ELECTRONIC CRASH, DEFECT AND CAUSATION ANALYSES

Donald Friedman
Jacqueline G. Paver Ph.D.
Josh J. Jimenez
Center *f*or Injury Research
United States
Paper Number ESV 13-0106

ABSTRACT

Since about 1990, all motor vehicles are equipped with Collision Data Recorders (CDR). These devices initially provided impact and status data, as well as deployment commands for occupant protection systems. More recently, vehicles are equipped with drive-by-wire systems with electronically-aided driver controls derived from more than 40 control modules interconnected by communication networks. A vast amount of additional data is collected and stored by these control modules. Diagnostic Trouble Codes (DTCs) identify, describe and store events, faults, limitations exceeded and corrective actions made by each control module. The functioning of a control module, access, and storage location codes are defined in its Product Definition Description (PDD) manual.

Several case studies are presented to demonstrate the effects of control module algorithms, events, faults and actions. A complete case study identified a defect and proved that defect was the proximate cause of the injury and death. Surprisingly, these modules can seize control of a drive-by-wire vehicle and actually cause loss of control, resulting in a crash and injury ranging in severity from minor to fatal.

INTRODUCTION

In the 1960's, the first author, while working at General Motors Research on the Lunar Rover and other electric vehicles, foresaw the advent of electronic controls as driver aids by demonstrating lane following, adaptive cruise control, and electric and hybrid electric drives [1-3]. In the late 1970's and early 1980's the National Highway Traffic Safety Administration's (NHTSA)/Minicars, Inc. Research Safety Vehicle (RSV) demonstrated anti-lock brakes; radar-controlled airbag deployment, emergency braking, cruise control, and electronic transmission shifting [4-7].

Since then, the operational control of motor vehicles has been taken over by lighter, less expensive, and more efficient and accurate digitally-programmable electronic control modules, labeled as drive-by-wire systems.

This widespread shift from manual mechanical driver control to electronically-aided driver control and the need for crashworthiness and occupant protection data has spawned the implementation of collision data recorder (CDR) systems. In 2006, NHTSA promulgated 49 CFR Part 563 crash data recording [8].

The benefits of the shift to electronic control of vehicles are not without control module algorithm faults. The algorithm interactions and decisions leading to those faults are correctable by reprogramming when investigated, discovered and proven. Optimization of such a complicated electronic system requires the shared knowledge of programmers (with little knowledge of the vehicle's mechanical functioning) and mechanical automotive engineers (who know little about programming).

This paper presents examples of the electronic data of several real-world crashes. In addition a complete case file describes the relationship between the crash reconstruction, the physical evidence, the correlation with the CDR records and the electronic identification and confirming proof of defect and injury causation.

METHODS AND DATA

For the cases studied a systems analysis was performed to determine and prove defect and causation. In addition to the accident reconstruction, the medical records and the physical evidence, the key to a responsible system analysis is an understanding of the electronic components and operation of the drive-by-wire system.

For example, in a manual driver-controlled system, there is a mechanical connection between the accelerator pedal and the engine fuel and air intake throttle valve. However, in a drive-by-wire system, the accelerator pedal is connected by wire to a computer in the engine compartment that can activate the throttle in conjunction with emissions and fuel economy sensors.

Since about 1990, all motor vehicles are equipped with Collision Data Recorders (CDR). These devices initially provided impact and status data, as well as deployment commands for occupant protection systems. More recently, vehicles are equipped with drive-by-wire systems with electronically-aided driver controls derived from more than 40 control modules interconnected by communication networks. A vast amount of additional data is collected and stored by these control modules. Diagnostic Trouble Codes (DTC's) identify, describe and store events, faults, limitations exceeded and corrective actions made by each control module. The functioning of a control module, access, and storage location codes are defined in its Product Definition Description (PDD) manual.

Typically the control module are distributed in three categories of Powertrain, Body and Chassis modules all interconnected by a local area network (LAN) and central area network (CAN). Most of the control modules have extensive storage capacity to record parameter changes, events and impacts over time.

Perhaps the most important control modules are the sensing and diagnostic module (SDM) and the electronic brake control module (EBCM). The SDM calculates impact forces and decides if and/or when to deploy the airbags. The EBCM integrates and controls ABS, Electronic Stability Control (ESC), braking and throttle; it can steer by braking or speeding the rotation of an individual wheel (ESC function).

