

The Use of Event Data Recorders in the Analysis of Unintended Acceleration Incidents

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ABSTRACT

Public complaints of unintended acceleration in motor vehicles are regularly received by Transport Canada's Defect Investigations and Recalls group. Some years ago, a major study of such cases was conducted using conventional investigative techniques, including physical inspections of subject vehicles and in-depth interviews with their operators. The results of this study demonstrated that the phenomenon was essentially due to operator error and not related to malfunction of any vehicle control system. In particular, the incidents resulted from so-called "pedal error" where drivers were pressing down hard on the accelerator pedal while believing themselves to be fully applying the vehicle's brakes. The advent of vehicles equipped with event data recorders (EDR's) capable of storing a range of pre-collision information, including the status of the brake-light switching circuit, and the disposition of both the accelerator pedal and vehicle throttle, has provided investigators with an objective dataset with which to evaluate unintended acceleration complaints. The present work uses recent public complaints of such incidents that have been received by Transport Canada, where the case vehicles were equipped with EDR's, and pre-crash data stored on these devices were downloaded following the alleged incidents. The analysis of these data clearly demonstrates the potential for EDR's to assist in determining the precise operator actions leading up to unintended acceleration incidents.

RÉSUMÉ

Le groupe d'Enquêtes sur les défauts et rappels reçoit régulièrement des plaintes du public concernant l'accélération involontaire de véhicules motorisés. Il y a quelques années, une étude importante a été réalisée sur le sujet au moyen de techniques d'enquêtes courantes, y compris l'inspection des véhicules touchés et la tenue d'entrevues en profondeur avec les conducteurs. Les constatations de l'étude démontrent que ce phénomène est principalement causé par une erreur du conducteur et non à une défaillance des systèmes de commande des véhicules. Plus particulièrement, les incidents découlent du fait que les conducteurs ont confondu les pédales, en ce sens qu'ils croient appuyer à fond sur la pédale de frein alors qu'ils appuient sur l'accélérateur. L'arrivée de véhicules dotés d'enregistreurs de données routières (EDR) pouvant

garder en mémoire une variété de renseignements préalables à une collision, y compris l'état du circuit du commutateur des feux de freinage et la position de l'accélérateur et du papillon des gaz, a permis aux enquêteurs de disposer d'un ensemble de données objectives pour évaluer les plaintes d'accélération involontaire. Le présent document est basé sur des plaintes récentes du public que Transports Canada a reçues pour ces incidents, lorsque les véhicules en cause étaient dotés d'un EDR, et sur les données préalables à la collision enregistrées dans l'EDR qui ont été téléchargées à la suite des présumés incidents. L'analyse des données démontre clairement que l'EDR aide à déterminer avec précision les actions du conducteur ayant mené à une accélération involontaire.

INTRODUCTION

Unintended acceleration (UA) is a broad category of powered runaways of motor vehicles where it is alleged that a rapid acceleration event occurs without any corresponding control input from a vehicle's driver. Furthermore, such complaints are often associated with a report that the driver fully applied the vehicle's brakes but that this action caused the vehicle to accelerate and failed to bring it to a stop.

These events are frequently reported as occurring when the vehicle is at rest, or moving very slowly, and the driver has shifted the automatic transmission into a forward drive gear. Alternatively, the vehicle may be in motion, in traffic, and a light throttle application is alleged to result in excessive acceleration. Such incidents are frequently of short duration, affording drivers little time to react, and resulting in minor collisions with objects or vehicles ahead. However, extended runaway incidents are also reported where a longer-term acceleration results in a high ultimate vehicle speed. Extended application of the brakes, in conjunction with depression of the accelerator, can cause the brakes to overheat and make it difficult to slow the accelerating vehicle.

In older vehicles, the throttle linkage was purely mechanical such that stuck throttles, and hence powered runaways, could occur through various means. Examples include braided accelerator cables that became worn, with broken strands in the cable interfering with the smooth motion of the inner cable through the outer sheath, and distorted mechanical linkages that prevented the accelerator's return springs from bringing the engine back to an idle condition once the driver released pressure on the accelerator pedal. In more recent models, drive-by-wire systems include an accelerator pedal assembly that incorporates an electrical potentiometer. As the accelerator pedal is depressed, an increasing electrical voltage is generated and communicated to an engine management control unit. This control system responds by metering a specific quantity of fuel, and opening the vehicle's throttle, to produce an appropriate level of acceleration. Unintended acceleration involving recent vehicle models has been alleged to result from an internal failure of these electro-mechanical systems.

Cruise control is an additional speed-control feature that is installed in many vehicles. These systems allow drivers to select a specific vehicle speed that is then maintained by automatic application or reduction of the vehicle's throttle. Clearly, failure of such a system could potentially result in unintended acceleration; however, there are a number of independent means through which cruise control can be deactivated (e.g. application of the vehicle's brakes).

