

A Study of Pre-Crash Events Using Information Retrieved from Event Data Recorders

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Abstract

Late-model General Motors' vehicles are equipped with event data recorders, many of which provide a significant amount of pre-crash information. In-depth investigations of collisions involving such devices provide an opportunity to learn more about the events leading up to a given collision by means of data recorded during the actual event. This paper reports the results of a series of such investigations where pre-crash data was available from at least one of the involved vehicles. In some cases, the electronic data confirmed the driver's recollection of the collision events, while in other cases there were significant discrepancies between the two data sets. Drivers tended to under-report their actual speed, this being particularly marked for the small group of individuals travelling considerably in excess of the speed limit. In general, drivers were found to brake late in the sequence of collision events, most

frequently within the last two seconds prior to impact. The majority of drivers in the study were belted with belt use being confirmed by the recorded data. In contrast, drivers who were actually unbelted at the time of a crash were frequently found to misreport their restraint status. Pre-crash information captured by current event data recorders is subject to a variety of limitations. Nevertheless, by providing objective data, these systems provide an extremely valuable tool for research into causal factors for motor vehicle collisions.

Résumé

Les récents véhicules de General Motors sont équipés d'enregistreurs de données. Beaucoup d'entre eux fournissent une quantité importante de renseignements pré-collision. Des recherches approfondies sur des collisions impliquant des véhicules équipés de ces dispositifs permettent d'en apprendre plus sur ce qui s'est passé avant la collision grâce aux données enregistrées en temps réel. Ce document donne les résultats d'une série d'études pour lesquelles on disposait des données pré-collision d'au moins un des véhicules impliqués. Dans certains cas, les données électroniques confirment ce que le conducteur dit s'être passé, tandis que dans d'autres cas, il y a de grandes divergences entre les renseignements recueillis par les enregistreurs et ceux fournis par les conducteurs. Ces derniers avaient l'habitude de ne pas donner la vitesse exacte à laquelle ils roulaient avant la collision; ceci s'applique particulièrement au petit groupe de personnes qui dépassait largement la limite de vitesse. En général, on a remarqué que, lors des collisions, les conducteurs freinaient tard (deux secondes avant la collision dans la majorité des cas). Les données enregistrées confirment que la plupart des conducteurs dans cette étude portaient leur ceinture de sécurité. Cependant, les conducteurs qui ne portaient pas leur ceinture de sécurité au moment de la collision communiquaient fréquemment des

renseignements inexacts à ce sujet. Les renseignements pré-collision recueillis par les enregistreurs de données sont assujettis à une variété de limites. Néanmoins, grâce à leur capacité de fournir des données objectives, ces systèmes demeurent des outils très précieux lors des recherches de facteurs de causalité en ce qui a trait aux collisions de véhicules motorisés.

Introduction

It has long been recognized that motor vehicle collisions have both tragic and extremely costly consequences for society. While major efforts have been expended to enhance the crashworthiness of motor vehicles, and improve occupant protection systems, less attention has been paid to the challenge of reducing the incidence of collisions, or at least of reducing their severity. Central to the development of strategies to provide effective collision avoidance measures is a broad-reaching understanding of the significant factors involved in collision causation. Not the least of such factors are those relating to the individuals involved, the pre-crash human factors.

High-level data from real-world collisions such as initial vehicle speeds, drivers' perception and reaction times, braking and steering inputs, and impact speeds are fundamental to research into pre-crash human factors. However, very often, objective data on these important aspects of collisions are not readily available. As a result of a lack of hard data on driver actions prior to impact, most studies of pre-crash factors in the real world have relied heavily on accounts from involved parties and independent witnesses.

The relatively recent introduction of on-board crash recorders into the vehicle fleet and, more particularly, the general availability of crash data retrieval systems, offer the promise for objective study of some of the factors related to collision causation. The object of the present paper is to illustrate the capabilities of current event data

recorder (EDR) technology in this regard, and to identify limitations that might be addressed in future versions of these devices.

Pre-Crash Data

Many late-model General Motors' light-duty vehicles are equipped with event data recorders that form part of sensing and diagnostic modules (SDM) that control deployment of air bag systems. EDRs can capture certain information relating to both the pre-crash and crash phases of motor vehicle collisions.¹ These systems can be interrogated by means of a Crash Data Retrieval (CDR) tool allowing the stored data to be retrieved, analyzed and reported.^{2 3 4 5 6}

When pre-crash data are available, this information consists of the vehicle's speed (mph), engine speed (rpm), throttle position (%), and the status of the brake light switch (on or off) for a period of five seconds prior to the event that triggered the recording. In addition, the EDR indicates the status of the driver's seat belt buckle switch (buckled or unbuckled) at the time of the event. It is these particular data elements that are of specific interest in the present work.

