The Use of Event Data Recorders in the Analysis of Real-World Crashes

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Abstract

Event data recorders are installed on many late-model cars and light trucks as an adjunct to air bag sensing and control systems. These devices offer tremendous potential to traffic safety researchers, affording access to a wealth of new data, enabling better understanding of on-road traffic safety issues, and providing opportunities for the development of new and effective countermeasures.

The authors report on a series of test programmes and pilot studies of collisions involving vehicles equipped with event data recorders. These include instrumented crash tests which can be used to validate the quantitative results obtained from on-board recorders, and in-depth investigations of real-world collisions where results obtained using standard reconstruction techniques can be compared to the electronic data relating to crash severity. Our current studies also include an evaluation of pre-crash factors involved in real-world situations, based on in-depth investigation techniques, detailed occupant interviews, and analysis of a variety of pre-crash data elements obtained from event data recorders in collision-involved vehicles.

A lack of standardization as to the nature of the data which is recorded, the formats in which it is currently stored, the proprietary means by which data can be retrieved, and concerns relating to individual privacy, may provide substantial roadblocks to wide data accessibility. It is imperative; therefore, that the traffic safety community considers the utility of these data systems at an early stage, and actively champions their further development and use if they are seen to be beneficial to the cause of furthering safe transportation.

Résumé

Des enregistreurs de données d'événements sont installés dans plusieurs récents modèles de voitures de tourisme et de camionnettes comme supplément aux systèmes de détection et de contrôle sur les sacs gonflables. Ces dispositifs offrent un immense potentiel aux chercheurs en sécurité routière, leur donnant accès à une grande quantité de nouvelles données, leur permettant de mieux comprendre les questions de sécurité liées à la circulation routière et leur fournissant des occasions d'élaborer des contre-mesures nouvelles et efficaces.

Les auteurs font rapport sur une série de programmes d'essai et d'études pilotes sur des collisions impliquant des véhicules munis d'enregistreurs de données d'événements. Ceci inclut des essais de collision avec instruments qui peuvent servir à valider les résultats quantitatifs obtenus des enregistreurs à bord des véhicules, et des enquêtes approfondies sur des collisions réels où les résultats obtenus à l'aide des techniques courantes de reconstruction peuvent être comparés aux données électroniques concernant la gravité de la collision. Nos études en cours comprennent aussi une évaluation des facteurs avant la collision et en cause dans des situations réelles, fondée sur des techniques d'évaluation approfondies, des entrevues détaillées avec les occupants et une analyse d'une variété d'éléments de données avant la collision obtenus à partir d'enregistreurs de données

d'événements installés dans les véhicules impliqués dans la collision.

Un manque d'uniformisation quant à la nature des données qui sont enregistrées, des formats dans lesquels elle sont actuellement gardées, et du moyen par lequel les données peuvent être extraites, ainsi que les préoccupations liées à la protection personnelle peuvent occasionner des difficultés importantes dans l'accessibilité répandue des données. Il est par conséquent impératif que le milieu de la sécurité routière prenne en considération l'utilité de ces systèmes de données au stade initial, et se fasse le champion de leur développement et usage ultérieurs, s'ils sont perçus comme étant bénéfiques à la cause de la promotion d'un transport en sécurité.

Introduction

The use of on-board crash recorders in the aviation industry is well known. In the event of a crash, the recovery of in-flight recording systems is a priority of collision investigators, and the data obtained becomes an integral part of the crash reconstruction process. A little-appreciated fact is that similar technologies are utilized in the marine and rail transportation environments. Perhaps even less well known is that event data recorders (EDR) are present on many late-model cars and light trucks, and some heavy trucks and buses. It is these systems which are of interest to the present discussion since they have direct application to many issues in the field of road and motor vehicle safety.

On-board event data recorders are not a new concept; such systems have been developed over a number of years, both in North America [1,2] and in Europe [3]. Some prior Canadian research has been aimed at developing in-vehicle recorders to capture either the crash pulse [4], or a wider range of collision-related variables [5]. In recent years, there has been a proliferation of such technology in the vehicle fleet, primarily due to the introduction of supplementary air bags and, in particular, because of the need to monitor and control the deployment of these systems.

Many modern air bag control systems have adopted electronic sensing systems where a vehicle-mounted accelerometer is used to monitor the crash pulse. A microprocessor analyzes the vehicle's acceleration-time history and, based on pre-programmed decision logic, determines when air bag systems should be deployed. Using some of the computer memory present in such systems, manufacturers have been able to store certain data relating to collision events. Analysis of these data has provided a means to refine the algorithms used for deployment logic.

Many other systems on the vehicle utilize electronic technology. For example, engine management and emission control systems often use microprocessors, as do anti-lock braking and traction-control systems. As a result, manufacturers are moving to the use of computer-bus systems to facilitate the flow of required information around the vehicle. The ready availability of such signals provides for the capture of pre-collision data elements such as vehicle speed, engine rpm, throttle position, brake-switch status, and seat belt use.

Such objective collision-related data are invaluable to safety researchers wishing to identify specific factors which precipitate collisions, or to determine the nature and severity of crashes. Of course, the data will also be of interest to other parties including law enforcement personnel, members of the legal community, and insurance companies. These groups will no doubt wish to use recorded collision data to assign fault and support legal action, and so questions as to the ownership, accessibility, and use of such data in individual cases will come into question.