One other situation that has been found to result in unintended acceleration events is interference with the accelerator pedal by a floor mat in the vehicle. Such occurrences are generally related to multiple stacked floor mats, or floor mats that are not tethered. If a floor mat slides forward, it may bunch up under the brake pedal and over the accelerator. Then, when the driver applies the brakes, the displaced floor mat also causes the accelerator to be depressed.

Prior to 2009, Transport Canada's office of defect investigations received an average of 29 complaints per year alleging unintended acceleration events. Then, in August of that year, a fatal motor vehicle collision took place in San Diego, California. An experienced police officer was driving a Lexus ES350, when the vehicle abruptly accelerated and could not be controlled. [1] A cellular telephone call from a passenger in the subject vehicle, made during the incident, was recorded by a 911 dispatcher, and was posted to the Internet. Subsequent media exposure elevated public awareness of the issue across North America. As a result, in 2009 and subsequent years, there was an abrupt spike in unintended acceleration complaints reported in Canada (see Figure 1).

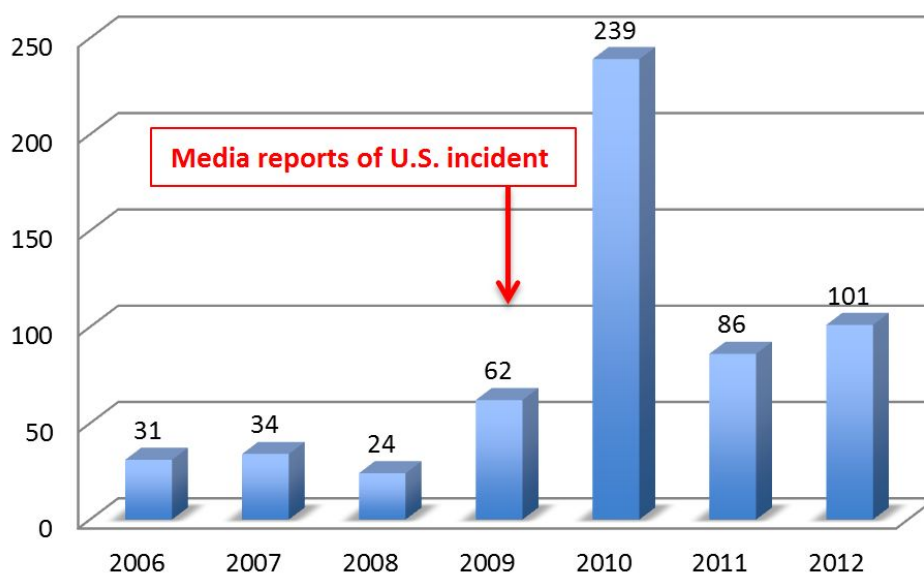


Figure 1. Frequency of Unintended Acceleration Complaints by Year

Historically, UA incidents have been investigated using conventional techniques, including physical inspections of subject vehicles and in-depth interviews with their operators. In addition, some of the involved vehicles were subjected to exhaustive analysis and testing of their control systems in an attempt to identify any fault and/or to replicate the alleged runaway condition. A major Transport Canada study conducted in the late 1980's, using the above approach, and including a review of the results of a number of similar international studies, concluded that the UA phenomenon was essentially due to operator error and was not related to malfunction of any

vehicle control system. [2] In particular, the incidents were determined to have resulted from so-called “pedal error” where drivers were pressing down hard on the accelerator pedal while believing themselves to be fully applying the vehicle's brakes.

In the intervening years, many motor vehicle systems, including engine controls and occupant safety systems, have benefited from rapid advances in electronic technology. Drive-by-wire accelerators and engine management systems have provided automotive manufacturers the ability to make vehicle operation both more reliable and more efficient. Similarly, enhanced occupant protection systems, such as seat belt pre-tensioners and air bags, have afforded greater levels of safety to vehicle users.

The implementation of electronic command and control systems has required the use of sophisticated vehicle sensors and microprocessor-based analytical systems for a range of vehicle functions. In particular, the air bag control system has sensors to detect collision severity, and computer algorithms to determine if the vehicle's air bags should be deployed. These units include the capability to record a range of data parameters related to both deployment and near-deployment events. Typically, these event data recorders (EDR's) capture information relating to both the pre-crash and crash phases of a motor vehicle collision, and thus provide a valuable resource for the in-depth investigation and reconstruction of the circumstances surrounding any given crash. [3]

In particular, the advent of vehicles equipped with EDR's capable of storing a range of pre-collision information, including the status of the brake-light switching circuit, and the disposition of both the accelerator pedal and vehicle throttle, has provided investigators with a new source of objective data, directly related to a driver's actions in using the control pedals. [4] These data may, therefore, be readily applied to the evaluation of complaints of unintended acceleration.

UNINTENDED ACCELERATION COMPLAINTS

The present study commenced in September, 2012 with a retrospective survey of public complaints of unintended acceleration that had been received by Transport Canada over the preceding two years. During the study period, 22 complaints of unintended acceleration were identified as involving vehicles that were equipped with EDR's and where relevant pre-crash data were available. A summary of these cases is shown in Figure 2.

