CRASH PULSE DATA FROM EVENT DATA RECORDERS IN RIGID BARRIER TESTS

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ABSTRACT

In recent years, major advances in field data collection and analysis have been achieved through the integration of real-world vehicle crash data captured by on-board, electronic, event data recorders (EDR's). For some time, data has been publicly available from EDR's in General Motors, Ford, and Chrysler vehicles. Recently, Toyota has provided a proprietary tool through which researchers can access EDR's installed in their vehicles. The current study looks at the crash data that are available and explores the accuracy of this information. The study uses a series of staged collisions with EDR-equipped vehicles and compares data downloaded from these devices to equivalent information captured by laboratory instrumentation. Full-frontal crash tests, conducted by Transport Canada, at 48 km/h into a rigid barrier are used. The results show generally good agreement between the two datasets, with some limitations in the EDR-reported data being noted. These comparisons of data obtained from on-board vehicle EDR's, with equivalent information collected using sophisticated laboratory instrumentation, provide a valuable measure of confidence in the use of similar data collected from real-world events.

INTRODUCTION

Event data recorders capture information about the status of various vehicle safety systems, such as seat belt use and air bag deployment; details of pre-crash driver actions such as inputs to the throttle and brake, and the nature of the crash pulse in the form of the vehicle's velocity change and/or acceleration time history. [1]

The objective collision data provided by EDR's have proven useful to a variety of interest groups, including automobile manufacturers, government regulators, safety researchers, law enforcement personnel, vehicle insurers, and the legal community. The data have allowed vehicle safety systems to be refined, vehicle regulations to be enhanced, safety-related defects to be identified and corrected, and have provided the basis for the resolution of court cases and insurance claims. [2]

General Motors Corporation (GM) pioneered the installation of EDR's in its vehicles, and was the first manufacturer to provide access to the data captured by these devices through a publicly-available crash data retrieval (CDR) tool. [3] In 2003, Ford Motor Company was the second manufacturer to adopt the CDR system for its EDR's. Subsequently, in 2008, Chrysler announced its use of the same tool for the EDR's in its vehicles.

Toyota started phasing EDR's into certain of its vehicles in 2001, and all vehicles from the 2007 model year forward are equipped with these devices. [4] While a publicly-available crash data retrieval tool is not yet available for use with Toyota EDR's, the company has provided prototype units to both Transport Canada and the National Highway Traffic Administration (NHTSA). It is one of the units provided to Transport Canada that has been used in the present work.

The study compares crash pulses recorded by EDR's installed in vehicles subject to crash testing to equivalent data captured by the test laboratory's instrumentation. For each test vehicle, the report

from the data retrieval tool provides the change in vehicle's velocity (delta-V) or its acceleration as a function of time. These data are provided in either 1 ms or 10 ms increments. For any given test, the laboratory data consist of the vehicle's acceleration profile during the crash on a much finer time scale (0.1 ms). Consequently, in order to allow direct and consistent comparisons, the laboratory data have been integrated to provide an equivalent profile of the vehicle's change in velocity to that produced by the EDR for each GM, Ford and Toyota vehicle. In the case of Chrysler, where only acceleration is recorded, integration of the acceleration data for both the EDR, and the laboratory data, were conducted in order to provide similar comparisons of delta-V.

An additional point of comparison is provided by some of the pre-crash data that are captured by the EDR's. In particular, the units record the pre-impact vehicle speed. Depending on the manufacturer, and the specific type of EDR, these values are last taken between 0.1 s and 1 s prior to algorithm enable (AE) in the vehicle's air bag control module. The initial speeds recorded by the EDR's were compared to equivalent data measured by the laboratory instrumentation.

Similar research conducted on General Motors' vehicles has been reported previously [5], while other prior work has included both GM and Toyota vehicles. [6,7].

CRASH TEST METHODOLOGY

Data were obtained from a series of staged collisions conducted by Transport Canada that involved vehicles equipped with event data recorders. In particular, full frontal rigid barrier (FFRB) crash tests were performed at a nominal impact speed of 48 km/h.

The instrumentation used for the staged collisions conducted at Transport Canada's Motor Vehicle Test Centre included accelerometers with a sampling frequency of 10 kHz. The test vehicle was instrumented with several such accelerometers, the most relevant of which, for the present purposes, were units mounted on the floor at the base of the left and right B-pillars, and on the central tunnel, at the vehicle's centre of gravity. These three accelerometers were in the closest proximity to the original-equipment event data recorders which form part of the air bag control module (ACM) located inside the passenger compartment.