Data records may be captured for both airbag deployment events and certain non-deployment events. In general, a non-deployment event consists of vehicle deceleration sufficient to trigger the sensing algorithm, but not severe enough to require deployment of the airbag. Both types of events were recorded in cases in our present series.

It is important to note that there is no real-time clock associated with the EDR. The total number of ignition cycles (i.e. ignition key turned on and off) since vehicle assembly is stored as part of each recorded event. Normally, the number of ignition cycles at the time data is retrieved from the EDR is also reported. Comparison of the ignition cycles for a recorded event to the ignition cycles at download

is used by collision investigators to associate, or disassociate, a data record with a collision.

Generally, once a vehicle's airbags have been fired as a result of a crash, the vehicle will not be driveable and will be towed from the scene. In such a case, the number of ignition cycles associated with the airbag deployment event will usually be very close to the number of ignition cycles recorded when the data are downloaded. In contrast, following a non-deployment event, the vehicle can often still be operated. Thus, if the number of ignition cycles associated with a non-deployment record is considerably less than the number of ignition cycles reported at the time of data retrieval, the non-deployment event will not be associated with a recent crash, and would have actually occurred at some time in the past.

The situation is further complicated by a variety of options in the storage system for non-deployment events, the details of which are beyond the scope of the present paper. Suffice it to say that considerable care must be exercised in attributing stored records to specific collision events.

Data relating to vehicle speed, engine speed, percentage throttle and brake switch status are stored in a buffer that is capable of storing five values of each data element. Values are recorded at one-second intervals with the most recent values superceding the oldest values. When the SDM senses a certain vehicle deceleration, the airbag deployment algorithm is enabled (AE) to monitor the crash pulse and determine if the airbags need to be fired. The last five values of the pre-crash data elements in the buffer are stored in non-volatile memory for subsequent retrieval. The pre-crash data are reported at one-second intervals, starting at five seconds prior to AE ($t = -5s$) and ending at one second prior to AE ($t = -1s$).

As a result of the manner in which these data elements are captured, much care must be given to their interpretation. For example, the fact that the EDR reports the driver's seat belt to have been

buckled is not necessarily indicative that the seat belt was actually used by the driver. The system cannot discriminate between a properly restrained driver and an individual who is unbelted, but who has deliberately fastened the seat belt buckle to defeat the warning system, and is sitting on the webbing.

Similarly, the signals from the sensor and control modules are not necessarily synchronized in absolute time. Thus, the reported position of the throttle at any given second may not correspond exactly to the status of the application of the brake. It should be further noted that no indication is provided of how hard the brake pedal was applied. The driver may have been touching the brake pedal lightly, sufficient to illuminate the brake lights, but not hard enough to develop much deceleration.

Recent research has shown that the EDR-recorded vehicle speeds are very accurate under steady state conditions.⁷ However, it should be noted that the accuracy of the recorded vehicle speed can be affected if the tire size or final drive axle ratio of the vehicle has been changed from the factory build specifications. When assessing the accuracy of the speed data one may also have to consider other factors such as wheel slip, ABS brakes, traction control systems and vehicle yaw.

Study Methodology

A series of real-world motor vehicle collisions, subject to conventional in-depth investigation and reconstruction techniques, have been included in this study. The individual cases were drawn from Transport Canada's on-going collision investigation programme. They include investigations focused on airbag deployment crashes, moderately-severe side impacts, and a trauma-based sample of children in collisions. The present series also includes a subset of cases from a human factors' pilot study in which detailed and comprehensive interviews were conducted with involved drivers.

The common element to the cases so gathered is the availability of pre-crash data elements downloaded from event data recorders present in at least one of the collision-involved vehicles. The present study includes 59 such collisions that involved late-model General Motors' vehicles.

In this demonstration project, no attempt was made to sample crashes in any systematic manner. The intention was merely to capture pre-crash data elements from EDRs to compare to information determined by conventional research techniques. By such means, the utility and limitations of these data with regard to identifying and quantifying issues related to collision causation can be explored.

Results

Deployment and Non-Deployment Events

The 59 collisions examined in this series were comprised of 39 airbag deployments and 20 non-deployments. In most cases the recorded data was found to be directly associated with the subject crash by there being comparable numbers of ignition cycles at air bag deployment and at the time of data retrieval. This was the case for all 39 deployment crashes and for 7 of the 20 non-deployment crashes. In one non-deployment crash, the vehicle was driven over a period of several days after the collision thus increasing the ignition cycle counter. However, reconstruction of the crash indicated that the recorded event was very likely the result of the collision that was under study.

In the remaining 12 non-deployment cases only the number of ignition cycles at the time of the event was stored such that it was not possible to definitively associate the EDR data with the specific crash under study. However, the recorded collision events were in reasonable agreement with the detailed collision reconstructions and, in each of these cases, the impact would almost certainly have triggered a non-deployment event. From these

considerations, all of the deployment and non-deployment cases were included in the study.

