The Application of Event Data Recorders to Vehicle Safety Research

Jean-Louis Comeau
William Holmes
Brian Monk
Transport Canada

Dainius Dalmotas
Alan German
D.J. Dalmotas Consulting, Inc.

Simon Schramm
Steven Thannhauser
Craig Good
Collision Analysis Ltd.

Abstract

Event Data Recorders (EDR's) have been installed in many motor vehicles since the 1990's. With the advent of sophisticated occupant restraint systems, including belt pretensioners and smart airbags, EDR's have recorded an increasing number of crash-related parameters. Similarly, advanced collision avoidance systems have become prevalent in the vehicle fleet and EDR's are now used to capture a wide range of pre-crash data elements relating to this technology and the resulting status of the vehicle and its control systems. Such data provide a wealth of information related to driver actions, and on the functionality and effectiveness of vehicle safety systems. The current paper will provide an overview of the scope of data elements captured by modern EDR's and will demonstrate the utility of these data through case studies of real-world events.

Résumé

Les enregistreurs de données d'événement (EDR) ont été installés dans de nombreux véhicules à moteur depuis les années 1990. Avec l'arrivée des systèmes sophistiqués de retenue des occupants, y compris les tendeurs de ceinture de sécurité et les coussins gonflables intelligents, les EDR enregistrent un nombre croissant de paramètres liés aux collisions. De même, les dispositifs avancés de prévention de collisions sont devenus plus courants dans la flotte de véhicules et les EDR sont maintenant utilisés pour enregistrer une large gamme d'éléments de données pré-collision concernant cette technologie et l'état résultant du véhicule et de ses systèmes de contrôle. Ces données fournissent une mine d'informations sur les actions des conducteurs et sur la fonctionnalité et l'efficacité des systèmes de sécurité des véhicules. Le présent document donnera un aperçu de la portée des données recueillies par les EDR modernes et démontrera l'utilité de ces données à travers des études de cas.

INTRODUCTION

The introduction of supplementary front airbag restraint systems into motor vehicles required automotive engineers to develop crash sensors, deployment algorithms and control systems in order to automate the use of these devices. Advances in automotive electronics resulted in the majority of these functions being handled by micro-processors with associated non-volatile memory. This technology allowed for the capture of a considerable amount of data relating to collision severity, the decision to fire airbags, and a wide range of pre-crash parameters relating to the state of various vehicle systems and specific driver actions. The need to understand the performance of passive safety systems under field conditions, to both ensure appropriate response for airbag deployment, and to further enhance vehicle safety, resulted in the widespread adoption of on-board event data recorders and, in particular, the development of tools to download and analyse the resulting data. [1]

Modern vehicles are equipped with a wide range of safety systems, many of which that are passive in nature. These include occupant protection features such as seat belt pretensioners, advanced frontal airbags, side airbags and curtains, and inflatable knee bolsters. Developments in collision avoidance systems have included the introduction of active braking systems, electronic stability control, lane-keeping assistance, and a variety of collision warning and mitigation systems. The automatic nature of all of these systems results in a need to record the parameters responsible for activating the related devices. Consequently, EDR's have become increasingly sophisticated over time. The net result is that the data captured by EDR's have become valuable tools in the research and analysis of motor vehicle collisions.

When making use of the information captured by EDR's, it is important to have confidence in the stored data. Early studies on EDR technology demonstrated the veracity of certain elements of the captured data, with some caveats. These included evaluations of the changes in velocity (delta-V) reported for vehicles involved in instrumented crash tests [2], and measurements of vehicle travel speeds under experimental conditions. [3] More recently, a wide-ranging review of related research studies has confirmed that, to a large extent, and within reasonable levels of accuracy, the data captured by these devices are indeed representative of the associated real-world collision situations. [4] This is true of measures of collision severity, such as the vehicle's change in velocity, and for pre-crash parameters such as vehicle speed and occupant seat belt use. Nevertheless, this is not always the case, and there remain some circumstances where the data retrieved from an EDR must be carefully scrutinized. However, overall, EDR data have been shown to be an extremely valuable resource for research and development over a wide field of endeavours.

In the Canadian context, this has been the case for a number of safety issues relating to both occupant protection and collision avoidance. For example, in a study of crashes involving airbag deployments, EDR data were frequently combined with conventional collision investigation and reconstruction techniques, to identify the nature of occupant injuries as a function of collision severity. In particular, it was shown that the overly-aggressive nature of first-generation airbag systems were a particular hazard for certain segments of the restrained-occupant population. [5] This was especially the case for children and short-statured females where a number of fatalities were observed in relatively low-severity crashes. [6] The results of an exhaustive process of in-depth collision investigation and reconstruction, combined with an intensive crash test programme, played a major role in the introduction of advanced airbag systems across the

North-American vehicle fleet. A further example is that of public complaints of unintended acceleration in motor vehicles. Drivers of a variety of vehicle makes and models reported that their vehicles accelerated despite full application of the brakes. The follow-up process included a number of conventional investigative techniques, such as interviews with the vehicle operators, physical inspection and testing of vehicle components, and diagnostic tests on vehicle systems. In addition, for cases where the subject vehicles were equipped with EDR's, the pre-crash data provided indications of driver actions with regard to application of the brake and/or accelerator pedals, typically for a five-second period prior to the collision. [7] Analysis of these objective data revealed that, for the most part, drivers had been subject to "pedal error" and had mistakenly applied the accelerator rather than the brake. The combined findings of the detailed investigations resulted in no problems being identified with the design or performance of any vehicle control system.

Going forward, with the rapid enhancements in technology, and the improvements in motor vehicle safety systems, it is certain that EDR's will continue to be both a useful and a necessary tool to understand the performance of safety systems and to promote their further refinement.

DATA RECORDED BY EDR'S

As noted above, modern EDR systems typically provide a wealth of data related to pre-crash driver actions and on-board collision avoidance systems, measures of crash severity, and the performance of passive occupant protection devices. The specific parameters that are available, and the level of detail provided, are highly dependent on the year, make and model of any given vehicle. The following extracts from a number of Crash Data Retrieval (CDR) reports, while not exhaustive, are intended to provide some insight into the range of the data elements that may be captured by EDR's and an indication of the detail provided.

