

Validation of Event Data Recorders in High Severity Full-Frontal Crash Tests

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ABSTRACT

This study evaluates the accuracy of 41 Event Data Recorders (EDR) extracted from model year 2012 General Motors, Chrysler, Ford, Honda, Mazda, Toyota, and Volvo vehicles subjected to New Car Assessment Program 56 kph full-frontal barrier crash tests. The approach was to evaluate (1) the vehicle longitudinal change in velocity or delta-V (ΔV) as measured by EDRs in comparison with the high-precision accelerometers mounted onboard test vehicles and (2) the accuracy of pre-crash speed, seatbelt buckle status, and frontal airbag deployment status.

On average the absolute error for pre-crash speed between the EDR and reference instrumentation was only 0.58 kph, or 1.0% of the nominal impact speed. In all cases in which the EDRs recorded the seatbelt buckle status of the driver or right front passenger, the modules correctly reported that the occupants were buckled. EDRs reported airbag deployment correctly in all of the tests. The average absolute error was 4.20 kph (6.6%) for final longitudinal ΔV and 4.32 kph (6.6%) for maximum longitudinal ΔV . Our results show that EDRs underreport the reference instrumentation ΔV in the vast majority of cases.

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INTRODUCTION

Most late model U.S. passenger cars and light trucks now contain an Event Data Recorder (EDR). EDRs record key information about the vehicle before and during a crash and often include vehicle velocity changes in the longitudinal and lateral directions, airbag deployment times, seatbelt pretensioner deployment status, as well as front occupant seatbelt buckle status. The change in velocity, or delta-V (ΔV), is a widely accepted measure of crash severity. The data stored by EDRs can provide important insight into a vehicle's crash performance over a range of impact conditions, and are useful for crash reconstruction.

The automakers began phasing EDRs into light vehicles over a decade ago. Many car companies were installing these devices, but each was using their own strategy for design and deployment into the fleet. Recognizing these differences,

several standards organizations and the National Highway Traffic Safety Administration (NHTSA) developed standards, recommended practices (RP), and regulations. SAE developed J1698, one of the first RPs on this topic. About 10 years ago, NHTSA became active in this area, first holding workshops and later soliciting public input regarding EDRs. In the fall of 2012, NHTSA's promulgation of the EDR regulation became effective; and is known as 49 CFR 563, Event Data Recorders (Part 563). The regulation sets forth five guiding principles: specifying a minimum set of data, standardizing the data set, increasing the survivability of the data, requiring a public tool to download the data, and requiring a standard statement in the vehicle owner's manual.

The data analyzed in this study were collected from EDRs designed and built prior to the effective date of the new regulation; hence they were not required to comply with the

regulation. These 2012 model year (MY) EDRs, however, should be a good indicator of original equipment manufacturers (OEM) progress toward meeting the EDR regulation since they immediately preceded the regulation and the design cycle of automobiles is several years. Note there may be EDRs in our sample that were phased out at the end of MY 2012 production, thus they would not be included in 2013 production.

This study reviews the accuracy of these MY 2012 EDRs in high severity crashes. New Car Assessment Program (NCAP) frontal crashes are very severe, demonstrated by the fact that they are representative of the 99th percentile of all frontal crashes. This paper will update previous studies of General Motors (GM), Ford, and Toyota EDRs from earlier model years and will examine the accuracy of Chrysler, Honda, Mazda, and Volvo EDRs in high severity crashes for the first time.

Delta-V Accuracy

Delta-V (ΔV) accuracy was first cited as $\pm 10\%$ by Chidester in 1999 [1] for GM vehicles. The error was primarily explained by the accelerometer percent of full scale error, with contributions from the analog to digital converter, resolution, and offset. While not expressly stated, it was implied that this was for crashes where the maximum acceleration did not exceed the range of the sensor.

In 2005, Niehoff [2] reported the recorded EDR data against reference instrumentation from 37 NHTSA crash tests of mostly GM, but some Toyota and Ford vehicles. The crash tests were at speeds between 40 and 64 kph (25 to 40 mph). For the 21 full-frontal barrier crash tests, the ΔV error was given as an absolute value (not signed) and reported as averaging 5.75% and ranging from 0.19 to 13.41% (other crash modes were also reported). It concluded “in nearly all cases, the delta-V recorded by the Event Data Recorders was less than the true delta-V”. The paper cited insufficient memory duration in some EDRs as a cause of under-reporting the ΔV and did not discuss clipping.