The majority (17) of the subject cases involve allegations of a vehicle suddenly accelerating from a stopped position, or accelerating uncontrollably while initially moving at slow speed. Four incidents were initiated while vehicles were moving at moderate speeds in traffic. A single case involved a vehicle, travelling at high speed on an urban roadway, that collided with the rear of a bus that was slowing in order to pick up passengers. The driver in this case was fatally injured and, consequently, no statement of his pre-crash actions was available.

While the majority of the collisions that ensued were relatively minor, a number of the cases involved high-speed crashes. In five incidents, the frontal collisions were sufficiently severe to result in deployment (D) of the vehicle's air bags. In these cases, the EDR recording relating to

Case No.	Year	Make	Model	Air Bag	ΔV (km/h)	Driver Report
1	2007	Toyota	Yaris	ND	6.6	Entering parking space, low speed, braked, UA, struck tree
2	2007	Toyota	Camry	D	29.8	Entering parking space, moderate braking, UA, struck wall
3	2009	Toyota	Matrix	ND	15.5	Entering garage, UA, struck wall
4	2010	Toyota	Corolla	ND	0.5	Entering parking space, accelerated lightly, UA, struck curb and fence
5	2009	Toyota	Corolla	D	16.1	Moving, accelerated lightly, UA, braked, struck rear of vehicle ahead
6	2010	Toyota	Corolla	ND	4.7	Reversing out of garage, UA, braked, struck vehicle shelter
7	2010	Toyota	Corolla	ND	12.5	Entering parking space, braked, UA, struck post
8	2008	Toyota	Yaris	ND	2.8	Entering parking space, braked, UA, struck concrete column
9	2007	Toyota	Camry	ND	17.5	Entering parking space, UA, struck wall
10	2011	Toyota	Corolla	ND	1.4	Accelerated from stop, UA, both feet on brake, passenger applied emergency brake
11	2010	Toyota	Corolla	D	28.5	Accelerated from stop, UA, braked, struck side of another vehicle
12	2010	Toyota	Corolla	ND	2.8	Started engine, transmission in Park, UA, struck buildings and parked vehicles
13	2012	Jeep	Liberty	D*	3.8	Accelerated from stop, UA, braked, reached high speed, struck building
14	2005	Toyota	Highlander	ND	4.1	Turned into into driveway, UA, braked hard, struck rear of parked vehicle
15	2011	Toyota	Camry	D	52.9	UA from stopped position, reached high speed, struck several vehicles
16	2012	Honda	Civic	D	38	Moving, approaching red traffic light, braked, UA, struck light standard
17	2010	Toyota	Camry	ND	10.1	Entering garage, UA, struck door and door pillar
18	2010	Toyota	Matrix	ND	8.9	Entering garage, UA, struck wall
19	2010	Toyota	Corolla	D	71.7	High speed, urban roadway, impact with rear of a bus that was slowing down
20	2009	Toyota	Corolla	ND	16.6	Positioning vehicle in parking space, braked, UA, struck parked vehicle
21	2006	Toyota	Rav 4	ND	16.6	Moderate speed on a bumpy road, UA, braked to a stop
22	2009	Toyota	Yaris	ND	12.2	Stuck throttle, impacted roadside ditch
* Case No. 13 - Side air bag deployment						

Figure 2. Summary of Public Complaints of UA during the Study Period

the incident was “frozen” and the associated pre-crash data could, therefore, be definitely attributed to the alleged runaway. In non-deployment (ND) cases, EDR recordings are not frozen and so care must be taken when attempting to attribute the stored data to a specific incident. Detailed analyses of the pre-crash data from the case incidents, together with additional material compiled as part of the associated investigations, provided reasonable certainty that the last-recorded event in the EDR was always associated with the alleged UA incident.

Follow-up investigations, conducted either by Transport Canada personnel or by representatives of the vehicle manufacturer, generally involved detailed inspection of a vehicle’s throttle and braking systems. In no case was any mechanical or electrical fault identified with these systems. Furthermore, brake-hold tests, conducted on the case vehicles where possible, demonstrated that the brakes would invariably overpower any degree of throttle application. In a single case, interference between a large, after-market floor mat and the vehicle’s accelerator pedal was identified as the likely cause of the accelerator failing to return to idle after the driver took their foot off the pedal.

A frequent assertion on the part of drivers involved in all the alleged runaway incidents was that, although they applied the brakes, the vehicle did not slow down but, rather, continued to accelerate, with the engine running at high revolutions. Analysis of the downloaded information from the vehicle EDR’s provides an opportunity to test these assertions with objective data, comprising snapshots, at each second, for a period of five seconds prior to the crash that triggered the EDR recording. The relevant data are shown in Figure 3.