A tape switch mounted on the vehicle's front bumper was used to establish the time of first contact with the barrier structure. The impact speed of the vehicle was captured by means of an external speed trap.

All the data from the laboratory instrumentation were sampled over 400 ms, and subsequently filtered in accordance with SAE Recommended Practice J221-1. [8] For each test vehicle, the acceleration data were integrated to provide the vehicle's change in velocity over the crash period.

Figure 1. Full frontal rigid barrier crash test.

Figure 2. Crash tested vehicle.

For General Motors, Ford and Chrysler vehicles, the change in velocity or the acceleration profile recorded by the on-board EDR were retrieved using a Bosch Diagnostics' Crash Data Retrieval tool. [9].

In the case of Toyota vehicles, the changes in velocity recorded by the on-board EDR's were retrieved using Toyota's Read Out Tool (ROT).

DATA PROCESSING

In processing the data from the EDR's the following manufacturer-specific procedures should be noted:

General Motors

For General Motors' vehicles, the vehicle delta-V is reported at 10 ms intervals. For deployment events, the EDR will record data up to 70 ms before the deployment criteria are met, and up to 220 ms after these criteria are met. Prior to impact, zero values of delta-V are recorded by the EDR. The equivalent laboratory data are synchronized to the actual time of initial impact through a tape switch mounted on the vehicle's front bumper. Consequently, in order to better match the timing sequences between the two datasets, any leading zeros in the delta-V data from the EDR's were discarded. The first non-zero value of delta-V was assigned to t = 10 ms.

Ford

Some Ford EDR's are unique in providing both delta-V and acceleration values at 1 ms intervals from a point approximately 100 ms prior to a nominal time-zero, and subsequently for a further 100 ms. While the downloaded delta-V values were plotted directly on the charts, the acceleration data were used to identify an appropriate time-zero.

Examination of the following figures illustrates the procedure adopted. Figure 3 shows the acceleration pulse recorded by the EDR. The acceleration (black line) initially remains close to zero, after which the onset of the crash pulse is quite apparent. In particular, after remaining between 0 and -1 g for almost 95 ms, the acceleration abruptly goes to -4.00 g at an implied time of t = -6 ms, and subsequently to -9.60 g at t = -5 ms. These specific values were obtained from the tabular EDR data as shown in Figure 4. Consequently, in this instance, a time shift of 7 ms was introduced to process the EDR data.

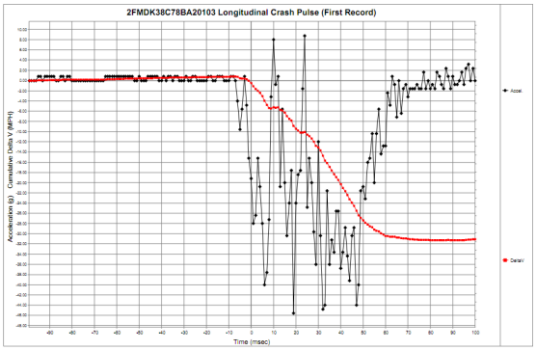

Figure 3. Crash pulse for 2008 Ford Edge (TC08-120).

Time (msec)	Recorded Vehicle Longitudinal Acceleration (g)
-10	0.00
-9	0.80
-8	0.80
-7	0.00
-6	-4.00
-5	-9.60
-4	-5.60
-3	0.80
-2	-4.80
-1	-15.20
0	-19.20
1	-28.00
2	-26.40
3	-15.20
4	-20.80
5	-28.00
6	-40.00
7	-37.60
8	-27.20
9	-3.20
10	8.00

Figure 4. Extract from the acceleration data for Test No. TC08-120.

Toyota

As for General Motors' vehicles, Toyota EDR's also report delta-V in 10 ms increments; however, no leading zeros were observed in any of the EDR readouts from these vehicles. The downloaded Toyota delta-V values were therefore used directly as obtained from the readout tool.

Chrysler

As noted earlier, Chrysler EDR's do not give direct readouts of delta-V, and provide only acceleration data. Two types of modules are employed, one manufactured by TRW Automotive and the other by Continental Corporation [10]. The Continental modules report acceleration over a period of 250 ms following AE. The TRW modules provide vehicle acceleration from approximately 100 ms before a nominal time-zero, and subsequently for a further 150 ms. Consequently, in order to refine time-zero, a similar procedure to that adopted for the Ford EDR's was applied to the TRW modules

RESULTS

In all of the charts that follow, the vehicle's delta-V computed from the accelerometer installed at the vehicle's centre of gravity is annotated in the form TC08_119_CG_DV, where TC08_119 refers to the number assigned to a specific crash test.