Thus, there are potentially several conflicting issues related to the availability and use of data from on-board crash recorders. The object of the present paper is to illustrate, primarily from a research perspective, some of the safety benefits which might well ensue from the widespread adoption of the technology.

Crash Data Retrieval Systems

While many new vehicles are already equipped with event data recorders, there is currently no standardization as to the nature of the data which is recorded, the format in which it is stored, and the means by which it can be retrieved. In fact, the data format and data retrieval tools are generally proprietary to any given motor vehicle manufacturer.

A notable exception to the latter is the approach taken by General Motors Corporation in developing a system which can be used to interrogate the sensing and diagnostic modules (SDM) installed on their late-model cars and light trucks [2]. The Crash Data Retrieval System (CDR) is available commercially from Vetronix Corporation [6]. As part of a cooperative research programme with General Motors of Canada, the CDR is one of the tools which has been used by the authors to obtain data from collision-involved vehicles.

While it is understood that the Ford Motor Company is in the process of developing a similar CDR system, currently, a proprietary tool is required to interface with their restraint control modules (RCM). The use of this tool is limited to certain vehicle models which are equipped with advanced air bag systems. These systems include such features as seat belt pretensioners, occupant proximity sensing, and air bags with dual-threshold deployment and dual-stage inflators [7]. The sophisticated nature of these systems, particularly the higher deployment threshold for belted occupants, and low output level in the first-stage inflator, offers the potential for significantly enhanced protection for belted occupants. Such developments are quite consistent with the findings of Canadian research into first-generation air bag systems [8]. Transport Canada and Ford Motor Company of Canada are, therefore, conducting a joint research project to help evaluate the real-world performance of these advanced restraint systems and, as part of this study, data from the on-board recorders are being obtained.

To date, information has been obtained from crash recorders installed in vehicles which have been subjected to staged collisions as part of Transport Canada's on-going research and regulatory development programmes, and from real-world crashes. Some of the initial results from this process are presented in this paper.

Staged Collisions

To provide some measure of the reliability of the crash data which can be obtained from production vehicles, data was obtained from a number of EDRs in vehicles which had been part of Transport Canada's crash testing programmes.

48km/h Rigid Barrier: Each of the results shown below is for a vehicle, travelling at a measured test speed (nominally 48 km/h), prior to undergoing a direct frontal collision with a rigid and immovable concrete barrier. The vehicle's change in velocity (ΔV) in the crash is that obtained from the EDR.

Rigid Barrier		
Test Number	**Impact Speed (km/h)**	**ΔV from EDR (km/h)**
1999 Chevrolet Cavalier		
99-236	46.8	51.5
99-238	47.1	50.5
1998 Chevrolet Malibu		
98-010	48.0	48.7 (power loss)
2000 Ford Taurus		
00-111	47.8	53.6

Figure 1. 48km/h Rigid Barrier Tests

In general, it can be seen that the ΔV obtained from the EDR is slightly higher than the vehicle's impact speed. This is normally a result of restitution. After attaining maximum dynamic deformation, the vehicle's structural elements relax, and the vehicle rebounds away from the face of the barrier. The rebound velocity is included in the recorded ΔV, and thus the latter value is greater than the impact speed alone. The rebound velocity is not routinely recorded as part of the test protocol, and so cannot actually be quantified here.

It should also be noted that, despite power being lost in Test No. 98-010, the ΔV versus time curve indicated that the total change in velocity had been captured. In the case of the Ford Taurus (Test No. 00-111), the maximum recorded ΔV corresponded to a spike in the acceleration-time curve. It is believed that this may be an artifact of structural deformation in the region where the EDR is mounted, and is therefore not truly representative of the vehicle’s total velocity change.

40 km/h, 40% Offset Deformable Barrier: The following test series forms part of a research programme designed to enhance the level of crash protection afforded by seat belts and supplementary air bag systems for occupants of short stature [9]. The test is conducted at a nominal speed of 40 km/h with the vehicle undergoing a 40% offset frontal crash into a deformable aluminum honeycomb barrier face.

Offset Deformable Barrier		
Test Number	**Impact Speed (km/h)**	**ΔV from EDR (km/h)**
1998 Chevrolet Cavalier		
98-212	40.1	46.6
98-213	40.2	43.4
98-214	40.3	42.4
1999 Chevrolet Malibu		
99-219	39.6	40.6
2000 Oldsmobile Alero		
00-216	40.2	38.6 (pre-impact speed)
2000 Ford Taurus		
00-204	39.9	21.6 (at 78 ms)

Figure 2. 40 km/h, 40% Offset Deformable Barrier Tests

The recorded ΔV is, once again, somewhat greater than the impact speed. In this configuration, some energy is absorbed by the honeycomb barrier structure. In addition, the struck portion of the vehicle's front end undergoes considerable deformation due to the asymmetrical load path. Thus, the test produces a relatively long and soft pulse. Test No. 00-216 involved a 2000 Oldsmobile Alero and resulted in no airbag deployment. In consequence no deployment file was created in the EDR. A near-deployment file was produced which recorded the vehicle's pre-impact speed for the test. It should also be noted that the duration of the pulse overran the limits of the data storage available in a 2000 Ford Taurus (Test No. 00-204), and so this system was unable to capture the complete ΔV (the dotted line in the following figure).