While much is known about the content and coding in the CDR report the source of the data collection and processing in the SDM has been mostly classified as proprietary to the manufacturer. The data collection retrieved from the sensors and calculations and the processing recovered from the algorithms and records are confidential, locked and not accessible with commercially-available tools. Moreover, the communications network which transmits the data, the algorithm faults and records of the control modules are also classified as proprietary. Recently, some of the once proprietary hexadecimal data records of the control modules became the property of the vehicle owner, and can be downloaded and translated to English.

The computer module's program called an algorithm is specified by the manufacturer's mechanical engineers and interpreted and defined by computer programmers in the PDD. The PDD describes how the module is supposed to work under all the possible combinations of signals from sensors and other control modules. It also describes the confidential electronic codes required to communicate and download data from the module and the limits of the signals that become issues (faults) as well as what "shall" (must) be done about the faults if communications between sensors and modules fail.

A fault or loss of communications generates a diagnostic trouble code (DTC) and may initiate a Fail-Soft procedure. A DTC is a message about parts that failed and need adjustment or substitute parts. The DTC manuals provide explanations of failures and corrective actions. The Fail-Soft procedure momentarily freezes the controls while the fault is cleared.

RESULTS

The following case studies illustrate how the control modules can prove defect and crash and/or injury causation.

Case Study 1: Steering Wheel Sensor Errors

Electronic Data The electronic control modules produced DTC's indicating:

- a known defect in the steering column connector and associated NHTSA recall,
- a loose and misaligned steering wheel position sensor,
- a difference between the steering wheel sensor angle and the vehicle's direction of motion, to which the ESC of the EBCM was very sensitive at high speeds, and
- vibration and/or noise in the electronics.

<u>DTC's.</u> The reported DTC's exceeded the following *Steering Wheel Sensor DTC Limits:*

- *C0710 - 4.9 V < Phase A&B < 0.2 V for 1.6 s,*
- *C0710.1 A Bias > 40°,*
- *C0710.1 F 106° < Phase A - Phase B < 84º continuously for 0.25 s*
- *C0710.5 2 - Changes between consecutive signal scans A&B > 36º.*

<u>Interpretation.</u> The steering wheel sensor malfunctioned, and exceeded set limits.

<u>Drive-by-Wire Commands.</u> The ESC commanded the left front wheel to brake to reduce the difference between the steering wheel sensor angle and the vehicle's direction of motion.

Case Study 2: Driver Door Mirror Sensor and Communication Errors

Accident Description Damage to the driver's side view mirror caused a short circuit in the door power supply control module disrupting communications.

Electronic Data The electronic control modules produced DTC's indicating problems in the door control module.

DTC's. The reported DTC's exceeded the following *Side Mirror DTC Limits: B1580 & B1590 - Mirror Horizontal or Vertical Position Sensor Circuit Voltage < 0.5 Volts or Voltage > 4.5 Volts for 2 sec.*
Interpretation. The driver's side mirror wires shorted, which created a low voltage in the door control module power supply that powered door sensors, communications and other functions.

Case Study 3: Front Pole Sensor and Communication Errors

Accident Description The left front side of the vehicle overran a small tree activating the electronic frontal sensor (EFS).

Electronic Data The electronic control modules produced DTC's indicating system faults.

DTC's. The reported DTC's exceeded the following *System Fault DTC Limits:*

- *U-1000 An expected message with unknown source was not received*
- *U1040, U1088, U1153, U1193 - Lost communications between EBCM, SDM, HVAC Control, and Remote Door Lock.*

Interpretation. The front pole sensor (EFS) failed to respond. The physical damage to the sensor disrupted the communication systems to the SDM, EBCM and to functions controlled at the driver's door.

Case Study 4: Fail-Soft Initiation

Event Description The vehicle electronics seized control of the vehicle traveling at high speed.

Electronic Data The electronic control modules produced DTC's indicating system faults.