Case No.	Brake						Accelerator					
	-5	-4	-3	-2	-1	0	-5	-4	-3	-2	-1	0
6	Off	Off	Off	Off	Off	Off	High	High	High	High	High	High
19	Off	Off	Off	Off	Off	Off	High	High	High	High	High	High
12	Off	Off	Off	Off	Off	Off	High	High	High	High	High	High
15	Off	Off	Off	Off	Off	Off	High	High	High	High	High	High
11	Off	Off	Off	Off	Off	Off	Medium	High	High	High	High	High
10	Off	Off	Off	Off	Off	Off	Medium	High	High	High	High	High
13	Off	Off	Off	Off	Off	Off	High	High	High	Low	High	High
16	Off	Off	Off	Off	Off	Off	Off	Low	High	High	High	High
2	Off	Off	Off	Off	Off	Off	Off	Off	Low	High	High	Medium
3	Off	Off	Off	Off	Off	Off	Off	Off	Off	High	Medium	High
7	Off	Off	Off	Off	Off	Off	Low	Low	Low	Low	High	High
18	Off	Off	Off	Off	On	Off	Off	Low	Low	Medium	Off	High
4	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Medium	High
9	Off	Off	Off	Off	Off	On	Off	Off	Low	Low	High	Off
22	On	On	Off	Off	Off	Off	Medium	Medium	Medium	Medium	Medium	Medium
1	Off	Off	Off	Off	Off	Off	Off	Low	Medium	Low	Low	Medium
17	Off	Off	Off	Off	Off	Off	Off	Off	Off	Low	Medium	Off
14	On	Off	Off	Off	Off	On	Off	Off	Off	Medium	Off	Off
20	Off	Off	Off	Off	Off	On	Low	Low	Low	Low	Low	Low
21	Off	Off	Off	Off	Off	Off	Off	Low	Low	Low	Low	Low
8	Off	Off	Off	Off	Off	Off	Low	Low	Low	Low	Off	Off
5	Off	Off	Off	On	On	On	Off	Off	Off	Off	Off	Off

Figure 3. Pre-Crash EDR Data

In this chart, the cases have been sorted such that the greatest level of application of the accelerator is shown first, with decreasing levels in the subsequent cases.

All of the EDR reports specify the driver's braking action in terms of the status of the brake light switch, i.e. on or off. If the driver does not press on the brake pedal, the brake light switch will remain off. By contrast, almost any level of brake pedal application will result in the brake lights switching on. However, note that this does not imply a specific level of braking effort, i.e. the brake light switch being on does not necessarily mean that the brakes were fully applied.

Since the cases involve different makes and models of vehicles, and not all EDR reports provide precisely the same descriptions of the degree of throttle application, a standard set of such descriptors has been devised for the current paper. In particular, the level of accelerator pedal application by the driver may be designated as being off, low, medium or high. "Off" implies that the driver is not pressing on the accelerator pedal. "Low" and "Medium" reflect slight and moderate levels of pedal application, respectively, while "High" is indicative of the pedal being fully or close to fully depressed. For most vehicles in the sample, voltage readings from a potentiometer in the accelerator pedal assembly were reported in the range 0.78 to 3.70 V. For simplicity, this range of voltage has been sub-divided into three equally-spaced zones to define the levels of accelerator application, namely: Off = 0.78 V, Low = 0.79 to 1.75 V, Medium = 1.76 to 2.72V, and High = 2.73 V and above. Similarly, where accelerator pedal application was reported as a percentage, three equally-spaced zones were used: Off = 0%, Low = 1 to 33%, Medium = 34 to 66%, and High = 67 to 100%.

For ease of reference, the levels of brake and accelerator pedal application have been colour coded. For the brake light switch status, the “On” condition is designated in red, while the “Off” condition has no associated colour. Similarly, a “High” level of accelerator application is represented as dark green, “Medium” in lighter green, and “Low” with the lightest shade of green. The “Off” condition for the accelerator has no associated colour.

It is clear from the chart that many drivers are confused with respect to their actual actions in terms of pressing on their vehicle’s control pedals. In particular, while most of the drivers involved in the subject cases insist that they had applied the brakes and not the accelerator, the EDR data clearly show the opposite to be true. Furthermore, there is a very evident pattern where drivers apply the accelerator fully throughout the series of data points, clearly believing that they are pressing on the brake pedal.

A second pedal application pattern is evident in the current subset of alleged runaway incidents where the brakes are applied in the final interval of the data series ($t = 0s$), and hence immediately prior to the collision event that triggered the EDR recording. In two incidents (Case Nos. 18 and 9) showing this pattern, application of the brakes followed a high or medium application of the accelerator, suggesting that the drivers had realized their error and were attempting to avoid the impending crash. While not evident from the simplified voltage ranges used for the chart, Case No. 20 also follows this pattern, with the accelerator voltage rising from 0.86 at $t = -2s$ to 1.48 V at $t = -1s$. Case No. 14 also involves final-interval brake application subsequent to medium accelerator application; however, here we can see that the vehicle’s brakes were also applied in the first data interval ($t = -5s$). This is a result of the vehicle being stopped in traffic, waiting to turn left into a driveway. The alleged runaway occurred after the driver released the brakes and commenced the turning manoeuvre.