In 2008, Gabler [3] reported on 48 crash tests of 2004-2007 model year GM, Toyota, and Ford vehicles ranging from 40 to 56 kph (25 to 40 mph), conducted by NHTSA and the Insurance Institute for Highway Safety (IIHS). Gabler noted that some EDRs did not have sufficient memory to record the entire crash pulse, but for the 32 frontal crashes that did, the average of the absolute values of the errors was 3.5% and the data ranged from 0 to 21.8%. The maximum error of -8.2 kph was in a 56 kph full-frontal barrier test of a 2005 Toyota Tundra.

In 2011 Comeau [4] reported ΔV for 14 Toyota full-frontal barrier tests which averaged -2.39 kph or -4.09% of the reference accelerometers and ranged from +0.47 to -8.84 kph. The -8.84 kph, which equated to -14%, and another “outlier” at -7.11 kph were not explained.

Speed Data Accuracy

The first paper to address pre-crash EDR speed data accuracy was published in 1999 by Chidester and his team [1], which included General Motors personnel. Chidester *et al.* reported the accuracy of speed data as $\pm 4\%$, a theoretical tolerance; however, no performance data could be cited as vehicles were barely into production. Subsequent EDR testing has been of three types. The first method used artificially created events during normal driving of specific test vehicles which compared EDR speeds to reference instrumentation, typically Global Positioning Sensor (GPS) or 5th wheel speed, all showing accuracy better than $\pm 4\%$ at highway speeds. This has been done on GM vehicles in 2003 by Lawrence [5] and in 2011 by Bare [6], on Ford vehicles by Ruth [7, 8], on Chrysler vehicles by Ruth [9] and Bortolin [10], and on Toyota vehicles by Ruth [10] and Brown [12, 13]. The second set of data comes from 40 to 64 kph (25 to 40 mph) barrier crash tests as reported in 2005 by Niehoff [2] who reported “within 1 mph” and in 2008 by Gabler [3] who reported “within 3%”, except for one unexplained outlier which was 8 mph or 22% low. In 2011 Comeau [4] also reported Toyota crash test speed data was from -2.4 to +0.2 kph (-1.5 to +0.1 mph). The third set of data comes from a NHTSA EDR validation of Toyota vehicles [14] in events created by low ΔV car-to-car collisions. They reported all speed data was within a ± 2.3 kph (1.5 mph) acceptance window.

Seatbelt Buckle Accuracy

Seatbelt buckle accuracy for EDRs are primarily found in the crash tests reported by Niehoff [2], Gabler [3], and Comeau [4], where all studies indicated seatbelt data is 100% accurate when reported.

OBJECTIVE

The objective of this study is to establish the accuracy of EDR measurements recorded during full-frontal crash tests.

APPROACH

This study was based on EDRs extracted from MY 2012 passenger vehicles subjected to full-frontal barrier crash tests conducted by NHTSA as part of NCAP. The EDR data were compared to the high-precision accelerometers installed in vehicles for the crash tests. NCAP full-frontal tests involve a vehicle that is perpendicularly impacted into a rigid concrete barrier at 56 kph. The two dummies used in these tests are seated in the driver and right front passenger positions.

Development of the EDR Dataset

The analysis was based on 41 EDRs from NCAP vehicles in full-frontal tests. The data was downloaded from the NHTSA Vehicle Crash Test Database [15] and all modules in our sample were generated using the publicly available Bosch Crash Data Retrieval (CDR) system v.10. The reports

indicated that the data was collected using Bosch CDR tool from versions 4.2 to 10.0.

As shown in [Table 1](#), EDRs from GM, Chrysler, Ford, Honda, Mazda, Toyota, and Volvo vehicles were included in the analysis. The frontal airbags deployed in all of the crash tests. The EDRs are designed to capture and record data in crashes like these, and lock the data in its memory in the case of an airbag deployment. [Table 1](#) also presents the distribution of EDR module types using the nomenclature by which modules are identified in Bosch .cdrx files.

Table 1. Composition of the analyzed EDR dataset

Variable	Number of Tests
All	41
Vehicle Make	
Chrysler	12
Ford	6
General Motors	7
Honda	5
Mazda	1
Toyota	9
Volvo	1
EDR Module Type	
CHRY0000	1
CHRY0305	5
CHRY0403	3
CHRY4005	2
CHRY4101	1
FordAB10	1
FordRC6_2011	2
FordRC62011CGEAD	3
Honda001	5
MAZDA002	1
SDM10	5
SDM10P	1
SDM11_AUTOLIVNEW	1
Toyota001	9
Volvo001	1