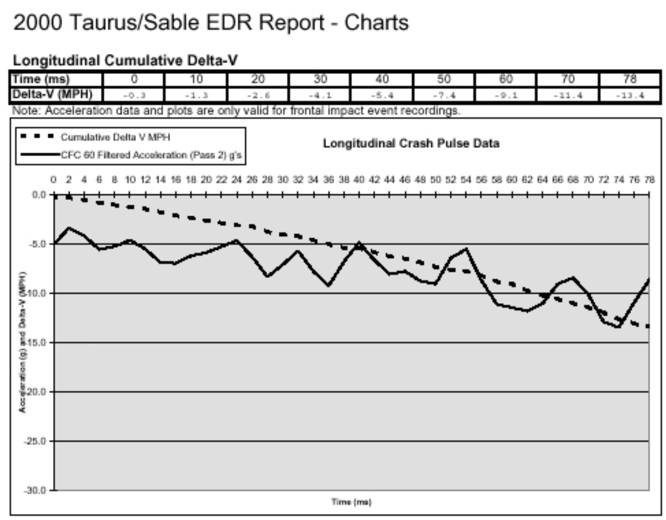


Figure 3. 2000 Ford Taurus Longitudinal ΔV

Rear Underride Guard Tests**:** The final series of tests reported here involves passenger cars impacting prototype rear underride guards designed for use on semi-trailers [10]. The configuration of the crash was such that the test vehicle's electrical system was frequently compromised and a loss of power was noted in the EDR recording.

In the first two tests of this series, the recorded ΔVs were close to the impact speeds of the test vehicles (although it should be noted that a power loss occurred during Test No. 98-501). These results seem reasonable since the nature of the underride events was such that little restitution occurred. The final test (Test No. 98-506) was conducted at a higher impact speed. This resulted in extensive engagement with the guard structure, and power seems to have been lost to the vehicle's EDR well before the maximum ΔV had occurred.

Rear Underride Guard		
Test Number	**Impact Speed (km/h)**	**ΔV from EDR (km/h)**
1998 Chevrolet Cavalier		
98-501	48.9	50.5 (power loss)
98-502	48.9	49.4
98-506	64.8	56.8 (power loss)

Figure 4. Rear Underride Guard Tests

Field Investigations: General Motors' Vehicles

General Motors have adopted a sensing strategy whereby triggering of data capture is initiated when a vehicle deceleration in the order of 2g is identified in the SDM. At this point the air bag deployment algorithm is activated and the system monitors the vehicle acceleration, acquiring data on which a firing decision is ultimately based. This point in time is referred to as algorithm enable (AE).

There is no real-time clock integrated into the electronic data systems of current General Motors' vehicles. Consequently, there is no means of determining when algorithm enable occurs in real time. In addition, individual systems providing data inputs (e.g. vehicle speed, brake switch status, etc.) function in an asynchronous manner. As we will see in the following case studies, the lack of real-time information and data synchronization requires some interpretation of the stored data.

ACR5-1606: The driver of a northbound 2000 Pontiac Sunfire failed to stop for a red traffic light. The driver braked, but the front of the Pontiac struck the left side of a 1999 Buick Century which was travelling westbound through the intersection. The maximum crush to the front of the Pontiac was 29 cm (01FDEW2), while that to the side of the Buick was 34 cm (10LYEW3). Damage analysis produced a total ΔV of 27 km/h, a longitudinal component of 25 km/h, and a closing speed of 55 km/h for the Pontiac. The EDR in the Pontiac recorded a maximum adjusted longitudinal ΔV of 22 km/h, 110 ms after AE. This ΔV was in good agreement with the value of 25 km/h calculated from damage analysis.

Figure 5. 2000 Pontiac Sunfire

Pre-crash data were also obtained from the EDR and indicate that the speed of the Pontiac dropped from 63 km/h at 2 s before AE to 53 km/h at 1 s before AE, which is consistent with moderate braking (0.28g average deceleration).

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	61	1344	12	OFF
-4	63	1408	12	OFF
-3	63	1344	12	OFF
-2	63	1344	12	OFF
-1	53	1216	0	ON

Figure 6. 2000 Pontiac Sunfire Pre-Crash Data

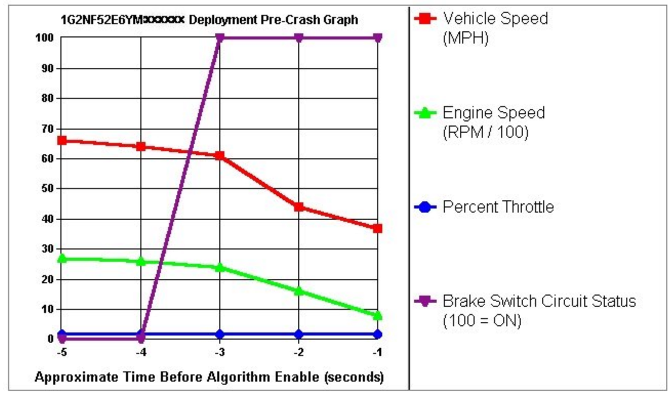
As previously noted, the exact time of impact within the 1 s to 0 s window before AE is not available. However, the impact likely occurred close to 1 s before AE since one would have expected a less severe impact had the vehicle continued to decelerate from 53 km/h for a full second. This is supported by the fact that the closing speed of 55 km/h obtained from damage analysis is consistent with an impact speed of 53 km/h. Also, the extent of crush to the Buick was in the range of values typically documented in 50 km/h car-to-car side impact tests.