Case No. 18 also involves a late brake application; however, in this incident there is clear confusion on the part of the driver about which control pedal to use. The vehicle was entering a garage attached to a residence. At both $t = -4$ and $-3s$ there was a low level of effort applied to the accelerator followed, in the next data interval, by medium pressure on the accelerator. At $t = -1s$, the engine and vehicle speeds had increased. The driver now released the accelerator pedal and applied the brakes. However, in the final data interval, the driver reversed this action by releasing the brakes and fully applying the accelerator. As a result, the vehicle struck the back wall of the garage.

Case No. 5 is unique in that the brakes were applied in each of the final three data intervals, while no accelerator effort was noted in any of the data intervals. In this case, the vehicle was initially travelling at approximately 44 km/h when traffic ahead slowed down. The driver clearly attempted to brake but was unable to bring the vehicle to a stop to avoid the rear-end collision.

Case No. 22 is similarly unique, showing brake application in the first two data intervals, while there is a medium level of accelerator application in all of the recorded data intervals. In this case a floor mat was interfering with the operation of the accelerator pedal and holding the throttle open.

The general comments noted above are exemplified through the following case studies.

Case No. 1

The female driver of a 2007 Toyota Yaris drove into a parking lot and was in the process of manoeuvring her vehicle into a parking space. She reported that, as she pressed on the brake pedal, the vehicle abruptly accelerated. She then pressed harder on the brakes, but the vehicle accelerated even more. The vehicle mounted a curb and continued forwards towards an adjacent building. The driver steered away from the building, but the front of vehicle came into a minor collision with a number of small trees.

A post-impact inspection of the vehicle did not identify any faults with either the brakes or the throttle system. A brake-hold test confirmed that the brakes would overpower the engine. The vehicle's EDR was downloaded and provided the pre-crash data shown in Figure 4.

Note that, despite the driver's assertions that she pressed on the brake pedal, the brake light switch remains in the off position throughout the recorded incident. Furthermore, there are various levels of effort applied to the accelerator. In particular, note that at $t = -3s$, the accelerator voltage rises to 2.54 volts, and then drops down in the next two time intervals. However, at the trigger point for the EDR recording (approximately $t = 0s$), the accelerator voltage is once again relatively high at 2.70 volts. These two accelerator applications may well correspond to the driver's belief that she initially pressed the brake pedal and subsequently pressed harder.

It can also be noted in the pre-crash data that the various levels of accelerator application are accompanied by expected increases in engine speed (RPM) and vehicle speed, subject to time lags between pedal actuation and engine response.

Case No. 9

A 2007 Toyota Camry was being driven into a parking space on the lot of a retail outlet. The driver indicated that she had her foot on the brake and was in the process of turning right into the parking space. When she was half way into the parking space, the vehicle suddenly surged forward, mounted a curb, and struck a building.

Transport Canada personnel subsequently inspected the vehicle's brake and throttle system and did not identify any problems. An On-Board Diagnostics (OBD) scan did not reveal any fault codes. A brake-hold test confirmed that the brakes were capable of holding the vehicle under a wide-open throttle. The vehicle's EDR was downloaded. The stored pre-crash data are shown in Figure 5.

These data show that the vehicle was initially travelling at approximately 12 km/h ($t = -5s$), with no brake application, and no accelerator application. At $t = -3s$, the accelerator voltage rises from 0.78 volts to 0.82 volts, and subsequently to 1.48 and 3.05 volts, indicating rapidly increasing pedal application. As a result, both the engine RPM and the vehicle speed can be seen to increase, with the vehicle's speed reaching 36 km/h at the trigger point for the EDR recording. In the final data interval, the accelerator pedal is shown to have been released and the brakes applied.