Crash Test Instrumentation Selection

Each of the EDRs used in our study recorded the longitudinal change in velocity (delta-V or ΔV) of the occupant compartment during the crash event. The EDR ΔV measurements were compared with ΔV computed from the laboratory-grade crash test accelerometers (reference instrumentation) aligned with the longitudinal axis of the vehicle. Only crash test accelerometers mounted in the occupant compartment were used in the analysis. Crash test accelerometers mounted in either the crush zone or to non-rigid occupant compartment components, e.g. the instrument panel, were excluded from the study. The data quality of each of the crash test accelerometers was checked by comparison

with other accelerometers in the occupant compartment to ensure that they were internally consistent with one another. Among the 4 available accelerometers that were mounted in the occupant compartment, those with the highest and lowest maximum ΔV were discarded and the remaining 2 accelerometers were averaged. In crash tests where a channel had failed and only 3 accelerometers were available, any channels with unrealistic ΔV (e.g. near-zero rebound velocity) were discarded. Author discretion was used for crash test 7732 involving a MY 2012 Honda CR-V, where the ΔV was indicated to be positive and near-zero in two accelerometers. For each test, the channels averaged are indicated in [Table A-1](#).

The electronic time history data for each accelerometer were acquired from the NHTSA Vehicle Crash Test Database [15] using Signal Browser v.1.3.6.2, the publicly available NHTSA signal analysis software. Additional information on each crash test was obtained from the crash test reports also available from the NHTSA vehicle crash test database website.

Event Recording Complete Status

Each EDR was checked to see whether the event recording was designated as complete. Some EDR modules also check that individual sections were completely recorded in addition to having an overall EDR recording complete status. These modules were checked for consistency between overall recording complete and individual section recording complete.

Seatbelt Buckle Status

Frontal NCAP tests are conducted with both the driver and right front passenger belted. Post-crash photographs and the test reports were manually inspected to confirm the seatbelt buckle status. In the tables which follow, “Y” was recorded for observed seatbelt use and “N” was used to denote no seatbelt use in the crash test. The Bosch CDR tool reports were manually examined for seatbelt use. A value of “Y” was recorded if the EDR indicated that the seatbelt was buckled and “N” was used to indicate that the EDR recorded no seatbelt buckled. Other designators are used for non-recorded conditions.

Airbag Deployment

Post-crash photographs from the test reports were inspected manually to determine whether the driver and right front passenger dummy airbag had deployed. “Y” was recorded for observed airbag deployment and “N” was used to denote no airbag deployment in the crash test. This value was compared to test report tables, when available.

Most EDRs explicitly provided frontal airbag deployment times. However, in 5 modules, the Jeep Liberty (7567), Dodge Durango (7525), Chrysler 200 (7482), Dodge Avenger (7464), and Chrysler Town & Country (7460), this was not provided. These modules instead offered “Frontal Airbag Deployment, Time Between Squib #1 and Squib #2” for the

driver and right front passenger. A value of “Y” and the airbag deployment time were recorded if the EDR signified a deployment and “N” was used to indicate that the EDR recorded no airbag deployment.

Pre-Crash Vehicle Speed

The speed at barrier impact for the crash test was determined from the NHTSA Vehicle Crash Test Database files. The EDRs in our sample recorded pre-crash speed for 5 seconds before the crash at either 1 or 2 samples per second. The last pre-crash vehicle speed value recorded in the EDR was compared with the crash test impact speed.

Delta-V

For each crash test, laboratory-grade accelerometers were integrated to obtain a reference longitudinal ΔV . EDR ΔV and the reference ΔV were compared in three ways: final ΔV , maximum ΔV as determined from the ΔV versus time data, and maximum ΔV as reported on the Bosch CDR report. A visual representation of maximum and final ΔV is shown in [Figure 1](#).

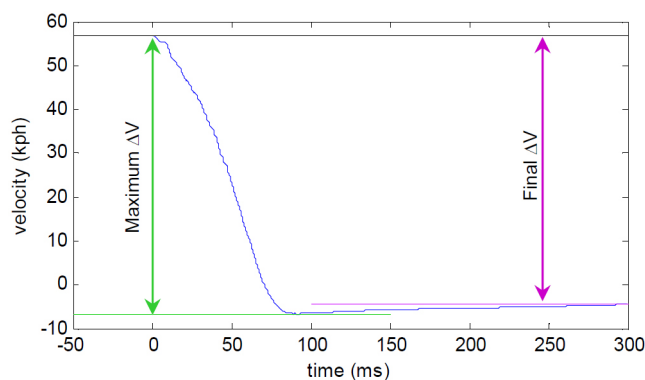


Figure 1. Definition of Maximum and Final ΔV

The study also plotted the EDR and reference instrumentation ΔV versus time for each crash test. This section describes how the EDR data was aligned prior to the comparison with the reference instrumentation. We emphasize that the sole purpose of the alignment described below was to allow the EDR and reference signals to be plotted on a single graph for visual comparison. The alignment had no effect on the analysis of ΔV accuracy presented later in this paper.