Figure 7. 1999 Buick Century

<u>ASF3-9622:</u> A 2000 Pontiac Grand Am was southbound when it failed to stop at a railroad crossing and was struck by an eastbound train. The train was equipped with a data recorder which indicated a pre-crash travel speed of 77 km/h. The maximum crush to the right side of the Pontiac was 88 cm (03RDAW5).

Figure 8. 2000 Pontiac Grand Am

The flashing lights and swing-arm barriers at the crossing were functional. Witnesses to the crash indicated that the driver appeared alert. The vehicle was equipped with an anti-lock braking system (ABS) and no skid marks were observed.



Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	106	2688	2	OFF
-4	103	2560	2	OFF
-3	98	2432	2	ON
-2	71	1600	2	ON
-1	60	832	2	ON

Figure 9. 2000 Pontiac Grand Am Pre-Crash Data

The pre-crash data indicate that the speed of the Pontiac dropped from 98 km/h at 3 s before AE to 71 km/h at 2 s before AE (0.77g average deceleration). The vehicle's speed then dropped to 60 km/h at 1 s before AE (0.31g average deceleration). Had the vehicle continued to decelerate at a rate of 0.31g from 60 km/h, its speed at time zero would have been 49 km/h. Since the exact time of impact prior to AE cannot be determined, the impact speed of the Pontiac can only be estimated as being in the range 49-60 km/h.

The EDR data confirmed that the driver was alert and taking evasive action prior to the collision. Based on the vehicle's speeds at the one second intervals in the pre-crash data, the driver would have been approximately 70-85 m from the point of impact when he applied the brakes and activated the brake light switch. Had the driver maintained a 0.77g deceleration from the time he initiated braking, he would have brought the vehicle to a stop in 54 m and avoided the collision with the train.

CHI2-9609: The driver of a westbound 1993 Ford Tempo slowed to make a left turn into a commercial establishment. The vehicle travelled into the path of a 2000 GMC Sierra 1500 pickup. The front of the GMC struck the right side of the Ford with its hood centered on the A-pillar. The maximum crush to the front of the GMC was 36 cm (12FDEW2). The maximum crush to the right side of the Tempo was 45 cm (03RYAW3).

A longitudinal ΔV of 26 km/h was calculated for the GMC using damage analysis. The closing speed was computed as 75 km/h. Pre-crash data were obtained from the EDR in the GMC and are presented below:

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	116	1920	30	OFF
-4	116	1920	30	OFF
-3	116	1920	0	OFF
-2	97	1728	0	ON
-1	76	1280	0	ON

Figure 10. 2000 GMC Sierra Pre-Crash Data

The EDR indicated that the speed of the GMC dropped from 116 km/h at 3 s before AE to 97 km/h at 2 s before AE (0.54g average deceleration). The GMC's speed then dropped to 76 km/h at 1 s before AE (0.59g average deceleration). Had the vehicle continued decelerating at 0.59g, its speed at time zero would have been 55 km/h. Since the exact time of impact prior to AE is not available, the pre-impact speed of the GMC is estimated to be 55-76 km/h. The closing speed of 75 km obtained by damage analysis is in good agreement with the upper end of this range.

The posted speed limit for the road was 90 km/h. The EDR data indicated that the driver of the GMC was travelling at 116 km/h several seconds prior to the collision. The GMC was equipped with ABS and did not leave any skid marks at the scene; however, the EDR data confirmed that the driver was braking in an attempt to avoid the collision.

ASF2-9610: A 1996 Thomas school bus was westbound on a downhill grade travelling through an intersection. A northbound 1999 GMC Sierra pickup failed to stop at the intersection and struck the front-left side of the bus. The bus rotated clockwise, travelled down an embankment, and rolled into a field (00TDDO2). The maximum crush to the front of the GMC was 62 cm (02FDEW3).

The maximum longitudinal ΔV recorded in the GMC's EDR was 66 km/h at 210 ms after AE. The ΔV decreased slightly from that point until it dropped to zero at 240 ms after AE.