System Status at Event (Most Recent Event)

Deployment Recorder Status	Complete
Safety Belt Status, Driver	Buckled
Safety Belt Status, Passenger	Buckled
Airbag Warning Lamp, On/Off	Off
Seat Track Position Switch, Foremost, Status, Driver	No
Seat Track Position Switch, Foremost, Status, Passenger	No
Maximum Delta-V Longitudinal (MPH [km/h])	-23.2 [-37]
Time, Maximum Delta-V, Longitudinal (msec)	255
Maximum Delta-V Lateral (MPH [km/h])	16.7 [27]
Time, Maximum Delta-V, Lateral (msec)	89
Time, Operation System Time (sec)	724500.65
Time, Airbag Warning Lamp On (min)	0
Total Number of Events	1
Operation Via Energy Reserve Only (Yes, No)	Yes
System Voltage at Event, Bussed (V)	5.0
Supply Voltage at Event, ECU (V)	12.2
Event Signal Transmission, Complete (Yes, No)	Yes
Odometer at Event (km)	10480.2
Ignition Cycle, Crash	1099
VIN, Original	3C4PDCCG2CT******
VIN Recorded at Event (last 8 characters)	CT******

Figure 1 EDR System Status Report

In the tabular data shown above we can see that the EDR confirms that data capture in the associated crash was completed successfully for a single collision event. The parameters recorded include the status for the seat belt use by both the driver and passenger (if a passenger was present in this case). In addition, the vehicle can be seen to be equipped with biaxial accelerometers since crash pulse characteristics (delta-V and delta-t) in both the longitudinal and lateral directions are recorded.

Pre-Crash Data (Most Recent Event - table 1 of 5)
(the most recent sampled values are recorded prior to the event)

Time Stamp (sec)	Pre-Crash Recorder Status	Engine RPM	Speed, Vehicle Indicated (MPH [km/h])	Engine Throttle, % Full	Accelerator Pedal, % Full	Raw Manifold Pressure (kPa)	Service Brake	PCM MIL	ABS Activity
-1.0	Complete	1,009	29 [46]	17.7	16.9	98	Off	Off	No
-0.9	Complete	1,011	29 [46]	17.7	16.9	98	Off	Off	No
-0.8	Complete	1,015	29 [46]	17.3	8.3	98	Off	Off	No
-0.7	Complete	1,014	29 [46]	0.8	0.0	86	Off	Off	No
-0.6	Complete	992	28 [45]	1.2	0.0	72	On	Off	No
-0.5	Complete	947	27 [44]	1.6	0.0	62	On	Off	No
-0.4	Complete	919	26 [42]	2.0	0.0	55	On	Off	No
-0.3	Complete	856	24 [39]	2.0	0.0	52	On	Off	No
-0.2	Complete	692	22 [35]	2.4	0.0	50	On	Off	Yes
-0.1	Complete	815	21 [33]	2.4	0.0	51	On	Off	Yes

Pre-Crash Data (Most Recent Event - table 2 of 3)
(the most recent sampled values are recorded prior to the event)

Time Stamp (sec)	ABS MIL (if equip.)	ESP MIL (if equip.)	Stability Control	Steering Input (%)	Yaw Rate (deg/sec) (if equip.)	Wheel Speed LF (RPM) (if equip.)	Wheel Speed RF (RPM) (if equip.)	Wheel Speed LR (RPM) (if equip.)	Wheel Speed RR (RPM) (if equip.)
-4.2	Off	Off	On	-4	-5	500	386	484	506
-4.1	Off	Off	On	-4	-7	483	278	472	476
-4.0	Off	Off	On	-8	-9	462	240	457	444
-3.9	Off	Off	On	-15	-11	432	254	422	398
-3.8	Off	Off	Engaged	-19	-8	443	309	422	410
-3.7	Off	Off	Engaged	-19	-6	429	307	375	361
-3.6	Off	Off	Engaged	-20	-5	408	439	381	352
-3.5	Off	Off	Engaged	-28	-5	421	423	391	340

Figure 2 Extracts from EDR Pre-Crash Data Reports

The range of pre-crash data captured by modern EDR systems is quite extensive. Whereas, parameters such as vehicle speed, brake and accelerator application have been recorded for many years, the previous records were usually limited to “snapshots” at one second intervals for a period of five seconds prior to impact. In more recent EDR’s, these parameters and many other data elements are stored with greater resolution. For example, the full tables from which the above-noted datasets have been extracted encompass the period t=-5.0 to -0.1 seconds in 0.1 second intervals. Note also that the data include the pre-crash history for activation of safety systems such as anti-lock brakes (ABS) and electronic stability control (ESC), and indicate the driver’s input to the vehicle’s steering system.

Deployment Command Data (Event Record 1)

Pretensioner Deployment, Time to Fire, Driver (msec)	12
Pretensioner Deployment, Time to Fire, Right Front Passenger (msec)	0
Frontal Air Bag Deployment, Time to Deploy/First Stage, Driver (msec)	33
Frontal Air Bag Deployment, Time to Deploy/First Stage, Right Front Passenger (msec)	0
Side Air Bag Deployment, Time to Deploy, Driver (msec)	50
Side Air Bag Deployment, Time to Deploy, Right Front Passenger (msec)	0
Side Curtain/Tube Air Bag Deployment, Time to Deploy, Driver Side (msec)	50
Side Curtain/Tube Air Bag Deployment, Time to Deploy, Right Side (msec)	0
Frontal Air Bag Deployment, 2nd Stage Disposal, Driver (Yes/No)	No (Not disposal)
Frontal Air Bag Deployment, 2nd Stage Disposal, Right Front Passenger (Yes/No)	No (Not disposal)
Frontal Air Bag Deployment, Time to 2nd Stage, Driver (msec)	53
Frontal Air Bag Deployment, Time to 2nd Stage, Right Front Passenger (msec)	0

Figure 3 Seat Belt Pretensioner and Airbag Firing Times

Understanding the performance of passive occupant restraints under real-world collision situations is critical to the development of enhanced safety systems. Many current EDR systems capture information on the deployment of seat belt pretensioners, advanced frontal airbags, side airbags and curtains, and inflatable knee bolsters. For example, the above table shows the firing times for a number of such pyrotechnic devices.