Collision Type

Frontal impacts (N = 41) were the predominant crash type for the EDR-equipped vehicle in this series. Useful pre-crash data was also recorded for side impacts (N = 17) over a wide spectrum of crash severity. A single rollover event was also recorded.

Most of the cases involved multiple vehicle collisions (N = 44), 40 of which occurred at intersections. Single vehicle collisions (N = 15) were less common in the series. Loss of directional control occurred prior to impact in 10 of these cases.

Maximum EDR Recorded Vehicle Speed

The maximum speed recorded by the EDR in the 5 second pre-crash interval was compared to the posted speed limit and is shown in Figure 1. The maximum recorded speed usually occurred at the -5 seconds to AE interval. Speed differentials below the posted speed resulted from situations such as the EDR equipped vehicle being stopped, or moving slowly in the process of turning left.

The EDR recorded a maximum speed above the posted limit in 60% of the cases, and was most marked in the single vehicle collisions where more than 70% of the vehicles were exceeding the posted speed limit by more than 20 km/h. While most of the multiple vehicle collisions were urban events, the single vehicle collisions frequently occurred on rural roads with higher posted speed limits.

Driver's Speed Estimates

Where possible, driver-reported speeds were determined either by interview or from the police report. In 43 of the cases in our series, both the driver-reported speed and the maximum EDR-recorded speed were available. Figure 2 shows a comparison between these speeds. When drivers

were travelling below the posted speed limit their reported speeds tended to be in relatively good agreement with the EDR. However, drivers frequently under-reported their speed when they were speeding, and most often reported speeds very close to the posted speed limit. Only 3 of the 43 drivers (7%) admitted to travelling more than 10 km/h above the posted speed limit and 2 of these individuals still under-estimated their speed by more than 30 km/h.

Speeding and Crash Severity

As might be expected, the crash severity, as measured by equivalent barrier speed (EBS)⁸, was observed to increase with the speed differential above the posted limit. Vehicles that were travelling less than 10 km/h in excess of the speed

limit tended to sustain less severe crashes than those vehicles where the speed differential was higher. For example, the average EBS was 17 km/h for 33 cases where the maximum recorded speed was no more than 10 km/h above the posted speed limit, while the average EBS was 26 km/h for 26 cases where the speed was greater than 10 km/h above the posted speed limit. Also, the average EBS was 34 km/h for the 8 cases where the maximum recorded speed was 30 km/h or more above the posted speed limit.

Pre-Impact Braking

The occurrence of some degree of pre-impact braking was identified by the EDR recording the brake status as being on in at least 1 of the 5 pre-crash sampling intervals. This was the situation in

Figure 1
Maximum EDR Recorded Speeds for Single and Multiple Vehicle Collisions

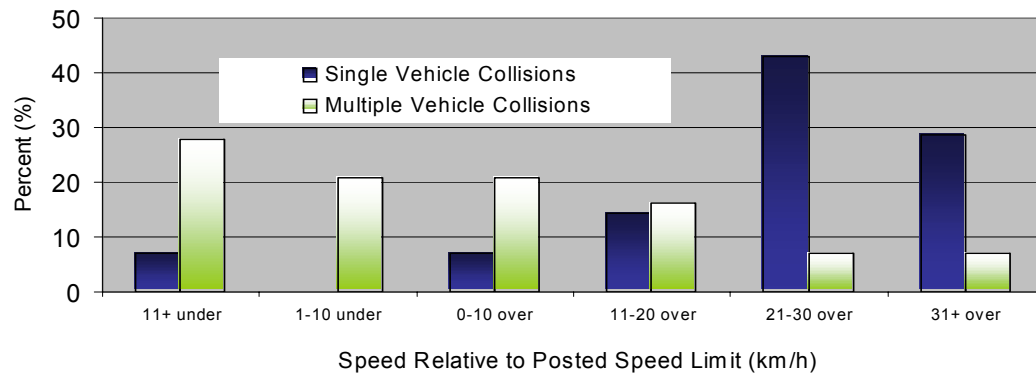
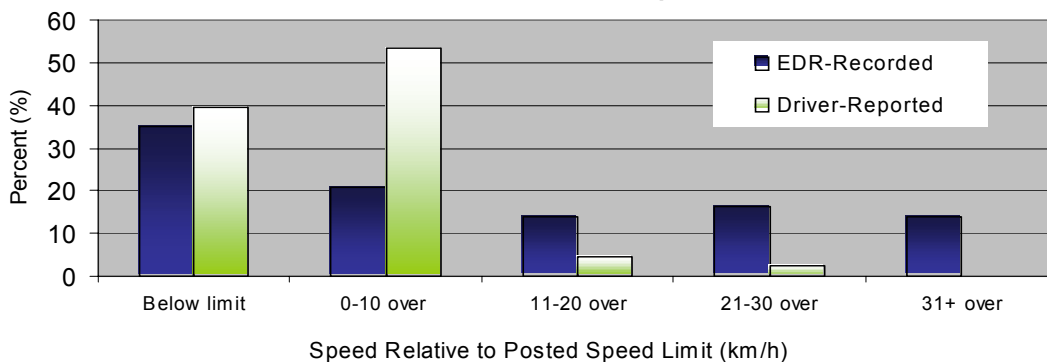