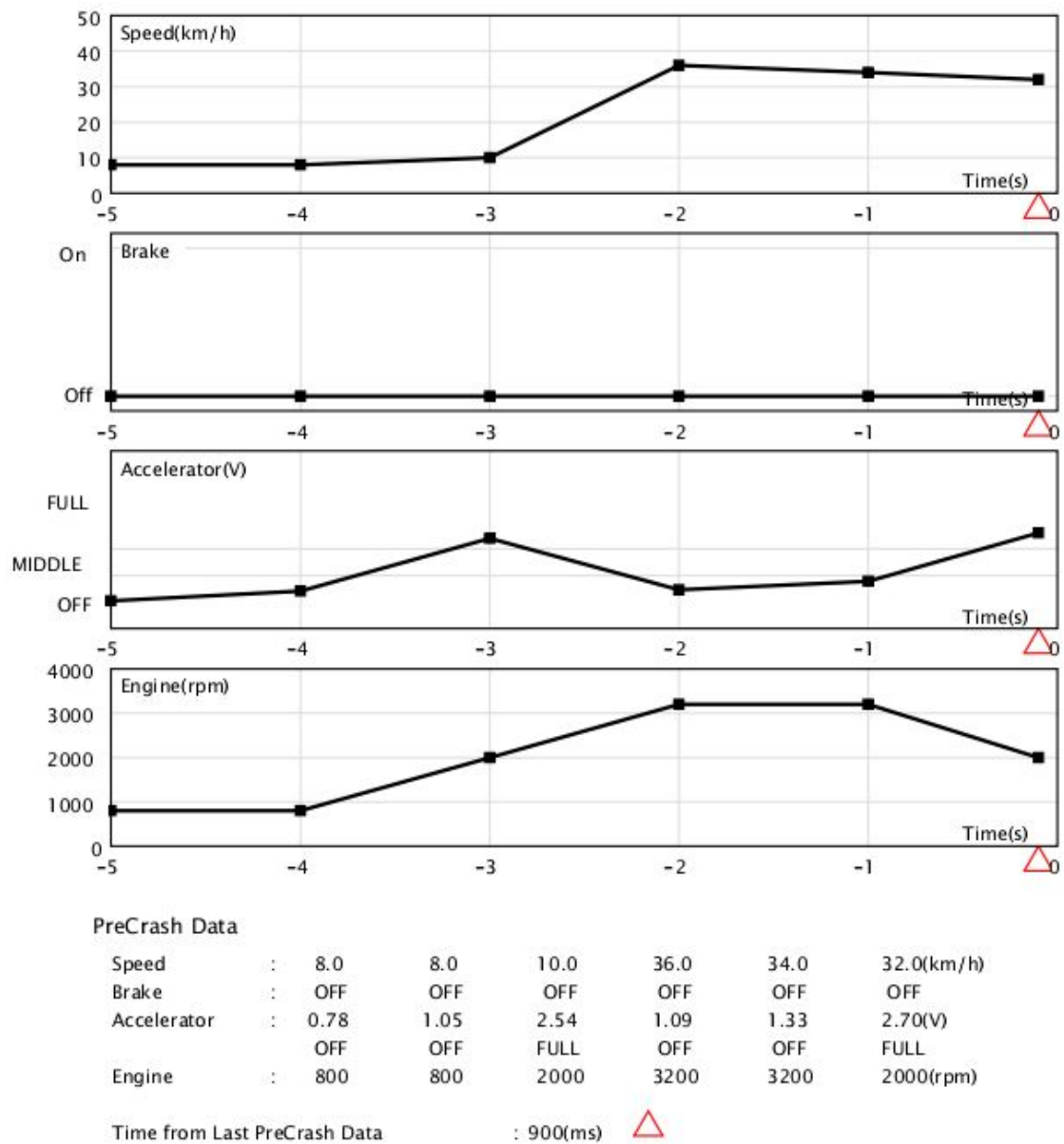


Figure 4. Pre-Crash Data for Case No. 1

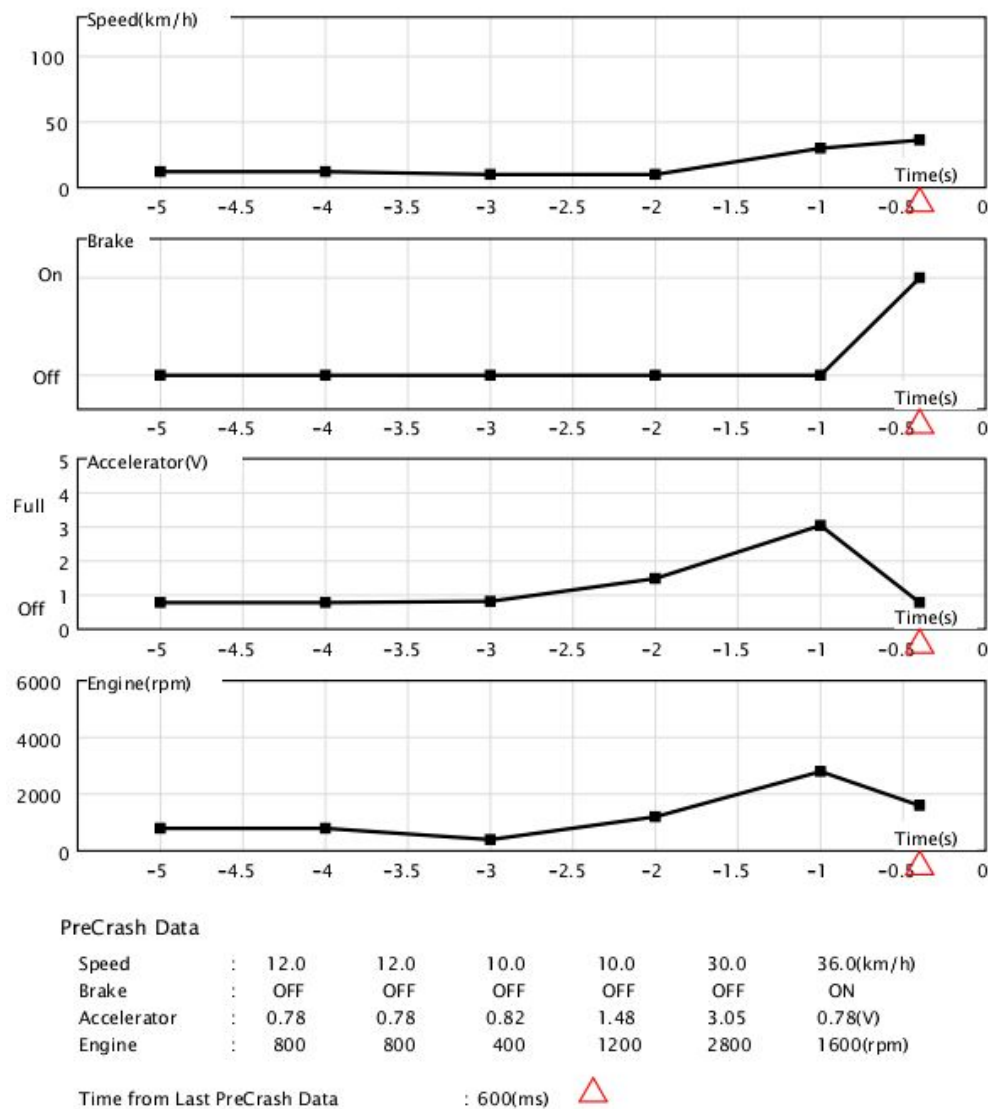


Figure 5. Pre-Crash Data for Case No. 9

Case No. 15

The case vehicle, a 2011 Toyota Camry was being operated as a taxi. The male driver arrived at a restricted marshaling area and stopped at a gate controlling access. After obtaining access through the gate, the driver alleges that the vehicle abruptly and very rapidly accelerated. The vehicle continued forward, travelling at high speed, until it impacted a line of parked vehicles and contacted an individual standing next to the struck vehicles. The progress of the fast-moving vehicle just prior to the collision was captured by a security camera.



Figure 6. Damage to the 2011 Toyota Camry

As can be seen in Figure 7, in the five seconds prior to impact, the vehicle accelerated from 70 km/h to 92 km/h. At no time did the driver apply the brakes. By contrast, in each data interval the recorded accelerator voltage was approximately 3 volts, showing a high level of accelerator pedal application.

Pre-Crash Data, -5 to 0 seconds (Most Recent Event, TRG 2)

Time (sec)	-4.7	-3.7	-2.7	-1.7	-0.7	0 (TRG)
Vehicle Speed (MPH [km/h])	43.5 [70]	47.2 [76]	49.7 [80]	53.4 [86]	55.9 [90]	57.2 [92]
Brake Switch	OFF	OFF	OFF	OFF	OFF	OFF
Accelerator Rate (V)	3.09	3.13	3.01	2.93	3.01	3.01
Engine RPM (RPM)	4,400	4,800	4,800	5,200	5,200	5,200

Figure 7. Pre-Crash Data for Case No. 15

Case No. 22

A 2009 Toyota Yaris was travelling at approximately 40 km/h and approaching a slower-moving vehicle. The female driver of the Yaris accelerated to pass the vehicle ahead; however, when she released the accelerator pedal, the vehicle continued to accelerate.