Most EDR's will provide specific details of the crash pulse experienced by the vehicle. Such records may include a time history of the vehicle's change in velocity and/or acceleration in the longitudinal and/or lateral directions. Such results are often displayed in a graphical format and, in some cases, have restraint deployment information overlaid on the delta-V curve as shown below.

Longitudinal Crash Pulse (1st Prior Event, TRG 2 - table 1 of 2)

Recording Status, Time Series Data	Complete
Time from Time Zero to TRG (msec)	39
Length of Delta-V (msec)	250
Max. Longitudinal Delta-V (MPH [km/h])	-22.5 [-36.2]
Time, Maximum Delta-V, Longitudinal (msec)	269
Power Supply Status at Max. Delta-V	ON

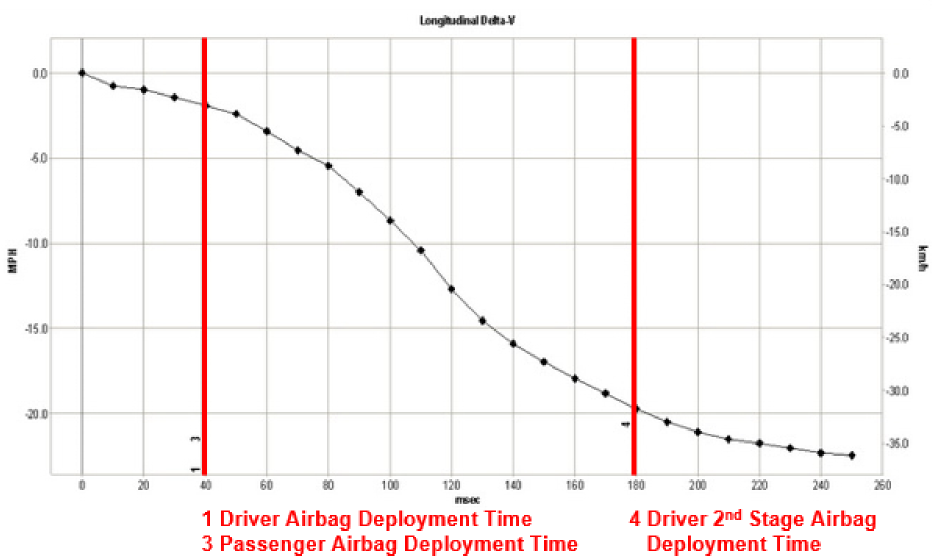


Figure 4 Longitudinal Crash Pulse (Enhanced to clarify the airbag timing information)

In addition to longitudinal and lateral accelerometers, some current vehicles are equipped with roll sensors. In such cases, as well as information on the horizontal crash pulse being available, details of the rollover crash pulse are recorded. The following figure provides an example of such a data record.

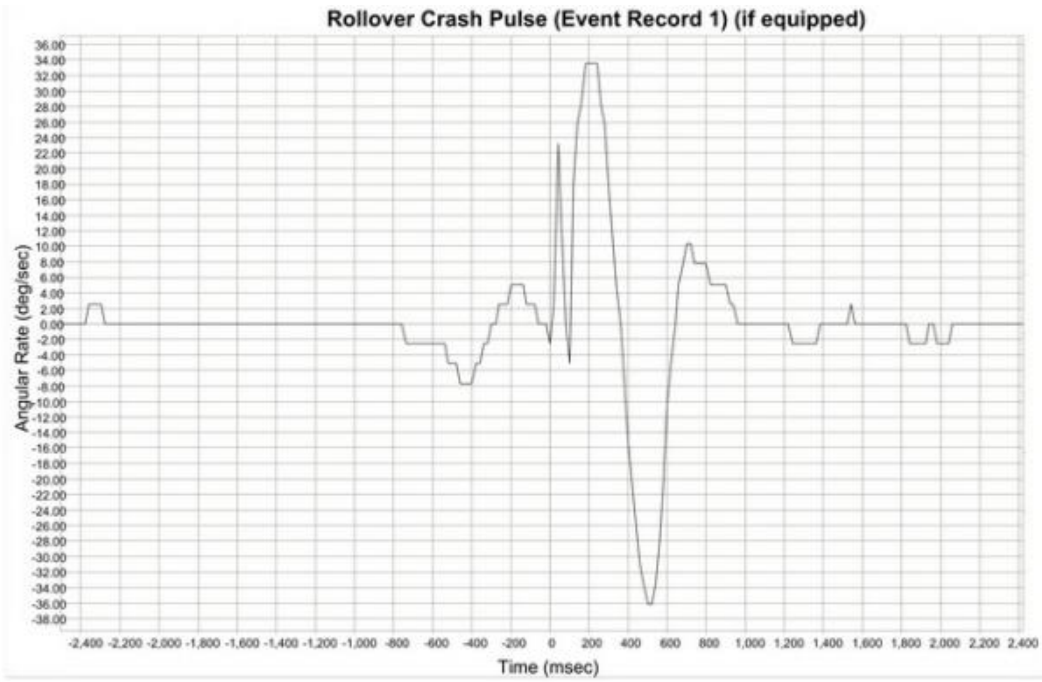


Figure 5 Rollover Crash Pulse

CASE STUDIES

The present paper looks at a number of areas where the current generation of EDR's have proven to be a beneficial component in the investigation of real-world motor vehicle collisions, have provided useful insights into the nature of driver actions leading up to crashes, and have demonstrated the effectiveness (or ineffectiveness) of some safety systems in specific circumstances. The following case studies are extracted from reports of real-world crashes that have been studied by the authors.