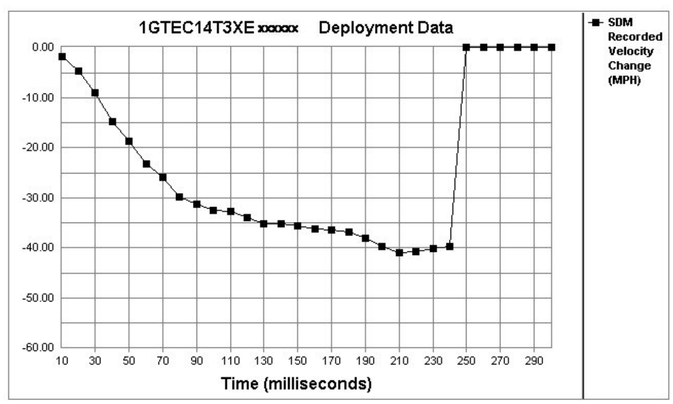


Figure 11. 1999 GMC Sierra Crash Data

The EDR also indicated that the "Ignition Cycles At Deployment" and "Time From Near Deployment To Deployment" values were 0. These are default values and are indicative that a loss in electrical power in the vehicle had occurred during the collision event.

The EDR indicated that the driver's seat belt was unbuckled, and inspection of the belt confirmed that the driver was unrestrained. Data from the EDR indicated that the right-front passenger's air bag was not suppressed. Investigators noted that the passenger's manual cut-off switch was in the air-bag-on position, and that the air bag did deploy as expected.

ASF2-1819: A 1998 Chevrolet Silverado pickup, travelling southbound, came into a head-on collision with a northbound 1991 Honda Civic. The maximum crush to the front of the Chevrolet was 94 cm (11FDEW4), and that to the front of the Honda was 160 cm (01FDAW7).

Crash-pulse data obtained from the EDR in the Chevrolet are shown in the following graph. A longitudinal ΔV of 49 km/h was recorded at 140 ms after AE. The ΔV remained approximately constant from that point until it abruptly dropped to zero at 210 ms after AE.

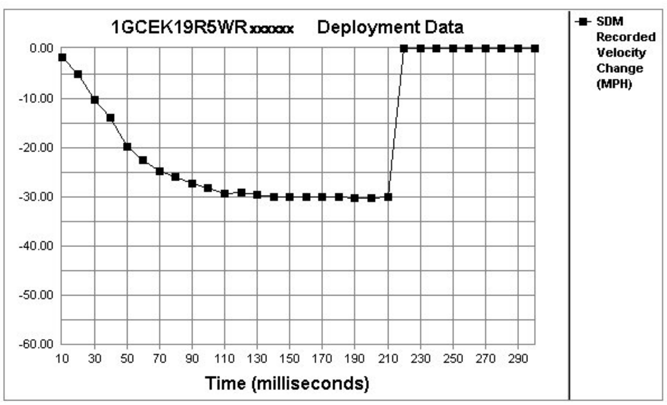


Figure 12. 1998 Chevrolet Silverado Crash Data

The sudden drop was attributed to a loss in electrical power to the EDR. The EDR also indicated that the "Ignition Cycles At Deployment" and the "Time From Near Deployment To Deployment" values were 0. As noted in the previous case, these are default values, and indicate a loss of power during the event.

The EDR indicated that the driver's seat belt was unbuckled. Physical inspection of the seat belt confirmed that it was not in use. The EDR also indicated that the right-front passenger's air bag was not suppressed. However, in contrast to the previous case, investigators noted here that the manual cut-off switch for the front passenger's air bag was in the air-bag-off position, and the air bag had not deployed.

This apparent discrepancy is explained by the fact that the data stream will be interrupted when electrical power is lost, in which case some data elements may remain at their default values. In particular, data related to the status of the driver's seat belt buckle, and that of suppression of the right-front passenger's air bag, are not written to the output file until after the ΔV data are recorded. Thus, in the current case, since power was lost during the period when the ΔV data were being written, the seat belt and air bag status codes remained at their default values, and are not necessarily reflective of the actual situation. This indicates that, when power is known to have been lost in a specific crash, some caution must be used in interpreting the stored data. In fact, the electronic data should always be reviewed in the context of other physical evidence of the collision.

ASF3-1811: A 1999 Chevrolet Cavalier was travelling northbound behind a 1997 Chevrolet Silverado pickup truck. The Silverado stopped and the front of the Cavalier struck the rear bumper of the pickup. The maximum crush to the Cavalier was 10 cm (12FDEW1). There was no residual crush to the Silverado (06BDLW1).

Figure 13. 1999 Chevrolet Cavalier

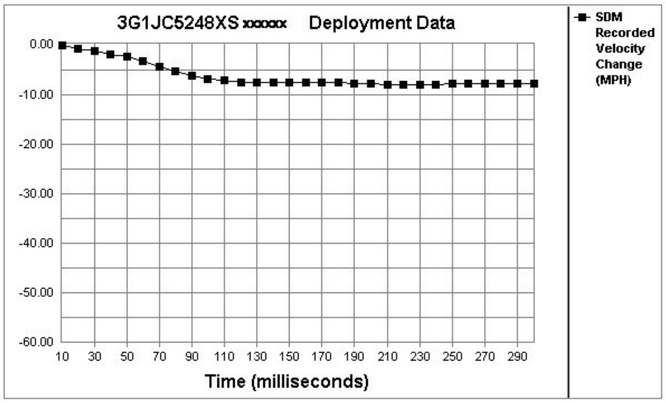


Figure 14. 1999 Chevrolet Cavalier Crash Data

Damage analysis produced a longitudinal ΔV of 22 km/h for the Cavalier. The crash data shown above indicate a low ΔV, long duration crash pulse, with a maximum longitudinal ΔV of 13 km/h at 210 ms after AE.