Similarly, the delta-V computed from the accelerometer mounted at the left-side B-pillar is designated as TC08_119_LS_DV, and that from the accelerometer mounted at the right-side B-pillar as TC08_119_RS_DV.

The delta-V values obtained from the vehicle's EDR are plotted in the graph annotated in the form TC08_119_EDR_DV.

A similar annotation convention has been adopted for the test results for all of the other vehicle manufacturers.

General Motors Vehicles

Four different General Motors models, namely the 2008 Chevrolet Malibu, the 2009 Pontiac G8 and Wave, and the 2008 Saturn Vue, were crash tested as shown in Table 1.

Table 1. Test Matrix for GM Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC08-119	2008 Chevrolet Malibu	47.77
TC09-142	2009 Pontiac G8	47.55
TC09-140	2009 Pontiac Wave	47.70
TC09-213	2009 Pontiac Wave	47.93
TC08-126	2008 Saturn Vue	47.79

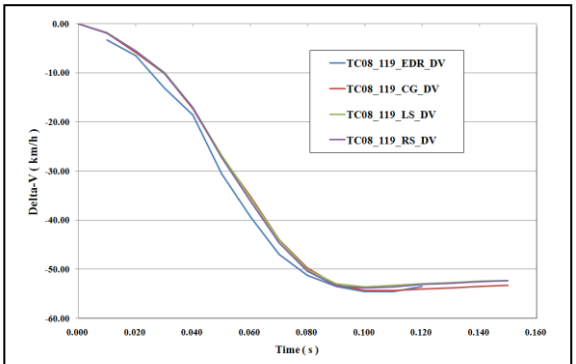

Figure 5. 2008 Chevrolet Malibu (TC08-119).

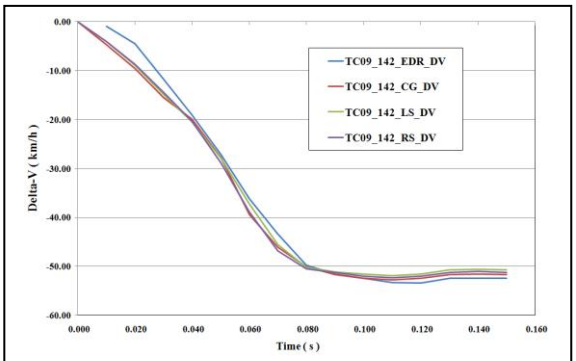

Figure 6. 2009 Pontiac G8 (TC09-142).

Figure 7. 2009 Pontiac G8 (TC09-142).

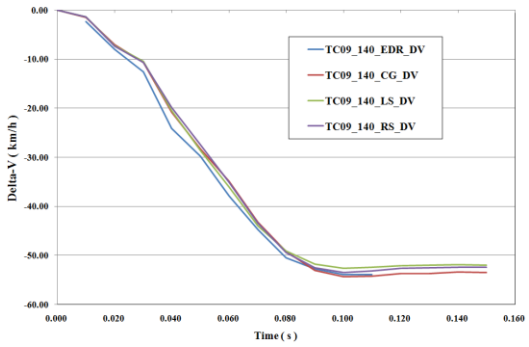

Figure 8. 2009 Pontiac Wave (TC09-140).

Figure 9. 2009 Pontiac Wave (TC09-140).

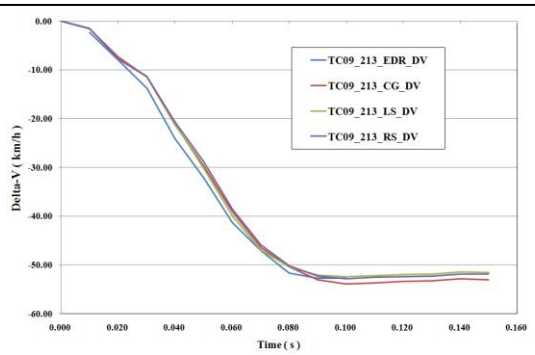

Figure 10. 2009 Pontiac Wave (TC09-213).

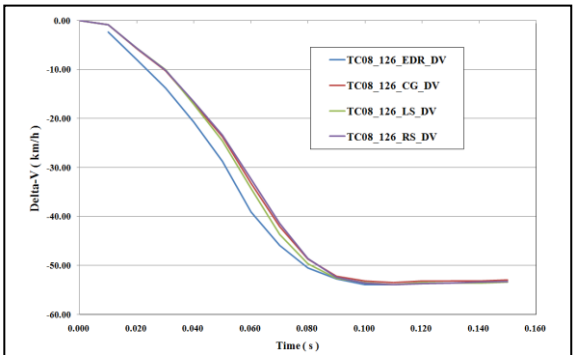

Figure 11. 2008 Saturn Vue (TC08-126).