Case Study No. 1 - Pre-Crash Driver Actions

A 2010 Dodge Journey sport utility vehicle was travelling westbound in the curb lane of a six-lane, undivided, urban arterial roadway, approaching a traffic-light-controlled intersection. An eastbound vehicle commenced a left turn across the path of the Dodge Journey. The Journey's driver steered abruptly to the right, and then to the left, in order to avoid a collision with the turning vehicle. The right-front wheel of the Journey struck and mounted the curb on the northwest corner of the intersection. The utility vehicle continued forward and impacted a post on which pedestrian control signals were mounted. The pole broke away at its frangible base.

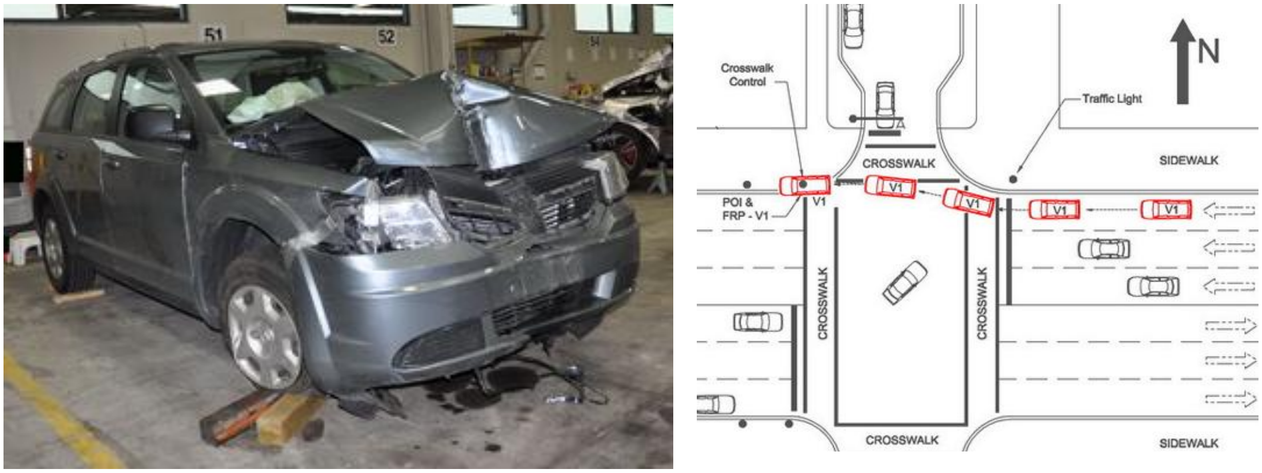


Figure 6 2010 Dodge Journey and Collision Schematic

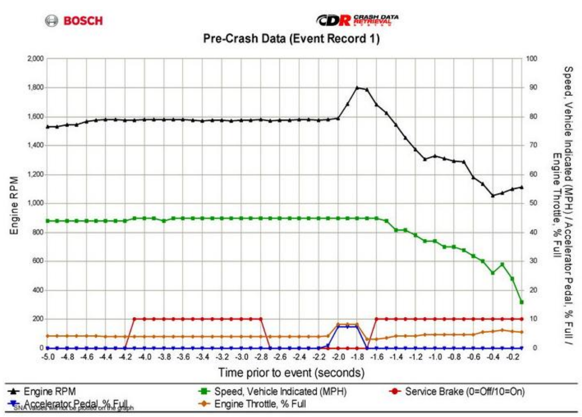
Pre-Crash Data (Event Record 1 - table 3 of 5)
(the most recent sampled values are recorded prior to the event)

Time Stamp (sec)	Steering Input (deg) (if equip.)	Yaw Rate (deg/sec) (if equip.)	Wheel Speed LF (RPM) (if equip.)	Wheel Speed RF (RPM) (if equip.)	Wheel Speed LR (RPM) (if equip.)	Wheel Speed RR (RPM) (if equip.)
-2.0	5	0	552	553	552	554
-1.9	5	0	552	552	552	552
-1.8	4	1	553	552	553	553
-1.7	-10	0	553	554	552	558
-1.6	-31	-2	529	522	552	545
-1.5	-63	-7	536	529	534	527
-1.4	-84	-12	521	485	522	501
-1.3	-104	-17	509	470	509	370
-1.2	-91	-21	360	435	493	456
-1.1	-34	-16	480	464	483	431
-1.0	-46	-10	445	419	470	451
-0.9	-56	-4	457	398	446	434
-0.8	1	-5	425	414	434	423
-0.7	42	0	265	416	418	412
-0.6	132	6	385	351	396	403
-0.5	201	13	177	377	309	390
-0.4	257	18	314	383	352	388
-0.3	316	24	210	364	342	377
-0.2	319	31	93	309	331	366
-0.1	327	21	205	268	334	141

Figure 7 Steering Input Data for the 2010 Dodge Journey
(Right steer = Yellow; Left steer = Blue)

Figure 7 shows the steering input data for the 2010 Dodge Journey, effectively for the last two seconds prior to impact with the pole. The driver's actions are indicated as the number of degrees of rotation of the steering wheel every tenth of a second. The data definitions included in the CDR report identify positive angles as indicative of counter-clockwise rotation of the steering wheel (i.e. steering to the left). Thus, we can identify that, between t=-1.8 and -1.3 s, the driver turns the steering wheel sharply to the right, with the steering wheel's angle reaching a maximum negative value of -104 degrees at t=-1.3 s. This is immediately followed by the driver turning the steering wheel to the left. Note that, from t=-1.2 s, the steering angle becomes less negative (thus indicating left steering). At t=-0.8 s and beyond, the steering angles switch to positive values and increase over subsequent measurements indicating continued left steering.