The damage pattern to the Cavalier was consistent with the vehicle underriding the back bumper of the Silverado. The crush at the Cavalier's bumper was less than the crush at the hood edge. The damage measurement convention generally adopted by collision investigators states that if, at any given measurement station, the crush above the bumper exceeds the crush at the bumper by 13 cm, then the two crush values should be averaged. [11]

Such an averaging process was used in the damage analysis and produced a ΔV of 22 km/h, almost twice that recorded in the vehicle's EDR. The measurement convention is empirical in nature, and this case indicates that, in certain situations, individual results should be treated with a degree of caution.

<u>ACR5-1206:</u> The driver of an eastbound 2000 Buick Century was attempting to negotiate a right-hand curve when he suffered a massive apoplectic stroke. The Buick ran off the roadway, travelled down an embankment into brush and tall grass, then crossed a level section of lawn and a gravel driveway before colliding with two large rocks. The Buick came to rest approximately 140 m east of the point where it had first left the roadway. The front undercarriage was damaged from the impact with the rocks, the lower radiator support being displaced rearwards by 17 cm (12FDLW3).

The fully-restrained, 83-year-old, male driver was lethargic at the scene. He was admitted to hospital but failed to respond to treatment. An autopsy did not identify any external injuries; however, in the brain, there was an extensive subarachnoid haemorrhage possibly associated with a ruptured berry aneurysm.

Figure 15. 2000 Buick Century

Pre-crash data obtained from the EDR indicates that the driver was neither operating the throttle nor the brakes for at least 5 seconds prior to impact with the rocks. These data are supportive of the Coroner's findings that the driver was incapacitated prior to the crash.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	66	1088	0	OFF
-4	71	1024	0	OFF
-3	53	704	0	OFF
-2	48	704	0	OFF
-1	48	512	0	OFF

Figure 16. 2000 Buick Century Pre-Crash Data

LOG-T110: A 1996 Pontiac Sunfire was travelling at 80 km/h on a straight and level highway when the right-front passenger's air bag deployed. The driver was taken unaware by the deployment but retained complete control of the vehicle. Following the incident, there was no evidence of any impact to the vehicle and the driver did not recall travelling over any bumps in the road.

Data obtained from the vehicle's EDR showed an AE to deployment command time of 5 ms. The time from AE to arming sensor closure was 319 ms. The maximum recorded ΔV was 2.5 km/h.

As a result of this and similar incidents, General Motors recalled the 1996-97 Chevrolet Cavalier and Pontiac Sunfire (Campaign No. 98026) for reprogramming of the SDM since certain calibrations resulted in an increased risk of air bag deployment in a low speed crash, or when an object strikes the floorpan.

Field Investigations: Ford Vehicles

In current Ford vehicles, the full crash pulse for certain collisions may not be captured. In particular, the pulse may be clipped at 78 ms where the data record ends. This may result in a recorded speed change which is somewhat less than the maximum value for the crash as a whole.

The features of the advanced restraint system in the 2000 Taurus include dual-threshold, dual-stage, air bags. The precise nature of air bag deployment is partly a function of the status of the switch which indicates seat belt use, and of the collision severity. A particular feature of the system is that it also monitors the position of the driver's seat and limits the air bag output to a first-stage deployment if the seat is forward of the middle position. Furthermore, the deployment threshold for the driver's air bag is set to that for an unbelted occupant if the driver's seat is forward of middle, irrespective of the driver's actual belt usage.

This latter scenario was observed in one of the crash tests (Test No. 00-204) reported earlier. In the 40 km/h offset frontal crash with a deformable barrier, two fully-restrained 5th percentile dummies occupied the front seats of a 2000 Ford Taurus. Both front seats were in the fully forward position. The sensing system called for a first stage air bag for an unbelted occupant, and no air bag for a belted occupant. In the crash, the first stage of the driver's air bag was deployed (belted driver, but driver's seat fully-forward), while the passenger's air bag was not.

ACR5-1608: A 2000 Ford Taurus struck the rear bumper of a stationary 1996 Ford Crown Victoria. Both front air bags in the Taurus deployed. The maximum crush to the front of the Taurus was 10 cm (12FDEW1), while that to the rear of the Crown Victoria was 15 cm (06BDEW1). The 66-year-old female driver was the only occupant of the Taurus. She was not using the available seat belt, and her seat was in the rearward of middle position.

The EDR in the Taurus indicated a longitudinal ΔV of 23 km/h (and a lateral ΔV of 1.5 km/h) at 78 ms after AE. The ΔV calculated from damage analysis was also 23 km/h suggesting that, in this instance, most of the crash pulse was captured within the available recording window.

Figure 17. 2000 Ford Taurus

Figure 18. 1996 Ford Crown Victoria

Time (ms)	0	10	20	30	40	50	60	70	78
ΔV (km/h)	1	3	7	11	13	16	19	21	23

Figure 19. 2000 Ford Taurus Longitudinal ΔV

At 20 ms after AE, the sensing system recognized a need to fire the seat belt pre-tensioner for a belted occupant, and for a first-stage air bag deployment in the case of an unrestrained occupant. Sensor inputs from the restraint system indicated that both the driver and passenger seat belt buckles were not engaged, and that the driver's seat was not forward of the middle position. As a result of the driver's unbelted status, the system did not activate the belt pre-tensioner; however, the first stages of both front air bags were deployed.