Ford Vehicles

Three different Ford models were crash tested as shown in Table 2.

Table 2. Test Matrix for Ford Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC08-120	2008 Ford Edge	47.88
TC08-121	2008 Ford Focus	47.66
TC09-128	2009 Ford F150	47.84

The resulting delta-V plots are shown in the following figures.

As noted earlier, the delta-V values obtained directly from the vehicle's EDR are annotated in the form TC08_120_EDR_DV.

For the 2008 Ford Edge and Ford Focus, pre-impact acceleration data allowed time-zero to be refined using the procedure noted earlier. In these cases, graphs with annotations similar to TC08_120_ EDR_DV_S have had a time shift introduced into the delta-V data stream.

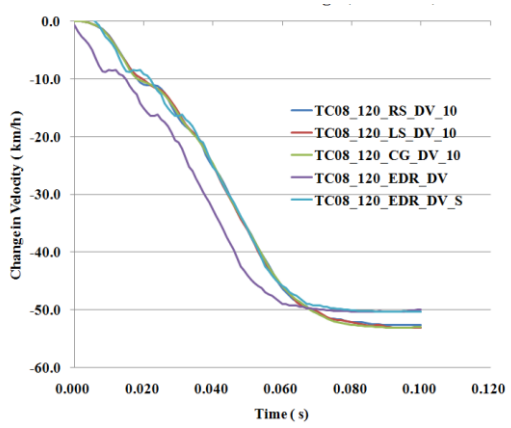

Figure 12. 2008 Ford Edge (TC08-120).

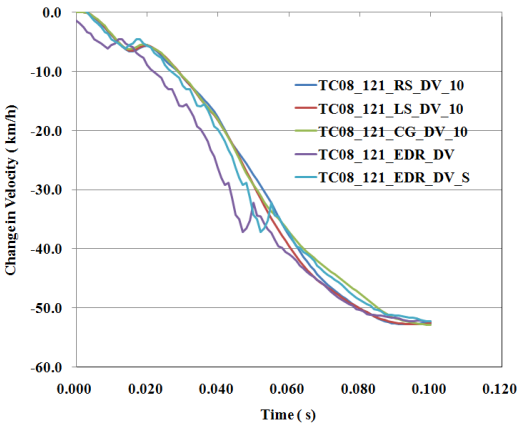

Figure 13. 2008 Ford Focus (TC08-121).

Figure 14. 2008 Ford Focus (TC08-121).

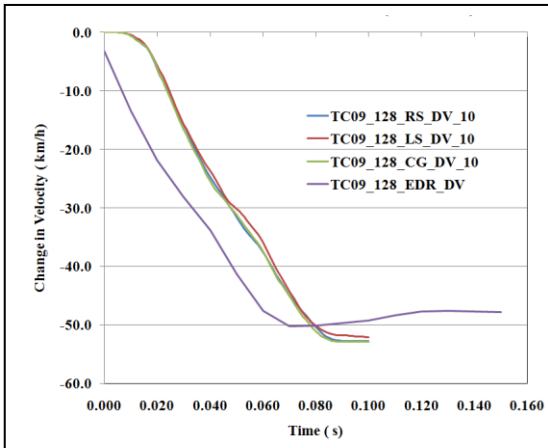

Figure 15. 2009 Ford F-150 (TC09-128).

Toyota Vehicles

Four different Toyota models were crash tested as shown in Table 3.

Table 3. Test Matrix for Toyota Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC05-119	2005 Toyota Camry	47.93
TC09-244	2009 Toyota Corolla	47.85
TC10-149	2010 Toyota Corolla	47.97
TC09-145	2009 Toyota Matrix	47.70
TC09-219	2009 Toyota Matrix	48.01
TC09-262	2009 Toyota Matrix XRS	47.91
TC09-146	2009 Toyota Venza	47.96

The resulting delta-V plots are shown in the following figures:

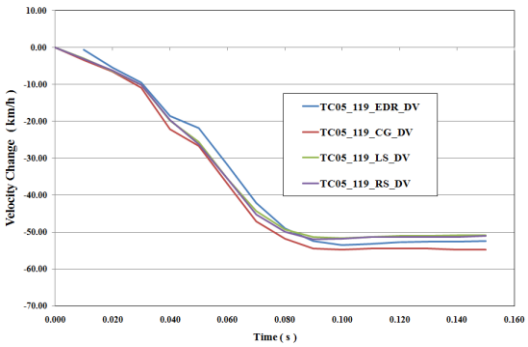

Figure 16 2005 Toyota Camry (TC05-119).