Figure 2
Relationship Between Driver-Reported and EDR-Recorded Speeds



47 of the 59 cases (80%). In the other 12 cases, the driver conducted no pre-impact braking.

The time interval which marked the onset of pre-impact braking is shown in Table 1. Pre-impact braking in the -1 or -2 s to AE intervals was an interesting and common characteristic, particularly for the multiple vehicle crashes which typically occurred at intersections.

	Time Before AE (s)					
	N/A	-1	-2	-3	-4	-5
All cases (N = 59)	12	20	11	4	4	8
Single vehicle (N = 15)	5	1	1	3	3	2
Multi-vehicle (N = 44)	7	19	10	1	1	6

Table 1 Onset of Pre-Impact Braking

Restraint Use and Loading Evidence

The driver's belt switch circuit status was reported by the EDR as being buckled in 53 of the 59 cases (90%). Frequently, due to collision-induced forces, witness marks are present on seat belt systems and these can be used to confirm belt use by occupants.⁹ In the present series, visible loading evidence on the restraint system verified the belt switch status in 22 of the 53 cases. As would be expected, loading evidence was often faint or not observed in low severity impacts. The calculated EBS was below 20 km/h in 25 of the 31 cases (81%) where visible loading evidence was not observed on the restraint system. By comparison, the calculated EBS was below 20 km/h in just 6 of the 22 cases (26%) where loading evidence was observed.

The driver's belt switch circuit status was reported as unbuckled in 6 of the 59 cases (10%). Two of these drivers correctly reported that they were unbelted. A third driver was fatally injured and could not report his belt use. This individual was ejected and the physical evidence indicated that he was indeed unrestrained.

Three of the 6 drivers that were identified by the EDR as being unrestrained reported to police that they were belted. In 1 of these cases, a high delta-V, and the lack of loading evidence on the restraint, supported the EDR seat belt status data and indicated that the driver was likely unrestrained. In 2 cases, the collisions were of minor severity and the lack of loading on the restraint system was not sufficient to positively establish that the restraints were not worn.

Accuracy of EDR Recorded Speeds

A pre-crash speed loss greater than 41 km/h in a 1 s time interval was recorded in 9 of 59 cases (15%). This magnitude of speed loss would require more than a 1 g deceleration and could not result from braking alone. Loss of directional control and yaw due to hard braking and steering were probable contributory factors in the cases where the recorded speed losses appeared unusually high.

Field Investigations

Case 1: Moderate Severity Intersection Crash

2002 Buick Rendezvous SUV

EBS: 19 km/h

Driver: 17 yr-F, Lap/torso/airbag, No injury

This T-type collision occurred in daylight at the intersection of an uncontrolled, north-south, four-lane, urban arterial and an east-west, two-lane, stop-sign-controlled roadway. The arterial had a posted speed limit of 50 km/h. The Rendezvous was travelling southbound in the right curb lane at a driver-reported speed of 50-60 km/h. A 2002 Pontiac Grand Am 4-Door Sedan was travelling northbound in the left median lane when its driver attempted a left turn at the intersection. The front end of the Rendezvous struck the right side of the Grand Am. The driver of the Rendezvous stated that the Grand Am turned suddenly in front of her and that she braked hard but couldn't avoid the

collision. She also reported that she was wearing her seat belt.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	60	1472	0	OFF
-4	60	1864	5	OFF
-3	60	1864	5	OFF
-2	60	1864	0	OFF
-1	37	960	0	ON

Table 2: Pre-Crash Data for Case 1



Figure 3 Case vehicle 1

The EDR indicated a maximum pre-impact speed of 60 km/h. Pre-impact braking was occurring at –1 s to AE. The EDR also indicated that the driver’s seat belt status was buckled.

