25, 2003.

[15] Oldenburg, D. Data Recorders Interest Parents, Police. *Washington Post*, September 9, 2003. http://www.computercops.biz/article3052.html, viewed September 25, 2003.

[16] http://grouper.ieee.org/groups/1616/Summary%20of%20Swedish%20Research%20Using%20Crash%20Recorder%20Data%2004-12-02.pdf, viewed October 3, 2003 .

[17] Shinmun, H. K., “Black Box for Automobiles,” *Global News Korea*, May 19,1999, p. 14. http://ssdc.ucsd.edu/news/korea/h99/korea.19990521.html, viewed October 6, 2003.
[18] http://www-nrd.nhtsa.dot.gov/edr-site/uploads/Digital_Eye-Witness_Systems-LMS_System.pdf, viewed September 25, 2003.
[19] http://www.iwiwitness.com/witness.asp, viewed September 30, 2003.
[20] http://www.vdona.com/fleet/fleetudsframes.html, viewed September 30, 2003.
[21] http://www.drivecam.com/video-event-data-recorder.html, viewed September 30, 2003.
[22] http://www-nrd.nhtsa.dot.gov/edr-site/uploads/accident_prevention_plus.pdf, viewed September 30, 2003.
[23] http://www.applus.com, viewed November 7, 2003.
[24] http://www.roadsafety.com/products_emergency.php, viewed September 30, 2003.
[25] Personal communication with Dr. Meny Benady (Meny.Benady@Mobileye.com), Vice President, Marketing and Business Development, MobilEye Vision Technologies, December 9, 2003.
[26] Summary of Findings by the NHTSA Working Group, Volume II: Supplemental Findings for Trucks, Motorcoaches, and School Buses, DOT HS 809 432. U.S. Department of Transportation, National Highway Traffic Safety Administration. Washington, D.C., May 2002. http://grouper.ieee.org/groups/1616/41EDRTruckBusFINAL.pdf, viewed October 3, 2003.
[27] Personal communication with Mr. Jeffrey Scaman, CEO of Evicam International, Inc., November 11, 2003.
[28] http://www.mitsubishi-electric.com.au/PRODUCTS/AUTO/airs.html, viewed December 11, 2003.
[29] http://www.yazaki-group.com/e/YazakiNews/YN77.pdf, viewed September 30, 2003.
[30] NHTSA EDR Working Group. Meeting Minutes. National Highway Traffic Safety Administration. Washington, D.C., June 6, 1999. http://www-nrd.nhtsa.dot.gov/edr-site/uploads/5218-3--Meeting_Minutes--MVSRAC--EDR_Working_Group--06-06-99c.pdf , viewed September 25, 2003.
[31] Campbell, K.L., Lepofsky, M., and Bittner, A. *Detailed Planning for Research on Making a Significant Improvement in Highway Safety*, Future Strategic Highway Research Program, Transportation Research Board, Washington, D.C., September 2003. http://gulliver.trb.org/publications/f-shrp/f-shrp_webdoc_2.pdf, viewed December 11, 2003.
[32] http://www.veridian.com/offerings/suboffering.asp?offeringID=368, viewed September 30, 2003.
[33] Fuglewicz, D. P. Presentation: *A Veridian Perspective: EDRs Past & Present – Lessons Learned*. National Academies IEEE P1616 Working Group Meeting, Washington, D.C., May 6, 2003. grouper.ieee.org/groups/1616/EDRs-Past-Present-Lessons-Learned.ppt, viewed October 3, 2003.
[34] http://www.nationaldefensemagazine.org/article.cfm?Id=806, viewed November 12, 2003.
[35] Neale, V.L., et al. *100 Car Naturalistic Driving Study Phase I - Experimental Design Intertim* Report. DOT HS 808 536, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., December, 2002.

http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/100CarPhase1Report.pdf, viewed October 6, 2003.

[36] http://www.harristechnical.com/cdr21.htm, viewed September 22, 2003.

APPENDIX A. DEFINITION OF GES VARIABLES

Accident File

A6	**First Harmful Event** Indicates the first property-damaging or injury-producing event in the crash.
A9	**Relation to Junction** Indicates if the first harmful event is located within a junction or interchange area.
A13	**Roadway Alignment** Horizontal alignment of roadway in the immediate vicinity of the first harmful event.
A14	**Roadway Profile** Vertical alignment of roadway in the immediate vicinity of the first harmful event.
A15	**Roadway Surface Condition** Condition of road surface at the time of the crash.
A16	**Traffic Control Device** Indicates whether or not a traffic control device was present and the type of traffic control device.
A18	**Speed Limit** Actual posted speed limit in miles per hour.
A19	**Light Condition** General light conditions at the time of the crash, taking into consideration the existence of external roadway illumination fixtures.
A20	**Atmospheric Conditions** General atmospheric conditions at the time of the crash.
A24	**Pedestrian/Cyclist Crash Types** Codes specific information about pedestrian-, cyclist-, and wheelchair-involved crashes.
A92	**Alcohol Involved in Crash** Indicates alcohol use for drivers, pedestrians, cyclists, and other type of non-motorists involved in the crash.

Vehicle/Driver File Codes

V11	**Travel Speed** Actual miles per hour.
V12	**Vehicle Contributing Factors** Indicates vehicle factors that may have contributed to the cause of the crash.
V20	**Most Harmful Event** Indicates the most severe property-damaging or injury-producing event for the vehicle.
V21	**Movement Prior to Critical Event** Records the attribute that best describes the vehicle’s activity prior to the driver’s realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt any evasive maneuvers.
V23	**Accident Type** Categorizes the pre-crash situation.

V26 Critical Event
Identifies the critical event that made the crash imminent (i.e., something occurred that made the collision possible). A critical event is coded for each vehicle and identifies the circumstances leading to this vehicle’s first impact in the crash.

V27 Corrective Action Attempted
Describes the actions taken by the driver of this vehicle in response to the impending danger. Because this variable focuses upon the driver’s action just prior to the first harmful event it is coded independently of any maneuvers associated with the vehicle’s Accident Type (V23).

V28 Pre-Crash Vehicle Control
Assesses the stability of the vehicle during the period immediately prior to the vehicle’s initial involvement in the crash sequence.

V29 Pre-Crash Location
Identifies the path of the vehicle prior to its first involvement in the crash sequence, and further reports the results of the vehicle’s pre-crash stability coded in variable V28.

V92 Driver Drinking in Vehicle
Reports alcohol use by driver of the vehicle.

D2 Violations Charged
Indicates which violations are charged to drivers.

D4 Driver’s Vision Obscured by
Identifies visual circumstances that may have contributed to the cause of the crash.

D6 Driver Maneuvered to Avoid
Attempts to identify an action taken by the driver to avoid something or someone in the road. The maneuver may have subsequently contributed to the cause of the crash.

D7 Driver Distracted by
Attempts to capture distractions that may have influenced driver performance and contributed to the cause of the crash. The distractions can be both inside the vehicle (internal) and outside the vehicle (external).

D9 Speed Related
Indicates whether speed was a contributing factor to the cause of the crash.

Person File Codes

P11 Police-Reported Alcohol Involvement
Indicates that the person (drivers of in-transport motor vehicles and non-motorists only) had consumed an alcoholic beverage.

P13 Non-Motorist Location
Reports the location of non-motorists at the time of impact.

P18 Person’s Physical Impairment
Attempts to identify physical impairments for all drivers and non-motorists that may have contributed to the cause of the crash.