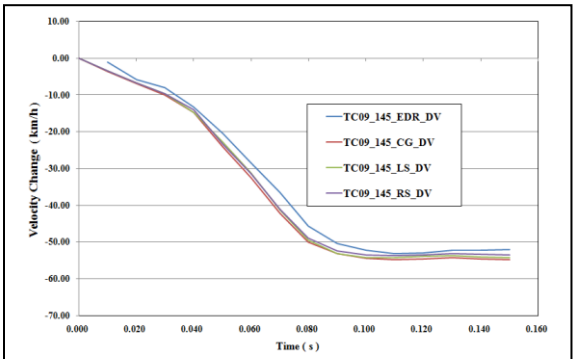

Figure 19. 2009 Toyota Matrix (TC09-145).

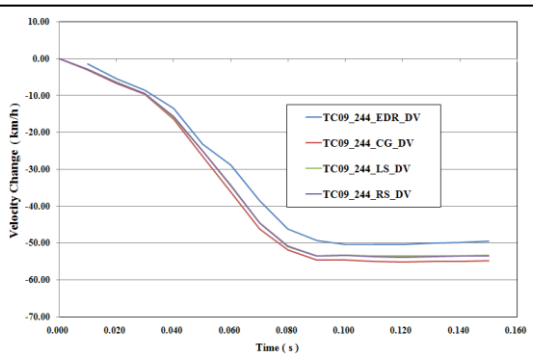

Figure 17. 2009 Toyota Corolla (TC09-244).

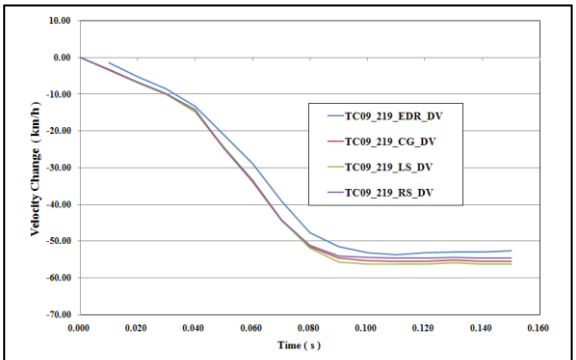

Figure 20. 2009 Toyota Matrix (TC09-219).

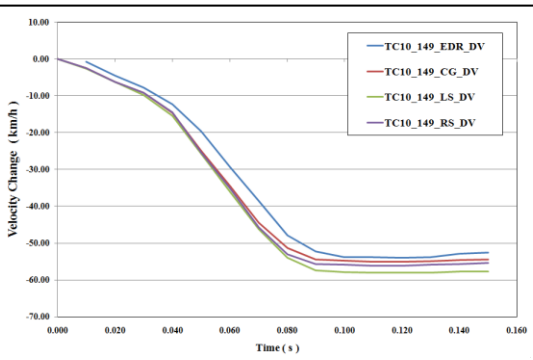

Figure 18. 2010 Toyota Corolla (TC10-149).

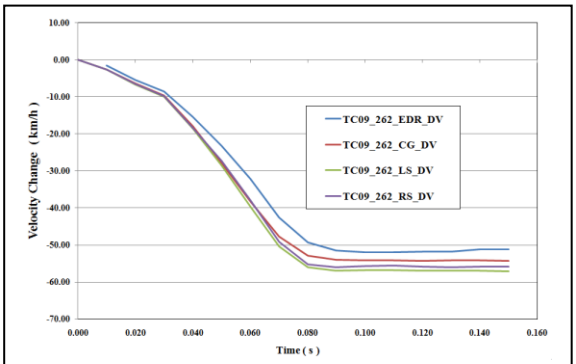

Figure 21. 2009 Toyota Matrix XRS (TC09-262).

Figure 22. 2009 Toyota Venza (TC09-146).

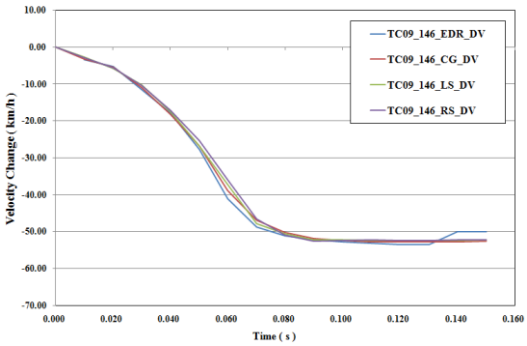

Figure 23. 2009 Toyota Venza (TC09-146).