Case 2: Fatal Intersection Crash

2001 Pontiac Montana Extended Minivan

EBS: 45 km/h

Driver: 42-yr-M, Unbelted/airbag, Ejection/Fatality

This severe side impact occurred during evening hours at the artificially-illuminated intersection of two multi-lane urban arterials. The weather was clear and the roadways were dry and in good condition. The posted speed limit was 50 km/h for both roadways and traffic was sparse. A witness reported that the minivan was northbound and turned left at the intersection in front of a tow truck. The minivan was struck on its right side by the front

of the southbound 1995 Dodge Ram Tow Truck. The unrestrained driver of the minivan was ejected and fatally injured. The EDR confirmed that the driver’s seat belt was unbuckled.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	66	1216	0	OFF
-4	66	1152	0	OFF
-3	64	1344	5	OFF
-2	64	1280	0	OFF
-1	64	1344	0	OFF

Table 3: Pre-Crash Data for Case 2



Figure 4 Case vehicle 2

Inspection of the pre-crash speed data from the minivan’s EDR indicated that it was travelling too quickly to have been in the process of turning left. It was apparent that the minivan was travelling straight through the intersection when it was struck, and that one of the drivers had travelled through a red light. There was no evidence of collision avoidance by the driver of the minivan. The driver of the tow truck had poor recollection of the events leading to the crash but reported to police that he entered the intersection on a green light.

Case 3: High Speed Intersection Crash

2002 Chevrolet Cavalier Z24 2-Door Coupe

EBS: 49 km/h

Driver: 22-yr-M, Unbelted/airbag, MAIS-1

This severe frontal impact occurred at the traffic-light-controlled intersection of a four-lane north-south urban arterial and a four-lane east-west urban arterial. The posted speed limit for both roadways was 50 km/h. The morning rush hour weather was clear and the roads were in good condition and dry. A northbound 1996 Cavalier attempted to turn left at the intersection into the westbound lanes on an amber light. A 2002 Z24 Cavalier was southbound in the right curb lane and also travelled into the intersection on the amber light. The left front end of the 2002 Cavalier struck the right front corner of the 1996 Cavalier.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	97	3136	1	ON
-4	94	3072	31	ON
-3	94	3072	0	ON
-2	94	3072	0	ON
-1	77	2816	0	OFF

Table 4: *Pre-Crash Data for Case 3*



Figure 5 *Case vehicle 3*

The brake status reported by the EDR was unusual due to the lack of significant speed loss until the brake status toggled off. Note that it was common in the intersection collisions that the driver of the bullet vehicle applied the brakes just prior to impact. However, in this case, it appeared that the driver stopped braking just prior to impact. It is possible that the driver had his foot lightly on the brake as he approached the intersection and that he

braked hard just prior to impact. Interestingly, his foot was not on the brake pedal at -1 s to AE.

The recorded 31% throttle and braking at -4 s to AE was not unusual and the appearance of simultaneous throttle and braking was observed in several other cases. As discussed earlier, the braking and throttle signals are not necessarily synchronized in absolute time so the reported position of the throttle at any given second may not correspond exactly to the status of the application of the brake. Note that the engine speed did not change with the throttle input indicating that the throttle input was very brief. It appeared from the EDR data that the driver was lightly applying the brake and that he attempted to accelerate as he approached the intersection, but quickly changed his mind, possibly when the traffic light turned amber.

The driver of the 2002 Cavalier reported to police that his initial speed was 65 km/h. He did not respond to requests for interview. The vehicle was equipped with ABS brakes and there were no pre-impact tire marks. The initial recorded speed of 97 km/h was almost double the posted limit and was a definite factor in the causation and severity of the crash. Both drivers were charged under the Highway Traffic Act with failing to yield the right of way.

Case 4: High Speed Loss of Control

2002 Pontiac Sunfire 2-Dr Coupe

EBS: 40 km/h

Driver: 16-yr-F, Lap/torso, No injury

This side impact collision occurred in the early morning on a two-way, two-lane, 50 km/h, undivided urban roadway. It was clear and dark and the road surface was dry and in good condition. The Pontiac was westbound in the right lane when the driver lost control in attempting to steer around a parked vehicle on the right roadside. The vehicle skidded sideways into a light standard located on the north side of the roadway. The young female

driver was impaired and had the highest recorded pre-impact speed in the series.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	152	4928	100	OFF
-4	121	3968	87	OFF
-3	84	2752	0	ON
-2	19	1408	0	ON
-1	3	960	0	OFF

Table 5 Pre-Crash Data for Case 4



Figure 6 Case vehicle 4

There are a number of considerations in the interpretation of the EDR data in this case. In the -5 and -4 s intervals the vehicle was decelerating beyond the capability of braking alone under high throttle. It appeared that loss of control had already commenced at these points. Note also that the dramatic speed decline from -3 s to -2 s is well beyond the capability of brakes. The recorded speed at -1 s to AE was certainly not representative of the true pre-impact speed of the side-slipping vehicle. While high speed was very likely in this case, there was significant uncertainty regarding the maximum speed provided by the EDR due to the extremely dynamic pre-crash actions of the vehicle.