Other pre-crash data retrieved from the EDR indicate an initial travel speed for the Dodge Journey of 72 km/h. The service brakes were applied at t=-1.6 s and the Panic Brake Assist system was activated at t=-0.5 s. Initially, between t=-1.6 and -0.4 s, the vehicle's speed dropped fairly uniformly as shown by the graph (green line) in Figure 8. The average deceleration calculated over this period was approximately 0.6 g. Subsequently, the reported speed increases at t=-0.3 s and then drops sharply. The average deceleration calculated over the last three readings was of the order of 2.8 g which is unreasonably high.



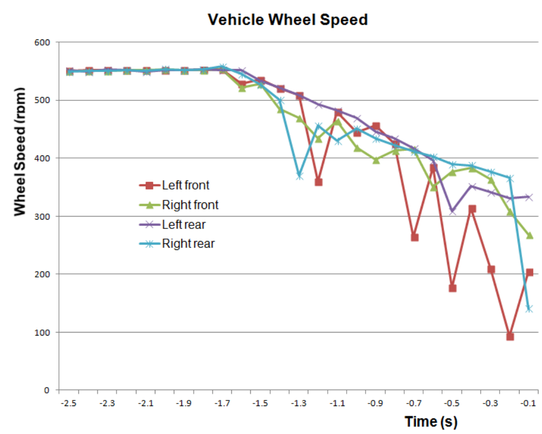


Figure 8 Pre-crash data **Figure 9 Vehicle wheel speed**

The reported vehicle speed is based on an average of the four wheel speeds. Speed values appear to become unreliable, especially over the last half second prior to impact, with individual wheel speeds varying considerably (Figure 9). Nevertheless, the driver's action in applying the brakes, and the activation of Panic Brake Assist, were responsible for reducing the impact speed and hence the crash severity.

The EDR reported a delta-V of 33 km/h with a crash pulse length of the order of 200 ms. This moderate severity collision resulted in activation of the seat-belt pretensioners and first-stage airbag deployments in both front seating positions. The 29-year-old male driver was fully restrained and sustained minor contusions to the chest. The 30-year-old, female, right-front passenger was also fully restrained and received no injuries.

Case Study No. 2 - Sudden Acceleration Complaint

A 2016 Audi A6 was stopped in traffic. The driver reported that he took his foot off the brake and the vehicle “bolted forward” such that the front of his vehicle struck the rear of the vehicle ahead. The pre-crash data captured by the Audi’s EDR included records of activation of both the brake and accelerator pedals every half second for five seconds prior to impact.

Pre-Crash Data -5 to 0 sec (Record 1, Most Recent)

Time (sec)	Speed, Vehicle Indicated (MPH [km/h])	Accelerator Pedal (%)	Service Brake Activation
-5.0	0 [0]	0	On
-4.5	0 [0]	0	On
-4.0	0 [0]	6	On
-3.5	0 [0]	0	On
-3.0	0 [0]	0	On
-2.5	0 [0]	0	On
-2.0	0 [0]	0	On
-1.5	0 [0]	52	Off
-1.0	5 [8]	73	Off
-0.5	14 [22]	99	Off
0.0	12 [20]	0	Off

Figure 10 Brake and accelerator pedal application for the 2016 Audi A6
(Brake pedal = Red; Accelerator pedal = Green)

The EDR data shown in Figure 10 clearly demonstrate that, after releasing the brake, the driver initially pressed down on the accelerator pedal. The accelerator was 99% engaged at t=-0.5 s and the vehicle’s speed had increased from 0 to 22 km/h. The data also show that pressure on the accelerator was completely removed (Accelerator Pedal = 0) at t=0.0 s.

The EDR also reported a delta-V for the frontal impact to the Audi of 11 km/h. This low severity crash did not result in the activation of the vehicle’s seat belt pretensioners nor its frontal airbags.

System Status at Event (Record 1, Most Recent)

Event Counter at Event (Counts)	2
Event Type	Frontal
Multi-Event, Number of Events	2. Event
Time from Initial Event to Current Event (msec)	815.5
Vehicle Clock, Date and Time at Event (YYYY-MM-DD, HH:MM:SS)	2016-10-09, 14:40:19
Vehicle Mileage (km)	27,140

Figure 11 Vehicle Clock and Mileage Record for the 2016 Audi A6

In similar non-deployment incidents that had been researched previously, investigators were sometimes unable to positively associate the EDR record with the subject collision. [7] However, the CDR report for the 2016 Audi A6 includes both the date and time on the system clock, and the total distance shown on the odometer at the time of the recorded incident (Figure 11). In the current case, the date and time on the CDR report were matched to the motor vehicle accident report completed by the investigating police service, and the recorded odometer reading was within 2 km of that determined when the case vehicle was physically inspected.

Case Study No. 3 - Rollover Dynamics

A 2013 Dodge RAM 1500 4x4 pickup truck was travelling westbound on a four-lane, median-divided, rural highway when the driver attempted to pass another vehicle. The road was partially snow-covered and the driver lost control during the passing manoeuvre causing the vehicle to enter the central median and roll over.

The EDR recorded a non-deployment event (NDE), followed 1.8 seconds later by a deployment event (DE). Each event included five seconds of pre-crash data. The pre-crash data for the NDE was complete, while a portion of the pre-crash data for the DE was incomplete, such that no pre-crash data was available following the beginning of the NDE.

The collision schematic (Figure 12) shows the vehicle dynamics which were determined through an analysis of the EDR data (Figure 13). Event timing shown in Figures 12 and 13 is relative to time zero for the NDE.

After steering into the left lane, the driver of the Dodge accelerated causing the vehicle's rear wheels to slip due to the low roadway friction. The EDR reported a difference in front and rear wheel speeds of up to 100 rpm. Subsequent to the wheel slip, the vehicle began a counter-clockwise yaw (Position I) at approximately 4 seconds prior to the NDE.

The vehicle's stability control activated at t=-3.5 s and remained engaged for most of the remaining pre-crash period. The driver responded to the counter-clockwise yaw with a clockwise steering input of up to 243 degrees which resulted in the truck entering a clockwise yaw (Position II).