Chrysler Vehicles

Five different Chrysler models were crash tested as shown in Table 4.

Table 4. Test Matrix for Chrysler Vehicles

Test No.	Test Vehicle	Test Speed (km/h
TC09-126	2009 Dodge Journey	47.90
TC07-218	2007 Jeep Compass	47.84
TC08-131	2008 Dodge Avenger	47.80
TC09-125	2009 Chrysler Aspen	47.69
TC09-127	2009 Dodge Ram	47.66

For the Chrysler vehicles, time shifts were introduced into the delta-V plots in cases where the modules provided pre-impact acceleration data. In the following charts, graphs with annotations such as TC07_218_EDR_DV relate to non-time shifted delta-V data, while TC07_218_EDR_DV _S indicates that a time shift was introduced into the delta-V data stream.

It should be noted that values of delta-V for these vehicles were calculated through integration of the acceleration data stored in the EDR's. The use of a value for time-zero different from that nominally identified by the EDR introduces a number of additional acceleration values into the calculation. The result of adopting such a procedure is, therefore, not only to time shift the curve, but also to change the shape of the curve itself.

The resulting delta-V plots are shown in the following figures.

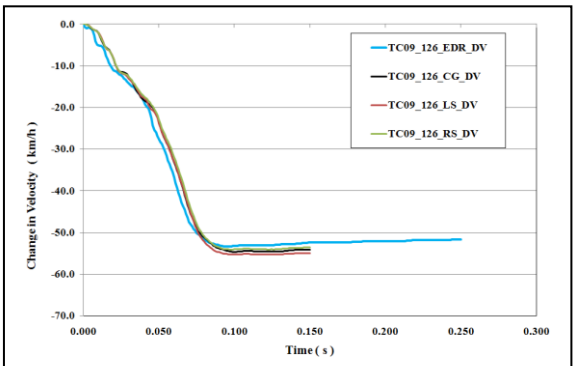

Figure 24. 2009 Dodge Journey (TC09-126).

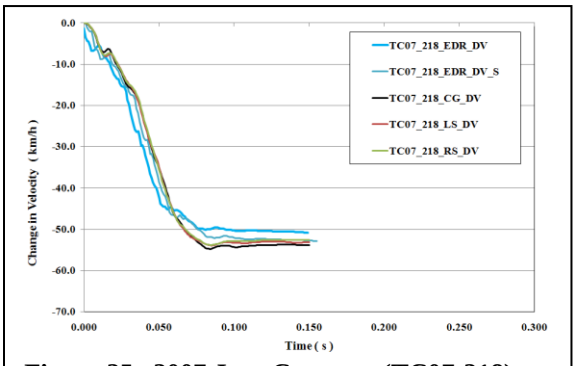

Figure 25. 2007 Jeep Compass (TC07-218).

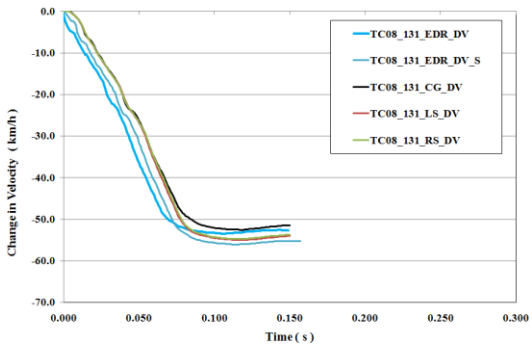

Figure 26. 2008 Dodge Avenger (TC08-131).

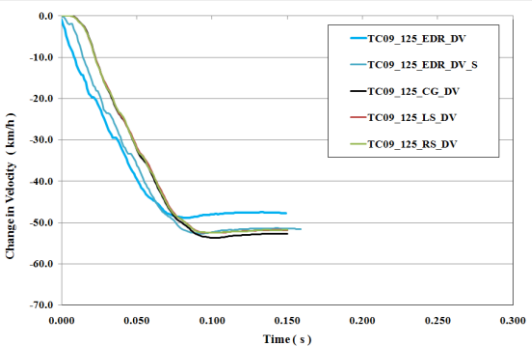

Figure 27. 2009 Chrysler Aspen (TC09-125).