Case 5: Single Vehicle Loss of Control

2002 Chevrolet Cavalier Z24 4-Dr Sedan

EBS: 27 km/h

Driver: 24-yr-M, Lap/torso/airbag, No injury

This single vehicle collision occurred on a two-way, 50 km/h, four-lane, undivided urban roadway. It was early morning, dark, and the roadway was artificially illuminated. The weather was active with a rain-snow mixture and the road surface was wet with slush. The driver of the Cavalier attempted to make a right turn onto a secondary residential roadway. The driver lost control of the vehicle which slid across the intersection. The vehicle mounted a concrete curb and then struck a wooden hydro pole with its front end. The male driver had been drinking but was not impaired and no charges were laid. The driver estimated his speed at 50 km/h.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	79	4160	0	OFF
-4	72	3520	0	ON
-3	56	1472	0	ON
-2	40	1024	0	ON
-1	10	896	0	ON

Table 6 Pre-Crash Deployment Data for Case 5

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	72	4416	99	OFF
-4	79	4160	0	OFF
-3	72	3520	0	ON
-2	56	1472	0	ON
-1	40	1024	0	ON

Table 7 Non-Deployment Data for Case 5



Figure 7 Case vehicle 5

The EDR recorded a deployment level event (pole impact) within 0.3 s after a near-deployment event (curb impact). The near-deployment provided an additional 1 s of pre-crash data at -5 s to AE when combined with the deployment event. The additional 1 s of pre-crash data was vital for the understanding of this crash as it indicated that the driver of the Cavalier was applying full throttle prior to braking and was driving quite aggressively.

The driver was exceeding the speed limit by 29 km/h before he began to slow his vehicle prior to making the right turn. The driver braked and steered the ABS-equipped vehicle but was travelling too quickly to negotiate the turn and apparently did not anticipate the slippery road conditions. The loss of control and subsequent collision were the result of excessive speed and aggressive driving on the slippery road. He was not charged and told police that he was travelling at the speed limit and simply lost control while making a turn on the slippery road surface.

Case 6: High Throttle Loss of Control

*2002 Chevrolet Impala 4-Dr Sedan
EBS: 27 km/h
Driver: 54-yr-F, Lap/torso/airbag, Not injured*

This single vehicle collision occurred at night in heavy rain at an artificially-illuminated intersection. The southbound Impala was stopped at a T-intersection with an east-west urban arterial. The driver of the Impala attempted a right turn at the intersection into the westbound lane. Witnesses reported that the Impala accelerated quickly, apparently to avoid approaching westbound traffic. The vehicle turned abruptly to the right, as result of the steering and heavy throttle input, and travelled onto the northwest roadside. The vehicle continued on the roadside for 12 metres narrowly missing a wooden hydro pole before striking a 35 cm. diameter tree with its front end. A maximum velocity change of 33 km/h was recorded by the EDR.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	6	1536	11	OFF
-4	15	1856	11	OFF
-3	18	1152	0	OFF
-2	46	4288	100	OFF
-1	62	4416	100	OFF

Table 8 Pre-Crash Data for Case 6



Figure 8 Case vehicle 6

The EDR indicated that the driver did not brake prior to impact, but rather was applying full throttle. Police reported that this hard acceleration was intentional. The driver was not familiar with the base model rental vehicle and apparently did not anticipate the vehicle reaction when she accelerated quickly on the wet asphalt. She had consumed 1.5 glasses of wine prior to the incident.

The EDR indicated that the driver was applying 100% throttle at the -2 s and -1 s intervals. The recorded speed increased dramatically from 18 km/h (11 mph) at -3 s to AE to 61 km/h (38 mph) at -1 s to AE. The front wheels were evidently slipping considerably as the vehicle would not be capable of such a large acceleration. Based on the damage to the vehicle, the impact speed was estimated as being well below 61 km/h, providing further evidence of considerable wheel slip at impact. The recorded speed at -1 s to AE was

certainly not representative of the true vehicle speed.

Case 7: Low Speed Single Vehicle

2001 Pontiac Sunfire 4-Door Sedan

EBS: 8 km/h

Driver: 27-yr-F, Lap/torso/airbag, No injuries

This very low severity frontal impact occurred during the late afternoon hours in a parking lot. It was daylight and the weather was active with snow and strong winds. The parking lot had icy patches covered with snow. The Sunfire was travelling through the parking lot at low speed and entered an assigned parking spot. The driver of the Sunfire stated that she braked hard and then the airbags deployed. She also reported that the Sunfire came to rest a short distance away from the wall and that the wall was not struck. The Sunfire sustained no measurable damage to its front end.