<u>ASF2-1520:</u> A 2000 Ford Taurus was travelling eastbound when a 1999 Lincoln Continental entered the roadway from a driveway on the south edge of the road. The front of the Taurus struck the left front door of the Continental. The maximum crush to the front of the Taurus was 23 cm (11FLEW1). The maximum crush to the left side of the Continental was 20 cm (09LYEW1).

Due to the crash severity, the sensing system determined the need for a seat belt pre-tensioner (belted), and for a first-stage air bag (unbelted), at 28 ms after AE. The driver's seat belt buckle was identified by the system as engaged, whereas the front passenger's seat belt was noted as unbuckled. The seat track sensor indicated that the driver's seat was not forward of the middle position.

Figure 20. 2000 Ford Taurus

Time (ms)	0	10	20	30	40	50	60	70	78
ΔV (km/h)	0	2	5	8	13	18	25	26	28

Figure 21. 2000 Ford Taurus Longitudinal ΔV

Algorithm Times (ms) Actual initiation depends on restraint system status (below)	
Time From Algorithm Wakeup to Pretensioner	28
Time From Algorithm Wakeup to First Stage – Unbelted:	28
Time From Algorithm Wakeup to First Stage – Belted:	0
Time From Algorithm Wakeup to Second Stage:	0

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

Deployment Initiation Attempt Times (ms)		
	Driver	Passenger
Time From Algorithm Wakeup to Pretensioner Deployment Attempt:	28	Unbelted
Time From Algorithm Wakeup to First Stage Deployment Attempt:	Not Deployed	Not Deployed
Time From Algorithm Wakeup to Second Stage Deployment Attempt:	Not Deployed	Not Deployed

Figure 22. 2000 Taurus EDR Report – Summary

In the crash, the pre-tensioner was fired for the belted driver, whereas the pre-tensioner on the front passenger's seat belt was not fired since this belt was not is use (there being no passenger). The driver's air bag was not fired, which is consistent with the sensing system calling only for a first-stage air bag in the case of an unbelted occupant. The front passenger's air bag was not deployed, even though the system had detected that the passenger's seat belt was not is use. Since the latter situation appears to be counter-intuitive, further explanation is required.

Ford has added specific logic to the restraint system's control algorithm to handle the situation where the driver's seat belt buckle is engaged but that of the front passenger is not. Currently, there are no sensors to determine if someone is actually occupying the passenger's seat. Consequently, while the buckled seat belt indicates that a driver is present, the system cannot distinguish between there being an unbelted passenger and no passenger being present. To limit the number of passenger air bag deployments where there is no occupant in the seat, the command logic is such that "the passenger follows the driver when the driver is belted." Thus, if the driver is belted and the passenger's belt remains unbuckled, the system considers that there is no passenger present. Deployment of the passenger's air bag is then based on the decision for the driver's system. In the present case, given the crash severity, no air bag was required for the belted driver. Thus, with the "passenger" following the driver's command sequence, no deployment of the passenger's air bag was initiated.

Discussion

It is clear that data such as those presented in the preceding case studies are extremely useful in identifying specific factors related to the occurrence of a collision, in determining the crash severity, and indicating the precise nature of the activation of advanced occupant restraint systems.

Indeed, we have seen that the pre-crash data stored in EDR systems can provide solid evidence of pre-impact vehicle speed, and driver actions such as brake application. This type of information can be very helpful in understanding specific collision situations, e.g. where no skid marks are identified, or in single-vehicle, single-occupant fatalities. Objective quantitative crash severity data often confirm calculations based on traditional collision reconstruction techniques, and can identify specific situations where general computer programs may not accurately model real-world events. The data stored in EDRs can also provide information relating to air bag systems, such as firing times, and the nature of dual stage deployments, which are unavailable from any other source. Consequently these data are critical in evaluating system performance. The stored data can confirm when air bags deploy as designed, and can also identify deficiencies in sensing and control systems.

While the case studies presented have illustrated the power of these new sources of crash data, they have also indicated the need to use caution in the interpretation of the information. It is evident that, in certain situations, the stored data may not correspond to the actual situation in the vehicle. This underscores the necessity to conduct thorough collision investigations, to carefully analyze all of the relevant data, and to completely understand both the functions and the limitations of any electronic data systems.

Whereas the scope of both pre-crash and crash-pulse data in the general vehicle fleet is currently rather limited, it seems certain that, as technology progresses, a much wider range of information will be captured and stored. One can envisage future systems which might be used to provide detailed accounts of the pre-crash history of a vehicle operator's inputs, the responses of various vehicle systems, and the resultant vehicle dynamics, over a considerable time period prior to any given collision event. Such systems would also be able to provide a precise acceleration-time history of a vehicle in the crash phase.