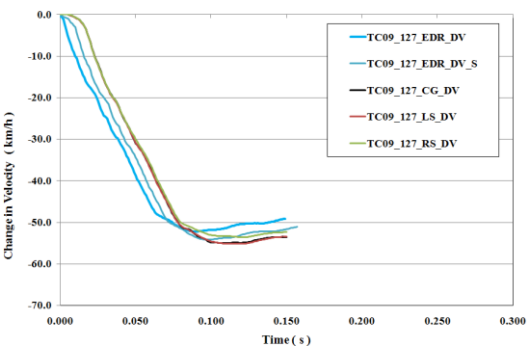

Figure 28. 2009 Dodge Ram (TC09-127).

Figure 29. 2009 Dodge Ram (TC09-127).

DISCUSSION

Comparisons of both the initial vehicle speed and the change in velocity (delta-V) between the values recorded by the EDR's and those measured by laboratory instrumentation are shown for each vehicle tested in Figure 30.

The initial speeds of the test vehicles as obtained from the pre-crash data recorded by the EDR's were generally within 2 km/h (4%) of the values measured by the crash test laboratory's instrumentation.

Delta-V values reported by the EDR's in General Motors' vehicles also closely matched the data captured by the test instrumentation. The graphs of the delta-V profiles obtained from the EDR's and those from all three laboratory accelerometers (Figures 5-6, 8 and 10-11) are all closely aligned. The tabular data shows that the differences in the maximum delta-V's ranged from 0.47 km/h (0.88%) to -1.13 km/h (-2.09%)

For the Ford vehicles tested, the delta-V curves for the EDR data generally matched those developed from the laboratory data (Figures 12, 13 and 15). For Test No. TC08-120 and TC08-121, pre-acceleration data allowed time-zero to be refined. In these cases,

Test No.	Test Vehicle	Test Speed (km/h	Initial Speed			Delta-V			
			EDR (km/h)	Difference (km/h	Difference (%)	Laboratory (km/h)	EDR (km/h)	Difference (km/h	Difference (%)
TC08-119	2008 Chevrolet Malibu	47.77	46.67	-1.10	-2.35	-54.42	-54.52	0.10	0.18
TC09-142	2009 Pontiac G8	47.55	46.67	-0.88	-1.88	-52.90	-53.37	0.47	0.88
TC09-140	2009 Pontiac Wave	47.70	46.67	-1.03	-2.20	-54.44	-53.91	-0.52	-0.96
TC09-213	2009 Pontiac Wave	47.93	46.67	-1.26	-2.70	-53.88	-52.75	-1.13	-2.09
TC08-126	2008 Saturn Vue	47.79	46.67	-1.12	-2.40	-53.55	-53.91	0.37	0.69
			Average	-1.08	-2.31		Average	-0.14	-0.26
TC08-120	2008 Ford Edge	47.88	47.15	-0.73	-1.54	-53.11	-50.37	-2.74	-5.16
TC08-121	2008 Ford Focus	47.66	46.83	-0.83	-1.77	-53.26	-52.29	-0.97	-1.83
TC09-128	2009 Ford F150	47.84	46.03	-1.81	-3.94	-53.09	-50.22	-2.87	-5.41
			Average	-1.11	-2.39		Average	-1.68	-3.16
TC05-119	2005 Toyota Camry	47.93				-55.17	-53.43	-1.74	-3.16
TC09-244	2009 Toyota Corolla	47.85	46	-1.85	-3.87	-55.13	-50.37	-4.75	-8.62
TC10-149	2010 Toyota Corolla	47.97	46	-1.97	-4.11	-55.16	-53.91	-1.24	-2.26
TC09-145	2009 Toyota Matrix	47.70	46	-1.70	-3.56	-54.80	-53.11	-1.69	-3.09
TC09-219	2009 Toyota Matrix	48.01	46	-2.01	-4.19	-55.50	-53.75	-1.75	-3.16
TC09-262	2009 Toyota Matrix XRS	47.91	46	-1.91	-3.99	-54.29	-51.98	-2.31	-4.26
TC09-146	2009 Toyota Venza	47.96	46	-1.96	-4.09	-52.96	-53.43	0.47	0.89
			Average	-1.90	-3.97		Average	-1.86	-3.38
TC09-126	2009 Dodge Journey	47.90	46	-1.90	-3.97	-54.60	-53.34	-1.27	-2.32
TC07-218	2007 Jeep Compass	47.84	47	-0.84	-1.76	-54.73	-52.85	-1.87	-3.42
TC08-131	2008 Dodge Avenger	47.80	48	0.20	0.42	-52.51	-56.11	3.59	6.85
TC09-125	2009 Chrysler Aspen	47.69	47	-0.69	-1.45	-53.71	-52.71	-1.00	-1.86
TC09-127	2009 Dodge Ram	47.66	47	-0.66	-1.38	-55.03	-54.17	-0.87	-1.57
			Average	-0.78	-1.63		Average	-0.28	-0.47