As the vehicle began this clockwise yaw the driver reacted with a counter-clockwise steering input of up to 540 degrees during the last second prior to the crash. Due to the loss of traction the driver did not regain directional control and the vehicle remained in a clockwise yaw as it entered the central median. When the vehicle was rotated clockwise approximately 81 degrees, the left side of the vehicle struck a snowbank (Position III) resulting in the NDE being recorded. No further pre-crash data was available between the NDE and the DE.

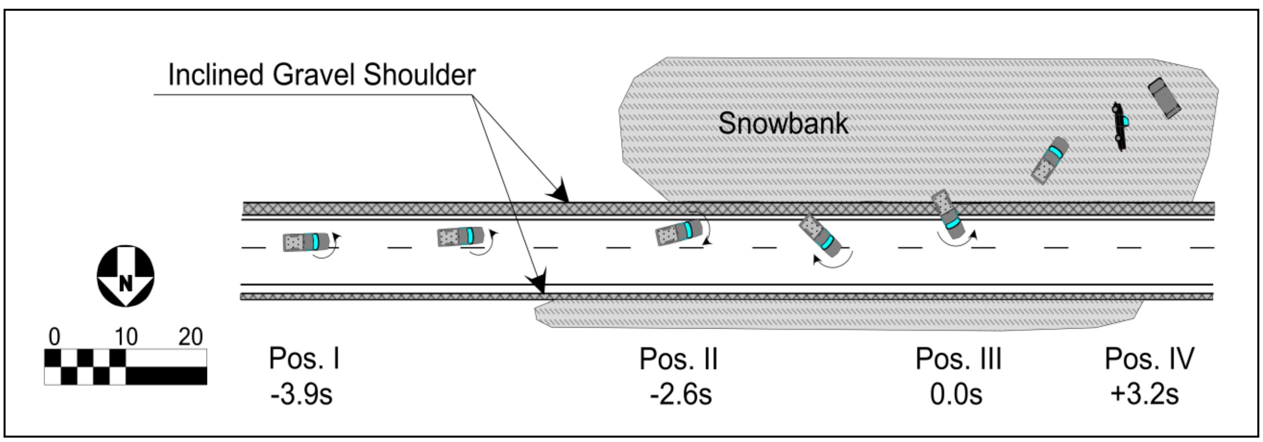


Figure 12 Collision Schematic

The DE documented the vehicle rollover and included approximately five seconds of angular roll-rate data about the vehicle's longitudinal axis. The roll angle was computed by integration of the roll-rate data (using the trapezoid rule, with zero initial roll angle). The DE and NDE data overlapped and the computed roll angle indicated negligible vehicle roll during the pre-crash period of the NDE. Following the non-deployment impact with the snowbank (t=0), the EDR data indicate that the vehicle rolled up to 31 degrees towards its left side. The vehicle then began a right-side leading rollover with a peak roll rate of 150 degrees/second, and a cumulative roll angle of 170 degrees at the point at which the vehicle came to rest on its roof (Position IV).