Already, after-market systems offer some of these capabilities, plus the possibility of capturing a driver's eye view of a crash by integrating a video-camera with an EDR system and digitally recording both pre- and post-crash footage. An ad-hoc working group established by the US National Highway Safety Administration (NHTSA) identified a range of variables which might usefully be captured by future EDRs [12]. One manufacturer has already indicated that some of these data will be incorporated into production vehicles by model year 2004. It is noteworthy that EDRs also have application to heavy trucks and buses, not only as crash data recorders, but perhaps also serving as electronic log books to capture accurate records of drivers' hours of service [13].

Having a large database of objective crash data gleaned from EDRs would be extremely helpful to researchers investigating a wide range of collision-related issues. The utility of such a database would be greatly enhanced if the data obtained from on-board crash recorders were linked to more conventional collision data systems, such as police reports and medical records. There are, however, considerable obstacles to be overcome in developing such linked data systems, not the least of which is implementing an efficient methodology for the capture of data from crash recorders.

Clearly, collision data could be captured by dedicated investigators, equipped to access the electronic data, which would be merged with crash data obtained from other sources (e.g. police reports, medical records) in an anonymous fashion. As with current in-depth collision investigation programmes, such a process would be extremely resource intensive and, while gathering extensive data on individual crashes, would necessarily be limited to small samples of collisions. At the other extreme one could envisage electronic data being downloaded from every collision-involved vehicle and stored in a mass database, in parallel with current police-reported information. Such a process would not be practical unless the crash data retrieval system was standardized, easy to operate, and affordable.

Standardization would require motor-vehicle manufacturers and their suppliers working cooperatively to develop a common system; non-governmental agencies establishing recommended practices; or governments introducing regulations. Whichever avenue is chosen, developing standards, and implementing these in new on-board devices, is likely to take considerable time.

In the interim, the rapid pace of development in electronics and communications may introduce new technologies which may well facilitate the process of accessing and storing crash data. For example, wireless systems may be developed which communicate directly with on-board crash recorders and download stored data without the need for physical cables and connectors. Similarly, advanced telecommunications systems installed in future vehicles may afford the opportunity to upload recorded crash data to a central location automatically.

Potential uses of information from crash recorders are subject to issues relating to the ownership of the data, under what circumstances data may be accessed, and to what purposes the data may be applied. From a research perspective, these questions are unimportant, since most research studies are conducted with the informed consent of study subjects, which usually includes the vehicle's owner or operator, and the resulting study data are recorded and stored in an anonymous manner. In contrast, the nature of the available data is such that the information will doubtless prove useful to various parties involved in litigation over a given crash. Eventually, the courts will have to test the admissibility of data obtained from EDRs with respect to issues such as its reliability, and to determine such factors as the need for search warrants, and any requirements for disclosure.

Additional privacy concerns which will need to be resolved in the future are those of a variety of agencies charged with the oversight of individual data systems, and the ensuing reluctance to share such information even for bona-fide research purposes. In principle, linkages of data from multiple sources can be made such that specific collision events and, more particularly, individuals involved in the crashes, cannot be identified. This is certainly the case with electronic data obtained from on-board crash recorders. Thus, there are no insurmountable impediments to the development of linked data systems. Nevertheless, considerable effort will have to be expended to achieve this on a national or even on a province-wide basis.

At least part of this process might be expedited through the extension of on-board crash-sensing systems to the post-collision situation, where data relating to a specific crash are transmitted to a central monitoring location. Such automatic collision notification (ACN) systems can make use of other electronic technologies such as global positioning systems in order to identify the specific location of a collision, and wireless communication systems to permit two-way conversation between individuals involved in the collision and personnel at a central office. Based on information obtained from such conversations and/or data uploaded from an event data recorder, the monitoring agency can request the assistance of appropriate emergency response services, and efficiently dispatch these to the correct location [14]. An evaluation of an operational test of one such system showed that the technology is quite likely to function as designed and result in efficiencies in the use of emergency services [15].

The work described here has indicated some of the promise for utilizing both pre-crash and crash-pulse data obtained by means of on-board recorders. Other researchers have come to similar conclusions based on preliminary studies involving a variety of on-board electronic recorders. Evaluations of injury mechanisms in real-world crashes have been enhanced by combining data from crash recorders with detailed medical information in quantifying neck injuries in rear-end impacts [16], and for injuries resulting from narrow-offset frontal crashes [17]. The utility of detailed pre-crash and crash pulse information in reconstructing individual crashes has also been highlighted [18]. The use of pre-crash data has been reported in a Japanese study [19] where an EDR was combined with an electronic driving monitoring system to capture data on a fleet of commercial vehicles. By using both technologies, the researchers were able to identify general characteristics of individual drivers and relate these to a specific driver's actions during an actual collision event. A recent European study used data from on-board recorders as feedback to participating fleet drivers and reported an estimated reduction in crashes for the study subjects in the order of 20% [20].

If we wish to enhance our scientific approach to traffic safety, it is clear that we require improved data systems. Electronic technologies, such as those described in this paper, offer an opportunity to capture significant quantities of objective data on a wide range of attributes of real-world collisions. Based on the preliminary results obtained to date, it is clear that traffic safety researchers should make every effort both to exploit the data sources which are available, and to support initiatives to expand the range of data collection.

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