Time zero alignment

The time zero for the reference instrumentation in crash tests is closure of a contact switch on the front bumper, intended to capture the instant of vehicle-barrier first contact. For EDRs, the time zero for the EDR may either be the time of algorithm wakeup or some other estimated time after impact, *e.g.* time of deployment. It typically is not the time obtained from the first contact with the barrier in the crash tests. In order to produce a plot of EDR versus crash test ΔV as a function of time, the time zero of the EDR was first

aligned with the time zero of the reference instrumentation. In the Bosch CDR report the time of algorithm wakeup is identified by many terms including “algorithm enable” (AE) in some Chrysler modules, when the “recording trigger is established” in Toyota modules, and “when the restraint control algorithm becomes active” in Volvo modules. The EDR time zero can also be more involved, *e.g.* the Honda definition which states “T0 is established by whichever of the following occurs first: (1) the change in longitudinal velocity at the SRS control unit equals or exceeds 0.8km/h over a 20ms timeframe; (2) the change in lateral velocity at the SRS control unit equals or exceeds 0.8km/h over a 5ms timeframe; or (3) a commanded deployment of any type of non-reversible deployable restraint device (*e.g.* airbag or seatbelt pretensioner).”

The change in velocity between each of the EDR time steps, referred to here as incremental ΔV , was next calculated over the entire range of EDR values. Incremental ΔV values were also determined for the reference instrumentation at identical time steps, such that the time series data for each overlapped. An example is shown in [Figure 2](#) determined from an EDR that reported ΔV sampled at 100 Hz. To optimize the time when the EDR incremental ΔV is most similar to the reference instrumentation, the EDR incremental ΔV was then time shifted in increments of 0.1 ms and the reference instrumentation incremental ΔV recalculated for the corresponding time steps. For each time shift, τ , bounded to a negative shift of 6 ms and positive shift of 40 ms, a similarity score difference was computed as a sum of squares using the following equation:

$$SSq = \sum_{i=1}^n (\Delta V(t_i + \tau)_{test} - \Delta V_{i,EDR})^2$$

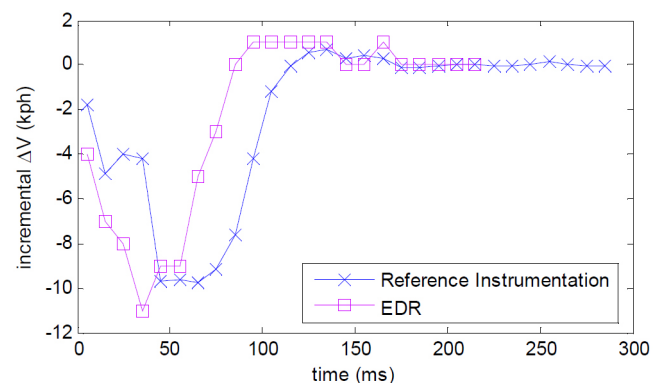


Figure 2. Alternative representation of crash pulse as incremental ΔV values (Test no. 7488)

Where n is the number of time points in the EDR incremental ΔV array and τ was a time phase shift in 0.1 ms increments. The time phase shift with the lowest sum of squares value was chosen as the best fit for the EDR ΔV with respect to the reference instrumentation ΔV . [Figure 3](#) presents

Table 2. Comparison of EDR and crash test pre-crash speed by vehicle make

Vehicle Make	n	Avg. Test Speed(kph)	Avg. EDR Speed(kph)	Avg. Arithmetic Error (kph)	Avg. Absolute Error (kph)	RMS Error (kph)	Avg. Arithmetic Error (%)	Avg. Absolute Error (%)	RMS Error (%)
Chrysler	12	56.34	56.17	-0.17	0.41	0.46	-0.30%	0.72%	0.81%
Ford	6	56.41	55.85	-0.56	0.56	0.69	-0.98%	0.98%	1.22%
GM	7	56.21	56.43	0.22	0.44	0.53	0.40%	0.79%	0.95%
Honda	5	56.39	56.20	-0.19	0.36	0.37	-0.34%	0.64%	0.66%
Mazda	1	56.44	55.00	-1.44	1.44	1.44	-2.55%	2.55%	2.55%
Toyota	9	56.29	55.33	-0.96	0.96	1.37	-1.71%	1.71%	2.42%
Volvo	1	56.53	56.00	-0.53	0.53	0.53	-0.94%	0.94%	0.94%
Overall	41	56.32	55.95	-0.37	0.58	0.82	-0.66%	1.03%	1.45%

an example time alignment in which the EDR ΔV was shifted 18.3 ms to match the reference ΔV time zero.