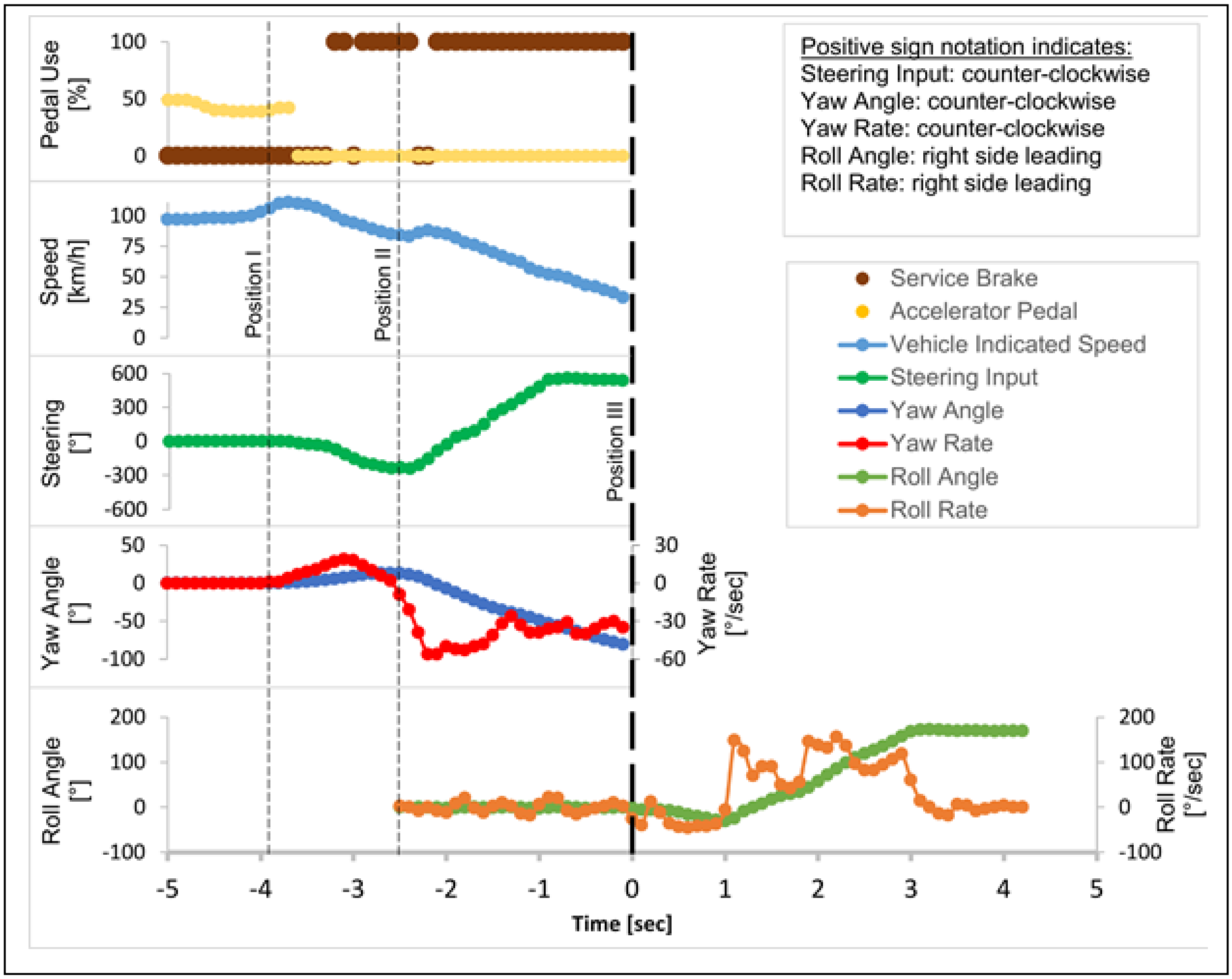


Figure 13 Pre-Crash and crash data for the 2013 Dodge RAM pickup truck

The Dodge RAM sustained 18 cm of downward crush on the left side of the roof. This is consistent with a right-side leading rollover as indicated by the EDR-reported data. Given the pre-crash data from the non-deployment event, and the rollover data, it is likely that the left side impact with the snow bank resulted in a counter-clockwise yaw of the vehicle following the NDE. The vehicle continued to so rotate until it tripped and initiated a right-side leading rollover approximately one second following the NDE.

The retractor pretensioners, side torso airbags and side curtain airbags were deployed for both front outboard seating positions. The restrained driver, and sole occupant of the vehicle, was not injured in the collision.

Case Study No. 4 - Side Airbag Non-Deployment

A 2012 Ford Fiesta hatchback was travelling southbound on a two-lane, undivided, rural arterial. The sole occupant was a fully-restrained, female driver. The Fiesta commenced a left turn across the path of an on-coming 2007 GMC Sierra pickup truck. The front of the pickup struck the right side of the Fiesta's occupant compartment. The Fiesta's left-side curtain was the only airbag that deployed during the crash. In particular, the side curtain airbag on the struck side did not deploy.

Figure 14 2012 Ford Fiesta hatchback

The Fiesta's EDR recorded maximum longitudinal and lateral delta-V's of 12.6 and 24.4 km/h respectively, and both the left-side and right-side airbag safing sensors were noted as being activated. The collision circumstances suggested, therefore, that deployment of the right-side curtain airbag was most likely warranted.

The manufacturer reviewed the case and determined that the software in the vehicle's restraint control module was programmed to disable activation of both the right-front passenger's side airbag and the right-side curtain if the occupant classification system determined that nobody was occupying the right-front seat.

However, it was recognized that this scenario would not account for an unoccupied right-front seat when there was an occupant in right-rear seating position. In such a case, the right-rear passenger would not have the benefit of the deployment of the curtain airbag. The manufacturer issued a Notice of Defect, and effected an associated vehicle recall, to correct this error in programming logic. [8]

Case Study No. 5 - Ignition Switch Defect

A 2007 Chevrolet Cobalt was rounding a large-radius curve to the left when the driver failed to maintain directional control. The vehicle crossed the centerline and ran into the ditch on the far side of the roadway where it struck a rock and several trees. The driver was the only occupant in the vehicle and was unrestrained. His airbag did not deploy and he sustained fatal injuries.

The vehicle's EDR contained a record for a non-deployment event. The maximum longitudinal delta-V for the crash was reported as 37.7 km/h which would normally have resulted in airbag deployment. However, it was observed that the Vehicle Power Mode Status was recorded as Accessory (Figure 16). This suggested that the ignition switch was in the "Accessory" position at the time of the collision, a condition that would result in no power being supplied to the airbag inflator such that no deployment could occur.

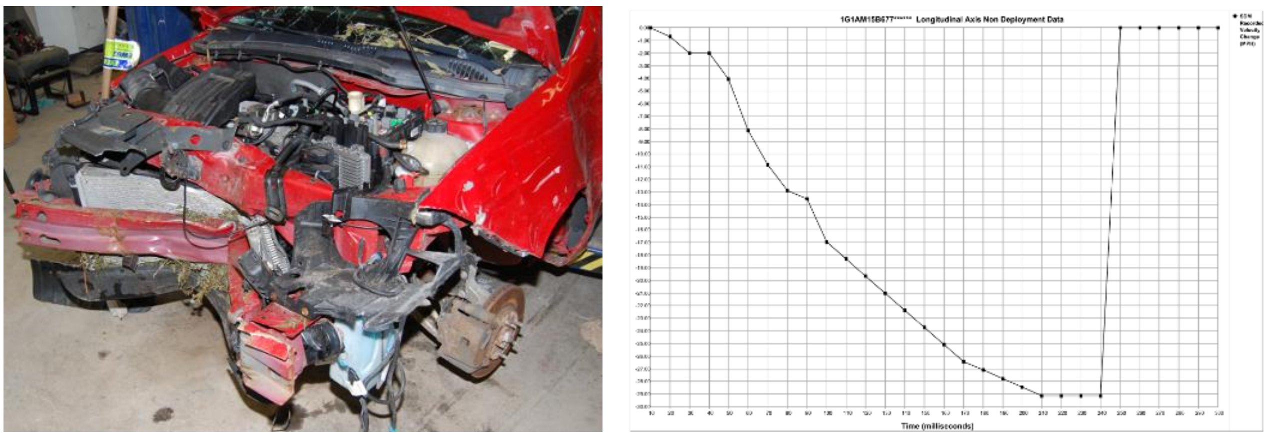


Figure 15 Frontal damage to 2007 Chevrolet Cobalt and longitudinal delta-V

System Status At AE

Vehicle Identification Number	**1AM15B*7***
Low Tire Pressure Warning Lamp (If Equipped)	C
Vehicle Power Mode Status	Access
Remote Start Status (If Equipped)	Inac
Run/Crank Ignition Switch Logic Level	Ac
Brake System Warning Lamp (If Equipped)	C

Figure 16 System status at algorithm enable

Subsequently, the manufacturer issued a Notice Of Defect for the ignition switch in this model of vehicle. [9] The rotational torque for the switch was determined to be below the manufacturer's design specifications. As a result, the switch could rotate from the "Run" position to the "Accessory" or "Off" position should the vehicle experience some form of jarring event.