Figure 30. Comparisons of initial speed and delta-V from vehicle EDR's and laboratory instrumentation.

the time-shifted delta-V plots were more closely aligned with those produced from the test centre's accelerometers. No similar accommodation was possible for Test No. TC09-128 since this EDR only provided cumulative delta-V. The maximum values of delta-V from the Ford EDR's that are shown in Figure 30 were extracted directly from the tabular data provided in the data retrieval reports. The differences in these delta-V's and those calculated from the laboratory data ranged between -0.97 km/h (-1.83%) and -2.87 km/h (-5.41 km/h). On average the difference was -1.68 km/h (-3.16%)

The shape and range of the delta-V curves obtained from the EDR's in Toyota vehicles (Figures 16-21 and Figure 23) are in good agreement with the laboratory data. The differences in delta-V for the Toyota vehicles tested ranged from 0.47 km/h (0.89%) to -4.75 km/h (-8.62%). On average the difference was -1.86 km/h (-3.38%).

For the Chrysler vehicles tested, the delta-V curves for the EDR data generally matched those developed from the laboratory data (Figures 24-28). As noted above for Ford vehicles, where pre-acceleration data allowed time-zero to be refined, the time-shifted delta-V plots for the Chrysler vehicles were more closely aligned with those produced from the test centre's accelerometers. As noted earlier, the shapes of the time-shifted delta-V curves for the Chrysler vehicles were also modified as a result of the calculations on a greater number of acceleration values. The values of the maximum delta-V's for the Chrysler vehicles shown in Figure 30 are for the time shifted calculations, i.e. those based on a time-zero identified by examination of the acceleration data captured by the EDR's. The differences in these delta-V's ranged between 3.59 km/h (6.85%) and -1.87 km/h (-3.42%). On average the difference was -0.28 km/h (-0.47%)

CONCLUSIONS

The initial speeds of the test vehicles obtained from the pre-crash data recorded by the EDR's were generally within 2 km/h (4%) of the values measured by the crash test laboratory's instrumentation.

The delta-V curves produced based on the EDR data generally matched those calculated from acceleration data captured by the laboratory instrumentation. In most instances only small differences were noted between the plots developed from the three accelerometers used by the crash test centre.

Some degree of time shifting of the EDR curves was evident in all cases. Where pre-impact acceleration data were available for certain Ford and Chrysler models, the procedure developed to refine time-zero, and to introduce a time shift into the curves, showed a beneficial effect in matching the curves.

For Chrysler vehicles, where it was possible to select a value for time-zero different from that reported by the EDR, a specific set of acceleration values could be identified as being related to the impact. The use of such time-shifted values introduces a number of non-zero acceleration values into the delta-V calculations that would otherwise be excluded. The calculated delta-V's then more closely match the values computed from the laboratory acceleration data than had the non-time shifted data (i.e. based on the EDR's reported t=0) been used. Consequently, it is recommended that end users of EDR data from Chrysler vehicles should examine the acceleration data stream in order to identify the most appropriate value of time-zero, and integrate the vehicle acceleration from this point onwards.

The differences in the maximum delta-V's recorded by the EDR's from all manufacturers were generally under-reported by approximately 2 km/h (3.5%) of those developed from the laboratory data. The maximum observed difference between the delta-V values was 4.75 km/h (8.62%).

Overall, the results from the series of crash tests undertaken in this study, for a number of different vehicle models, indicate that end users of the output from vehicle EDR's involved in real-world crashes can have some confidence in the accuracy of these data. However, since the current study is restricted to full-frontal crashes at a single speed, and noting that bi-axial accelerometers are employed in many vehicles, the specific accuracies noted here may not be generally applicable to all crash modes and speeds.

Past experience has shown that data captured by vehicle EDR's add considerably to the knowledge gained from real-world collisions where the information obtained from these devices through programmes of in-depth investigations is integrated into the analysis and reporting systems.

Comparison of data obtained from on-board vehicle EDR's in tightly-controlled crash test situations, with equivalent information collected using sophisticated laboratory instrumentation, provides a valuable measure of confidence in the use of similar data collected from real-world events.

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