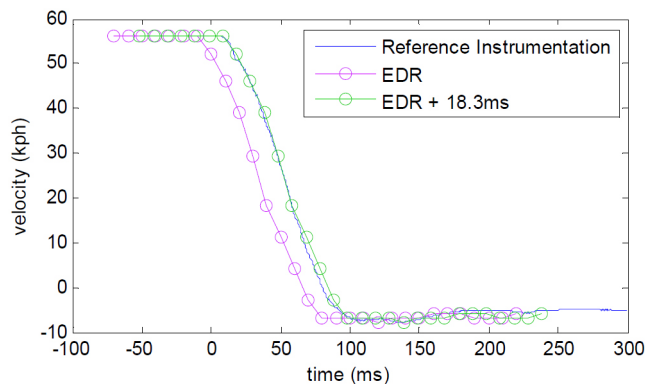


Figure 3. Sample time zero alignment shift where 18.3ms resulted in the smallest sum of squares (Test no. 7582)

This method of time alignment essentially seeks to align the crash deceleration pulses measured by the EDR and the reference instrumentation. Although we used incremental ΔV for computational expediency, the vehicle acceleration can be computed by simply dividing the incremental ΔV at each time step by the duration of the time step. Our rationale was that the two ΔV traces have been aligned once their corresponding crash pulses had been aligned. Appendix Table A-6 presents these crash pulses (in incremental ΔV form).

We emphasize that the time shift should not be interpreted as algorithm enable, wakeup, deployment time or any other timing parameter related to airbags. The time shift is simply the outcome of time alignment of crash pulses. The airbag squib was not instrumented in these crash tests and no evaluation of airbag timing was possible in this paper.

Delta-V alignment

The vehicle-barrier impact speed from the reference instrumentation was added to the EDR ΔV values to allow comparison of EDR and reference velocity versus time for each test. In all cases, any trailing zero ΔV values at the end of an EDR ΔV recording were first truncated. However in many cases a typically tiny amount of ΔV was not recorded by some EDRs between time of impact and the EDR time zero. For these cases, we used the reference ΔV to compute the velocity of the vehicle when the EDR started recording.

We added this velocity to the first time point recorded by the EDR. For those cases in which the EDR recorded data prior to impact, the impact speed was added to the first EDR point. An example of this operation is shown in Figure 4. It should be noted that the ΔV shift was a function of the time shift, and should not be interpreted as error in the EDR ΔV . For each test, this ΔV shift from the impact speed is presented in the tables which follow.

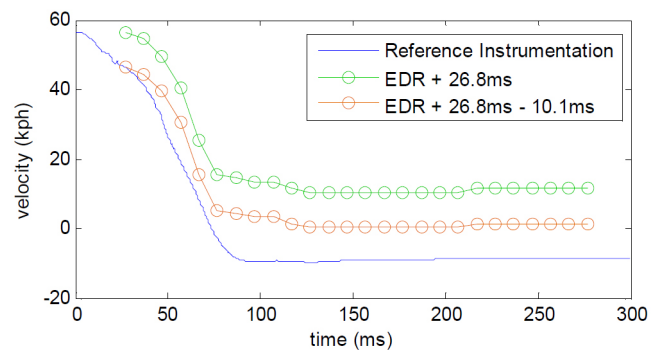


Figure 4. EDR velocity was shifted to match the reference instrumentation velocity after time shift (Test no. 7566)

RESULTS

All EDRs in our dataset contained a flag which indicated whether the event recording was complete. The event recording complete status of the EDRs is reported in Table A-2. Of the 41 modules, 39 EDRs reported indicated that the recording was successfully completed at the time of their original readout. The Dodge Journey (test 7471) recorded an interrupted status and had several pre-crash data elements display as “SNA” (signal not available) from $t = -4.3$ seconds to impact. The speed and ΔV data appeared to be recorded properly and were used in the analysis. The Dodge Durango (test 7585) reported an interrupted status but all data appeared to be recorded completely and has been used in this analysis.