Case Study No. 6 - Full-Scale Collision Reconstruction

A 2011 Toyota RAV4 utility vehicle was travelling eastbound on a two-lane, undivided, rural highway. The driver allowed his vehicle to drift across the centerline where it came into a head-on collision with a westbound 2011 GMC Sierra pickup truck.

Two-front seat occupants in the RAV4 were fully-restrained and had front airbags deploy. The 54-year-old male driver sustained major injuries, while his 55-year-old male right-front passenger received moderate-level injuries. A fully-restrained, 58-year-old, female, left-rear passenger sustained fatal head and chest injuries. A fully-restrained, 50-year-old female in the right-rear seat received fatal chest injuries.

The EDR for the RAV4 in the case collision indicated both the pre-crash travel speed and the longitudinal delta-V as 74 km/h. Similarly, an EDR in the Sierra showed a travel speed of 62 km/h, and a longitudinal delta-V of 60 km/h. This collision was the subject of a full-scale reconstruction through a crash test using two similar vehicles, and dummies as surrogates for the human occupants of the RAV4.

Figure 17 Staged Collision between a 2011 Toyota RAV4 utility vehicle and a 2011 GMC Sierra pickup truck

In order to reduce the risk of damage to the advanced THOR crash test dummies, and to the data acquisition systems installed in the RAV4, the vehicle speeds used in the crash test were reduced from those observed in the real-world collision.

For this purpose, and to adjust for the differing masses of the test vehicles, calculations were performed to ensure that the ratio of kinetic energies for the two vehicles, and total energy of the collision, were taken into consideration. Figure 18 compares the masses, pre-impact speeds, and the corresponding kinetic energies. The test speeds selected represent a 15% reduction in energy compared to the actual collision, while still respecting a ratio of 1.02 between the two vehicles.

	CASE VEHICLES			TEST VEHICLES		
	Mass (kg)	Velocity (km/h)	Energy (J)	Mass (kg)	Velocity (km/h)	Energy (J)
TOYOTA RAV4	1833	74 (EDR)	387250	2014	65	328285
GMC SIERRA	2558	62 (EDR)	379358	2659	56	321706
RATIO			1.0208			1.0205

Figure 18 Selection of crash test speeds

Although the crash test used somewhat lower impact speeds than those observed in the real-world incident, it reproduced the actual crash reasonably well in terms of both the delta-V's experienced by the involved vehicles and the resulting damage patterns. In addition, there was good agreement between the impact speeds and delta-V's recorded by the EDR's in both test vehicles and the associated laboratory instrumentation (Figure 19).

MVTC TEST DATA (actual)	2011 TOYOTA RAV4	2011 GMC SIERRA
IMPACT VELOCITY (km/h)	65.2	56.4
DELTA-V (km/h)	74.6	56.5
SEPARATION VELOCITY (km/h)*	-9.4	-0.1
TEST MASS (kg)	2014	2659
ENERGY (J)	330308	326318
RATIO	1.0122	
RESTITUTION VALUE	0.078	

*Negative separation velocities indicates the vehicles were redirected backwards from their initial travel direction

	2011 TOYOTA RAV4		PERCENT DIFFERENCE (%)
	EDR	TEST	
IMPACT VELOCITY (km/h)	62	65.2	5.2
DELTA-V (km/h)	70.3	74.6	6.1

	2011 GMC SIERRA		PERCENT DIFFERENCE (%)
	EDR	TEST	
IMPACT VELOCITY (km/h)	55	56.4	2.5
DELTA-V (km/h)	55	56.5	2.7

Figure 19 Crash data from the EDR's in the test vehicles and the associated laboratory instrumentation

DISCUSSION AND CONCLUSIONS

The case studies presented in this paper have shown some of the capabilities and features of modern EDR's. In particular, they have demonstrated the utility of the information provided by these systems for in-depth collision investigation and reconstruction, and for the identification of defects in motor vehicle components and control systems.

The data can also be seen to be a valuable resource to safety researchers on a wide variety of issues, such as the determination of specific driver actions, the performance of vehicle-based collision avoidance systems, and for the evaluation of the effectiveness of occupant protection systems in real-world crashes.

One of the limitations for the use of such data continues to be a lack of standardization on the data elements captured by different EDR modules, the means to interrogate the devices, and the widely differing report formats produced.

A specific concern is a general lack of timing information related to records captured by EDR's. While, data from an on-board clock was available in one of our case studies, this is currently by far the exception to the general rule. Many recent EDR's have the capability to record multiple collision events; however, the frequent lack of associated timing information, makes the interpretation of the event data overly complex and requires careful integration of material garnered from detailed collision investigation.

A further issue is that no batch processing system is available by which data can readily be extracted from multiple CDR files. In general, specific data elements must be extracted manually due to the widely varying report formats. This is currently a serious limitation for researchers wishing to work with a large volume of crashes in which EDR information is available.

Users of these data must also use caution in their interpretation. In the present series of case studies, we saw one example where deceleration calculations can produce unreasonably high values. This issue is similar to a number of instances where stored data was found not to correspond to the actual situation in the vehicle and/or the collision circumstances. [10] It is necessary, therefore, to conduct thorough collision investigations, to carefully analyse all of the relevant data, and to completely understand both the functions and the limitations of any electronic data systems.

Nevertheless, the range and level of detail of information captured and stored by EDR's has increased dramatically in recent years which affords new safety research opportunities. For example, recently published work has used information from event data recorders to look at driver actions prior to lane departure events [11], and evasive manoeuvres by drivers prior to intersection crashes [12], with the goal of refining in-vehicle collision avoidance systems. It is clear that event data recorders will continue to provide an extremely valuable tool for future motor vehicle safety research.

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The opinions expressed in this paper are solely those of the authors and do not necessarily represent the views and policies of their respective organizations.

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