Time before AE (s)	Vehicle speed (km/h)	Engine speed (rpm)	Throttle position (%)	Brake switch status
-5	3	640	4	OFF
-4	3	832	4	OFF
-3	3	576	4	OFF
-2	3	768	4	ON
-1	3	704	22	OFF

Table 9 Pre-Crash Data for Case 7



Figure 9 Case vehicle 7

The EDR recorded a maximum delta-V of 8 km/h at 90 ms. A license plate imprint was identified on the concrete wall adjacent to her parking place. While there was indeed a collision, the impact was of minor severity and did not warrant airbag deployment.

The pre-crash data for the Sunfire indicated a very low vehicle speed of 3 km/h at each of the 5 sampling intervals. Braking was recorded at the -2 s to AE interval only. The throttle increased from a constant 4% to 22% at the -1 s to AE sampling interval indicating that the driver accelerated just prior to impact. It appeared that she increased the throttle in an attempt to park the vehicle on a slick icy surface, and her vehicle picked up speed when her tires came into contact with a higher friction surface. The impact speed was calculated to be in the 4 to 7 km/h range.

Discussion

While the number of real-world cases available to the authors that included pre-crash data from on-board event data recorders was limited, the preliminary analysis of the resulting data provides some indication of the potential of these systems to enhance our understanding of factors related to collision causation.

In particular, as exemplified by Case 1 in our series, the versions of events reported by involved drivers were confirmed by the EDR data in the majority of cases. However, there were a number of situations where driver statements were demonstrably inaccurate. In some such cases, as was probably the situation in Case 5, drivers at fault were most likely misrepresenting the truth in order to avoid being charged with an offense. In other cases, drivers held misconceptions about the actual collision events, as was almost certainly the situation in Case 7. Furthermore, as shown by Case 2, the electronic record can provide an important voice, and critical information for the reconstruction of specific crashes, where drivers who are fatally or

seriously injured are unable to provide first-hand accounts.

Thus, EDRs can be seen to provide an objective mechanism to ascertain and quantify some of the major factors related to the occurrence of collisions.

Witness Statements

Real world field studies can yield tremendous insight into the factors that precipitate motor vehicle collisions. The strength of such in-depth studies is the quality of data, especially when these data are based on solid physical evidence. Softer data based on eyewitness recollections can also provide important insight into pre-crash events; however, witness statements and recollections can be very unreliable as was found in this and other studies.¹⁰

For example, when comparing driver-reported seat belt use to the belt status recorded by the EDR, it was noted that 3 of 6 unrestrained drivers in the present series of cases incorrectly reported that they were belted. While one might argue that in 56 of 59 cases the EDR matched and verified the driver's report, if one were interested specifically in identifying the unrestrained, data from this study suggest that use of driver-reported information may well result in large errors.

Similarly, drivers in this study usually reported speeds at or below the speed limit while the majority of recorded speeds were actually above the speed limit. In 30% of the cases the maximum speed recorded by the EDR was 20 km/h or more above the driver's report. While a driver's perception of the crash events may be quite different than the actual situation, there was an obvious tendency for drivers to misrepresent their speed when they were speeding.

In the majority of cases the EDR data reinforced the law-abiding driver's recollection of the crash event. However, in some cases the EDR provided a much different account of the collision particularly if the driver was speeding or was not belted. In

particular, the minority of drivers that were travelling well in excess of the posted speed limit tended to under-report their speeds by the widest margin. These drivers also tended to be involved in the most severe crashes. The EDR was found to be very useful at identifying instances of driver recklessness which otherwise might have been missed.

The Role of Speed and Braking

Over the years there have been many investigations into the role of speed in motor vehicle collisions. Most studies of speed and crash causation have relied heavily on witness reports or have been correlational in nature.¹¹ While both types of studies have yielded much useful data, there remain large gaps in knowledge, and the role of speed and braking in crashes is still highly debated. The current study has provided a glimpse of how EDRs might be used effectively to conduct detailed research in this area. The preliminary results suggest that a large-scale study of real world collisions utilizing EDR pre-crash data and state-of-the-art crash reconstruction techniques could provide tremendous insight into the role of speed and the influence of collision avoidance actions in motor vehicle crashes.

A recent Australian study of the role of speeding in real-world injury-producing collisions utilized data obtained through advanced crash reconstruction techniques.¹² Using a case-control study design and in-depth collision reconstruction, the speeds of cars involved in casualty crashes were compared with the speeds of cars not involved in crashes. The study relied heavily on analysis of scene evidence. The authors found that 71% of the 151 case vehicles skidded under emergency braking before the crash. Cars involved in the casualty crashes were generally travelling faster than cars that were not involved. In 14% of casualty crashes the vehicles were travelling faster than 80 km/h in a 60 km/h speed zone compared to less than 1% of those not involved in a crash.