Seatbelt Buckle Status

In all of the crash tests in our sample, both the driver and right front passenger were belted. All EDRs which recorded driver belt buckle status (37 of 41 cases) correctly recorded

Table 3. Comparison of reference instrumentation and EDR final ΔV by vehicle make

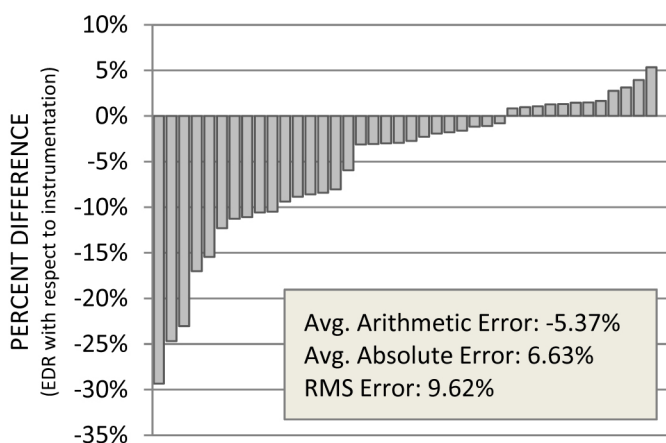
Vehicle Make	n	Average Test ΔV (kph)	Average EDR ΔV (kph)	Average Arithmetic Error (kph)	Average Absolute Error (kph)	RMS Error (kph)	Average Arithmetic Error (%)	Average Absolute Error (%)	RMS Error (%)
Chrysler	12	62.15	61.27	-0.94	1.79	2.63	-1.53%	2.88%	4.20%
Ford	6	63.23	62.74	-0.49	1.24	1.68	-0.78%	1.96%	2.66%
GM	7	62.40	59.14	-3.26	4.41	4.97	-5.16%	7.05%	7.94%
Honda	5	63.28	58.40	-4.88	6.54	8.70	-7.60%	10.28%	13.65%
Mazda	1	64.98	50.00	-14.98	14.98	14.98	-23.05%	23.05%	23.05%
Toyota	9	63.25	56.68	-6.58	6.71	8.36	-10.34%	10.55%	13.13%
Volvo	1	62.97	61.00	-1.97	1.97	1.97	-3.13%	3.13%	3.13%
Overall	41	62.82	59.44	-3.42	4.20	6.13	-5.37%	6.63%	9.62%

Table 4. Comparison of reference instrumentation and EDR maximum ΔV (from time series data) by vehicle make

Vehicle Make	n	Average Test ΔV (kph)	Average EDR ΔV (kph)	Average Arithmetic Error (kph)	Average Absolute Error (kph)	RMS Error (kph)	Average Arithmetic Error (%)	Average Absolute Error (%)	RMS Error (%)
Chrysler	12	64.50	64.00	-0.70	1.89	2.52	-1.08%	2.93%	3.91%
Ford	6	65.72	64.66	-1.07	1.23	1.80	-1.63%	1.88%	2.77%
GM	7	64.01	60.71	-3.29	4.09	4.82	-5.15%	6.42%	7.61%
Honda	5	66.20	59.20	-7.00	7.00	10.49	-10.46%	10.47%	15.68%
Mazda	1	66.19	51.00	-15.19	15.19	15.19	-22.95%	22.95%	22.95%
Toyota	9	65.33	58.30	-7.03	7.03	8.65	-10.79%	10.79%	13.29%
Volvo	1	64.58	62.00	-2.58	2.58	2.58	-3.99%	3.99%	3.99%
Overall	41	65.03	61.27	-3.83	4.32	6.54	-5.85%	6.62%	9.98%

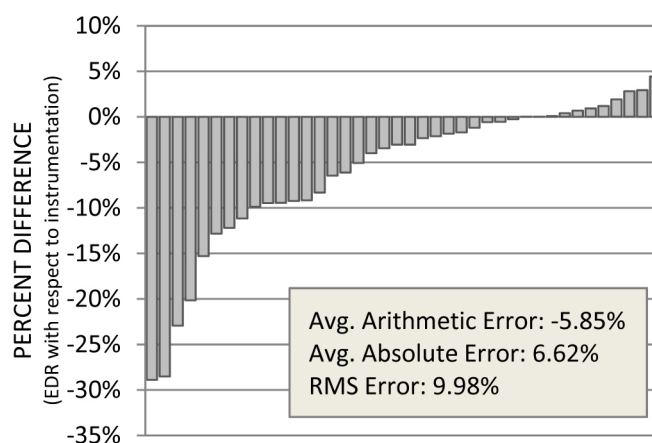
the status as buckled. In the remaining four vehicles, all Chrysler vehicles, the Bosch report stated that the module was not configured to store driver buckle status. These results are seen in Table A-2.