DTC's. The reported DTC's exceeded the following limits:

- *U-1000 An expected message with unknown source was not received*
- I*f the system does not stay or return "online" for as long as one second the SDM commands a mandatory one second recalibration, during which the throttle and brake are frozen. If the calibration does not re-establish communications the system repeats the calibration each second for an interval of up to 6 to 9 seconds before returning electronic controls to the driver. This mandatory calibration procedure is called Fail-Soft.*

Interpretation. According to the PDD, a mandatory calibration procedure, called Fail-Soft, was initiated by the fault conditions (i.e., limit speed exceeded, noise algorithm active, and ESC slip angle error). During Fail-Soft, the vehicle was controlled by the stored status of throttle position, wheel braking, and steering angle.

Case Study 5: Airbag Non-deployment

Crash Description The left side of the vehicle struck a concrete barrier at a speed of 30 mph with airbag non-deployment.

Electronic Data According to the EBCM translated download of the recorded history, the DTC's exceeded set limits for airbag deployment. However, the SDM was disabled and failed to activate the side impact airbags.

DTC's. The reported DTC's exceeded the following *EBCM DTC Limits:*

- C0186.09 - Yaw Circuits > 11g/s twice within 0.2 s,
- C0186.19 - Yaw Circuits > 0.5g for > 1 s,
- C0196.09 -Yaw Circuits Changes > $390°/s^2$
- C0196.1A - Bias > 7°/s

Interpretation. Although the EBCM sensors detected the crash, the lateral sensor of the SDM malfunctioned and failed to deploy the side impact airbag.

Complete Case Study: Angled and Full Barrier Crash -- Airbag Non-deployment Due to the Erroneous Passenger Weight Detection Algorithm

Crash Description A passenger car struck a Jersey barrier and then was redirected into an essentially head-on collision into a construction barrier. Occupants included the belted 175-pound female adult driver and belted adult male right front seat passenger. The driver airbag deployed, but the right front seat airbag did not deploy.

Electronic Data A complete time history record of the passenger seat weight was recovered by directly interrogating the Passive Occupant Detection System (PODS) memory [9]. This record provided insight into the crash events. The driver started the car before the passenger was seated. When the passenger sat in the car, his normal weight was recorded. When the vehicle hit the Jersey barrier, the passenger unloaded his seat. When the car impacted the construction barrier, the passenger was reported as a #2 Small Occupant and the SDM appropriately inhibited passenger airbag deployment.

Further analysis revealed that the SDM inhibited the deployment of the right front passenger airbag because the CDR-recorded passenger weight algorithm used the instantaneous measurements of passenger weight, which misidentified the occupant as a #2 Small Occupant.

Defect We concluded the continuous instantaneous assessment of passenger weight (without averaging) was the algorithm defect that caused the airbag non-deployment and passenger fatality.

Alternate Design Had the algorithm averaged the passenger weight, the adult occupant would have been identified, the airbag would have deployed and serious, life-threatening and certainly fatal injuries would have been prevented.

CONCLUSION

In conjunction with physical evidence, the stored data of events in the control modules supplement the CDR readout, can clarify and/or confirm crash reconstructions and provide proof of vehicle, electronic, algorithm, deployment defects and crash and/or injury causation.

REFERENCES

[1] Friedman, D., “The Correlative Advantages of Lunar and Terrestrial Vehicle and Power Train Research,” SAE Paper 660150, January 10-14, 1966.
[2] Friedman, D., “Engineering Requirements for Electric Vehicles,” IECES, August 1967.
[3] Friedman, D., “An Electric Automobile Power Plant Survey,” IEEE, March 1968.
[4] Friedman, D., “Automotive Vehicles of the Future,” Transportation Research Board, January 1978.
[5] Friedman, D., “The Research Safety Vehicle: Present Status and Future Prospects,” SAE Paper 780603, June 1978.
[6] Friedman, D., Belohoubeck, E., “The Near-Term Prospect for Automotive Electronics Minicars RSV,” SAE 780858, September 1978.
[7] Kossar, J., “The High Technology RSV,” ESV Conference. Germany, 1980.
[8] Department of Transportation, National Highway Traffic Safety Administration 49 CFR Part 563, Docket NHTSA-2006-25666 Event Data Recorders, Final Rule 8-28-2006.
[9] Martinez v. General Motors, et al. In the District Court of 139th Judicial District Hidalgo County, Texas Cause No. C-257311-C