A statistically valid evaluation of the role of speeding and braking was not possible in our present review of a very limited number of EDR cases. However, for comparative purposes, pre-crash braking was identified by the EDR in 78% of the cases. In 28% of the cases the driver of the EDR-equipped vehicle was exceeding the speed limit by more than 20 km/h. Crash severity generally increased with speed differential over the posted limit, and this was particularly noticeable in intersection collisions. While most of the crashes did not involve excessive speeding on the part of the driver of the case vehicle, the severe crashes usually involved a case vehicle that was travelling more than 20 km/h over the posted speed limit. Loss of control was a common pre-crash occurrence in single vehicle collisions and was often related to high initial speed.

Pre-crash events, such as the occurrence and effect of vehicle braking, can often be determined with significant accuracy through in-depth investigation and analysis of real world motor vehicle collisions. While crash reconstruction is an effective technique for determining pre-crash driver actions it relies heavily on fleeting evidence obtained from the crash scene. Wet or snow-covered roads, high traffic volumes, anti-lock brakes, competing scene evidence and the cover of darkness make the collision reconstructionist's job very difficult. Even in those cases where there is abundant scene evidence, immediate documentation is necessary as the evidence quickly deteriorates. Unless the crash is particularly severe, police are reluctant to close down roads while scene evidence is carefully documented. Besides providing additional data that would not be available through crash reconstruction alone, the EDR allows research into cases where scene evidence is not readily available.

Limitations of EDR Data

There are numerous interpretation considerations with current EDR data and it is critical that the pre-crash data be carefully evaluated in conjunction with analysis of the physical evidence.

For example, vehicle speed is normally determined by the Powertrain Control Module (PCM) which monitors a sensor located at the output shaft of the transmission. Vehicle speed is related to the rotational speed of the output shaft through the differential gear ratio and the rolling radius of the tires. The PCM monitors the speed of the wheels and not the actual ground speed of the vehicle. In some cases the speeds recorded by the EDR may not be representative of the actual vehicle speed, particularly if the vehicle is in a yaw or there is a heavy throttle input on a slippery surface resulting in wheel slip.

A pre-crash speed loss greater than 41 km/h in a one second time interval was recorded in 9 of the 59 cases (15%). This magnitude of speed loss would require more than a 1g deceleration and could not result from braking alone. Loss of directional control and yaw due to hard braking and steering were probable contributory factors in such cases where the recorded speed losses appeared unusually high.

In 17 of the 59 cases (29%) the speed recorded at –1 s to AE was not representative of the vehicle speed. Hard pre-impact braking and/or loss of directional control were observed in 15 of the 17 cases. In 1 of the 17 cases the front wheels were spinning under heavy throttle prior to impact. Sampling of the speed recorded at –1 s to AE actually occurring after initial collision engagement was believed to have been a factor in at least one case in this series that involved a side impact. It is understood that this may result from an internal problem in the buffering system in the subject EDR.

Steady state speed data from the EDR prior to collision avoidance manoeuvres, loss of control and/or significant wheel slip was found to provide an accurate measure of the true vehicle speed. Further research is needed to determine the precise influence of steering, braking and loss of control on the accuracy of the EDR speed data.

Crash avoidance manoeuvres such as braking were observed to frequently commence within 2 seconds of impact. An SDM sampling frequency of 1 Hz does not provide a good snapshot of those critical moments just before engagement. A higher sampling frequency would be very beneficial for the detailed study of pre-crash events.

The lack of synchronization between the sampled data points and imprecision on the timing of the onset of the crash and algorithm enable complicates interpretation of the pre-crash events. While a higher sampling frequency and more data points would help to alleviate such problems, a real time clock is needed to provide detailed timing information for the various events.

Similarly, the provision of additional information such as bi-axial (X-Y) or even tri-axial acceleration data, yaw rate and steering wheel angles at frequent intervals prior to AE would be extremely useful for evaluating pre-crash actions.

The EDR provided valuable pre-crash data over a variety of crash modes. Data collection was not restricted to frontal impacts and a high percentage of cases involved side impacts over a wide severity range. Data was also obtained for a single rollover collision although, in this case, as for several other single vehicle crashes, the initiation of loss of control was not captured by the EDR. Single vehicle collisions, such as rollovers, often involve loss of control where the time lapse between initiation of loss of control and impact may be significantly greater than 5 seconds. In these cases the recorded data in the EDR's limited buffer may not capture the initiation of loss of control. Review of the cases in this series, shows that an additional 5 to 10 seconds of pre-crash data would have been helpful for determining pre-impact speed and driver actions.

Research needs to be conducted into the function and timing of the EDR data collection and the various modules that provide data. The literature is

currently very limited in this area making interpretation of the pre-crash data quite difficult

In summary, event data recorders are excellent research tools that can lead to a much greater understanding of both pre-crash and crash events. However, the current systems have a number of limitations such that the data retrieved must be carefully interpreted in conjunction with conventional in-depth collision reconstruction techniques.

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