Likewise, all EDRs which recorded right front passenger belt buckle status (34 of 41 tests) correctly recorded the status as buckled. In the remaining 7 tests, the Bosch report stated that the module was not configured to store passenger buckle status (5 Chrysler EDRs), the passenger buckle status was not active (1 Ford EDR), or the passenger buckle status was not available (1 GM EDR). These results are seen in Table A-2.

**Figure 5. Distribution of EDR time series final ΔV percent difference with respect to reference instrumentation**

Airbag Deployment

The frontal airbag of both the driver and right front passenger deployed in all crash tests. In 100% of full-frontal crash tests (41 vehicles) the EDR correctly reported airbag deployment of a driver airbag and right front passenger airbag. The results are shown in Table A-2.

**Figure 6. Distribution of EDR time series maximum ΔV percent difference with respect to reference instrumentation**

Pre-Crash Vehicle Speed

As shown in [Table 2](#) and [Table A-3](#) the EDR pre-crash vehicle speed was very close to the crash test speed in all 41 frontal crash tests. The differences ranged from -2.67 kph to $+0.80$ kph. On average, the EDRs in our sample underestimated crash test pre-crash speed by 0.58 kph (1.0% of the nominal impact speed of 56 kph). Only 5 EDRs differed from the test speed more than 1 kph.

Speed errors can be affected by truncation, resolution, and rounding of the values before being output to the Bosch CDR report. For example, the data limitations section of the Bosch CDR report for Toyota001 modules states “Resolution is 2km/h (1.2mph) and the value is rounded down and recorded.” Compared to the nominal impact speed of NCAP full-frontal tests, 56 kph, an error of 2 kph is approximately 3.6% .

Similarly, the Bosch CDR reports for several Chrysler modules state in the data limitations section that “...the resolution is 1 kph,” which is 1.8% of the nominal impact speed. Most vehicles calculate speed in kph, but when the EDR records them it truncates to the next lower whole kph (GM, Ford, Chrysler, Honda), except Toyota which records to the next lower even kph. For example, in [Table A-3](#), the Toyota RAV4 (test 7744) EDR reported a vehicle speed of 54 kph. Although Toyota EDRs recorded vehicle speed at a resolution of 2 kph, the Bosch report for Toyota EDRs reported pre-crash speed to the nearest tenth of a mph. Some Ford EDRs reported pre-crash speed to a resolution of the nearest tenth of a mph after unit conversion from kph. In contrast, the EDRs installed in GM, Chrysler, Honda, and some Ford vehicles only reported pre-crash speed to a resolution of the nearest integer.

For the -2.67 kph largest error reported by the Toyota RAV4, up to 2 kph may be due to truncation to the next lower even kph value. The percentage (-4.7%) reported for this vehicle at 56 kph should not be applied to other manufacturers or to Toyotas at higher speeds, and it should be recognized that this error is in the negative direction and is not symmetrical about zero.

As shown in [Table 2](#), the accuracy of the EDR pre-crash speed varied somewhat by vehicle manufacturer. The Honda EDRs in our sample had the lowest absolute difference between EDR and crash test (0.36 kph, or 0.6% of the nominal test speed of 56 kph). Mazda had the largest absolute difference (1.44 kph, or 2.6% of the nominal test speed of 56 kph).

Delta-V

Of the 41 EDRs, only one did not record ΔV (test 7460, a 2012 Chrysler Town & Country). For all other crash tests, the EDR ΔV values were time shifted to adjust for time zero differences between the EDR and the reference instrumentation. The time shifts are shown in [Table A-2](#).

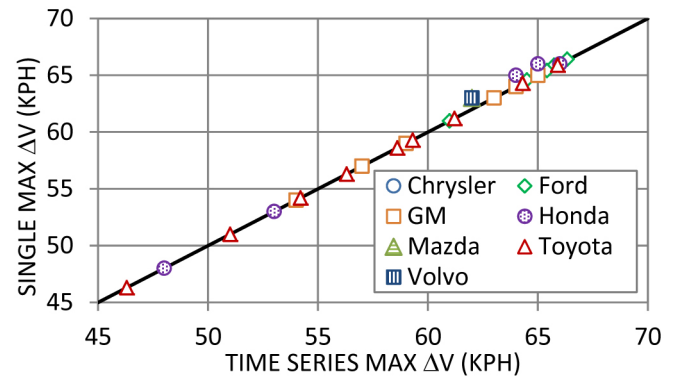


Figure 7. Comparison of calculated and reported maximum EDR ΔV by vehicle make

Most EDRs in our sample defined time zero to be the time of algorithm enable, wakeup, or recording trigger. For 6 GM EDRs (test 7488, 7494, 7509, 7521, 7564, and 7582), the time zero in the Bosch report was defined to be the time of deployment. To align these tests with the balance of the data set, the time of first stage deployment was subtracted from the algorithm derived time shift.