The driver pumped the accelerator trying to free the pedal. When this failed, she indicated that she attempted depressing the clutch, braking, and downshifting the transmission. The driver did not believe that any of her actions slowed the vehicle. Finally, she unbuckled her seat belt, steered to the right, and jumped out of the vehicle. The vehicle egressed from the roadway and impacted the embankment of the adjacent ditch.

The case vehicle was subsequently inspected by a Toyota engineer. The accelerator pedal and throttle assembly were examined and were found to be functioning normally. Diagnostic tests of the electrical system revealed no faults. A road test of the vehicle was conducted with all systems proving to perform normally.

One issue that was identified in the vehicle inspection was the presence of a large, after-market floor mat in the driver's position. This mat was not fixed to the vehicle floor in any manner, and had moved over top of the original equipment mat. This secondary floor mat probably interfered with the proper return of the accelerator pedal and held the throttle open resulting in the runaway condition reported by the driver.

Pre-Crash Data, -5 to 0 seconds (Most Recent Event, TRG 1)

Time (sec)	-4.2	-3.2	-2.2	-1.2	-0.2	0 (TRG)
Vehicle Speed (MPH [km/h])	24.9 [40]	23.6 [38]	27.3 [44]	37.3 [60]	65.9 [106]	55.9 [90]
Brake Switch	ON	ON	OFF	OFF	OFF	OFF
Accelerator Rate (V)	2.34	2.34	2.23	2.23	2.19	2.19
Engine RPM (RPM)	2,400	2,400	3,200	4,400	5,200	5,200

Figure 8. Pre-Crash Data for Case No. 22

The vehicle's EDR was downloaded. The associated pre-crash data are shown in Figure 8. In this chart, it can be seen that, in every data interval, the voltage reading for the accelerator pedal is above 2 volts, i.e. considerably greater than the 0.78 volts that would normally indicate no accelerator pedal application. The results of this steady accelerator input are reflected in the increases in both engine speed and vehicle speed over time.

It is also worth noting that at both $t = -4.2s$ and $t = -3.2s$, the brake light switch is shown to have been on, indicating that in these time intervals the driver was pressing on the brake pedal. Furthermore, during this time period, the vehicle speed was reduced from 40 km/h to 38 km/h, showing that the braking procedure was somewhat effective in decelerating the vehicle.

In particular, the transient brake application noted above, occurring at the same time as the relatively-steady accelerator input, is highly suggestive that floor mat interference with the accelerator pedal was indeed a factor in the case incident.

DISCUSSION AND CONCLUSIONS

The series of cases presented in this paper have all been subject, where possible, to conventional investigative techniques, including interviews with the vehicle operators, physical inspection and testing of vehicle components and control systems, and diagnostic tests on vehicle systems. None of these procedures identified any problems with the design or performance of any vehicle control system.

The majority of the cases in our sample involve Toyota vehicles; however, this is largely related to the high level of media attention that this manufacturer's products received following the fatal crash in the United States in 2009. Following the noted incident, the National Highway Traffic Safety Administration (NHTSA) launched an extensive investigation into the complaints of unintended acceleration that they had received. Furthermore, the National Aeronautics and Space Administration (NASA) was tasked to review the potential for the occurrence of unintended acceleration through failure of the engine's electronic control systems. NHTSA's conclusion was that "...the inspections indicated that many UA incidents continue to occur as the result of the driver's inadvertent application of the accelerator pedal rather than the brake or simultaneous application of the accelerator and brake". [5] NASA's analyses of Toyota's electronic throttle system did not identify any hardware or software problem that could either result in a large throttle opening sufficient to cause a UA condition or inhibit the brakes. [6]

Since the specific subset of public complaints that have been studied here all involve vehicles equipped with event data recorders, for which pre-crash data relevant to the subject incident were available, the conventional complaint analyses have been supplemented by a detailed evaluation of the data captured by the on-board crash recorders.

In all of the cases studied, data from the EDR's proved to be a valuable tool in understanding the specific actions of vehicle drivers, even when individuals were evidently confused as to what had actually transpired. For example, in one case incident, not only did the involved driver claim that, after starting the vehicle's engine, he had not applied the accelerator, he also insisted that he had not shifted the transmission out of park! However, data from the EDR indicated conclusively that, during the case incident, the transmission was in drive, the brakes were never applied, and the accelerator was applied fully over the entire five-second period of data capture.

In fact, claims of brake application were frequently disproved through the objective evidence of the EDR that the brakes had never been applied in the period leading up to the collision event. Furthermore, there was frequently definitive evidence that, rather than the driver's foot being on the brake, it was actually planted on the accelerator pedal. Thus, EDR's have proven a very capable assistant in positively identifying "pedal error" in allegations of powered runaways. In addition, the recorded data usually provided further confirmation of this underlying causation of the incidents in question through analysis of the associated readouts of engine speed (RPM) and vehicle speed (km/h).

While, as noted above, the data now available from EDR's provide considerable augmentation of conventional investigative methods, a useful adjunct would be the inclusion of an on-board clock, to assign date-time stamps to individual records, and thus facilitate direct attribution of data elements to specific aspects of both deployment and non-deployments events.

The wide occurrence of misapplication of the vehicle's control pedals that resulted in crashes, with the consequent potential for property damage, personal injury, and even death, are indicative that greater public education is required to raise drivers' awareness of the need to familiarize themselves with the available controls, and the appropriate steps to follow should unintended acceleration occur. In particular, drivers need to know the options available to them in such circumstances which typically include: application of the brakes (which will overpower the engine), shifting the transmission to neutral, and turning the ignition to the "Off" or "Accessory" position (so as to disable the engine but not lock the steering wheel). [7]

The present study clearly shows that the information available from EDR's can provide an objective means of determining causation in unintended acceleration incidents, and facilitate the resolution of complaints of vehicle malfunctions by both manufacturers and government safety agencies. Furthermore, the data captured can demonstrate to the individuals concerned how an event occurred and thus dispel the uncertainty and doubt associated with their often imperfect recollection of circumstances which usually transpire over a short time period and are frequently traumatic.

These same data also have considerable utility for other interested parties. For example, police, vehicle insurers, and lawyers can use the information as an adjunct to conventional data sources in order to resolve conflicting accounts of collision situations. Similarly, coroners will find utility in such objective data sources that can be used to give an account of a deceased driver's actions (as was the situation in Case No. 19) and either obviate the need for a public inquest or provide substantive information for use by the coroner's jury.

In addition to the foregoing uses of the data available from EDR's, we should note that these devices provide a wealth of objective information, not only on driver actions, but also on the performance of a multitude of vehicle control systems, and specific parameters related to real-world crash situations. These features provide new sources of data to safety researchers, automotive designers, government agencies and others, and will provide valuable input into the development of enhanced educational services, advanced safety systems, and improved safety regulations as we move forward.

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The conclusions reached, and opinions expressed, in this paper are solely the responsibility of the authors. Unless otherwise stated, they do not necessarily represent the official policy of Transport Canada.

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