The time shifted velocity graphs are shown in [Table A-5](#) and incremental ΔV graphs are shown in [Table A-6](#). As shown in this table, the alignment algorithm generally appears to properly time align the EDR data with reference instrumentation. In a small number of cases, the time shift was negative. In these cases, the first reported time point in the EDR Bosch report time series was not zero.

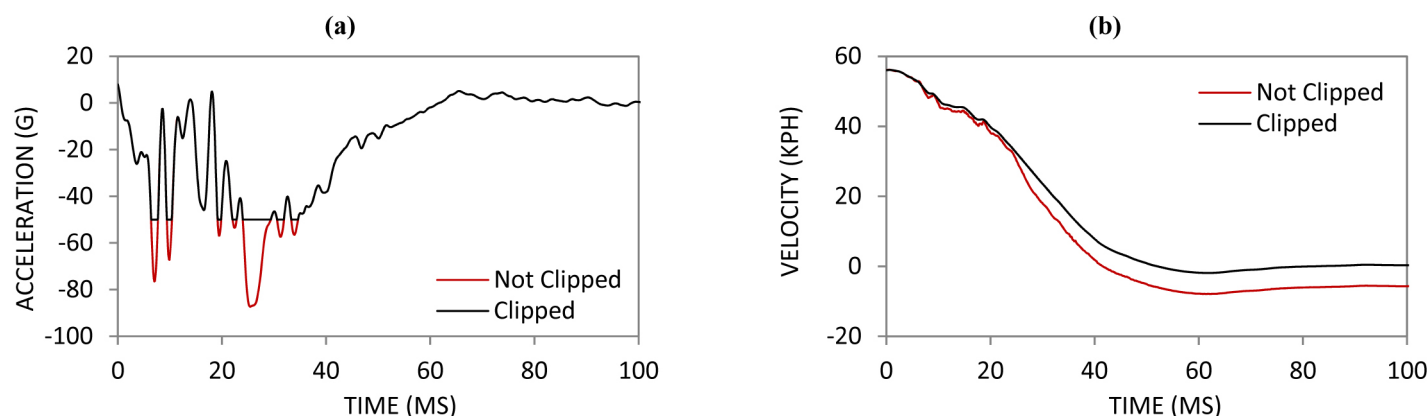
A table of ΔV measurements for each test is shown in [Table A-4](#). The distribution of final ΔV percent difference for longitudinal data is shown graphically in [Figure 5](#). Further accuracy metrics are presented in [Table 3](#). On average, the EDRs in our sample underestimated reference final ΔV by 4.20 kph (6.6% error). The largest observed error was 19 kph for the 2012 Toyota Sienna (test 7615). In our dataset, Ford EDRs had the lowest average absolute error (1.24 kph or 2.0%) with reference instrumentation. The Mazda EDR (test 7566) had the highest average absolute difference (14.98 kph or 23.1%).

[Table 4](#) and [Figure 6](#) present a comparison of maximum ΔV for EDR versus reference instrumentation. The average absolute error between the reference and the EDR was 4.32 kph (6.6%). The 2012 Honda CR-Z (test 7622) had the greatest error, 19.16 kph (28.5%). Across OEMs, the average absolute error for maximum ΔV ranged between Ford's 1.23 kph (1.9%) and Mazda's 15.19 kph (23.0%).

[Figure 7](#) compares the EDR maximum ΔV determined from the time series to that reported by the Bosch report. Note that the EDR maximum ΔV on the Bosch report may be different than that observed in the table of ΔV values versus time. The largest error seen was only 1 kph (1.6%). This can be due to calculating at an intermediate point in time, or by using the NHTSA definition of the end of a crash to calculate the “maximum” value. [Table 5](#) compares the single

Table 5. Comparison of reference instrumentation and EDR reported single maximum ΔV by vehicle make

Vehicle Make	n	Average Test ΔV (kph)	Average EDR ΔV (kph)	Average Arithmetic Error (kph)	Average Absolute Error (kph)	RMS Error (kph)	Average Arithmetic Error (%)	Average Absolute Error (%)	RMS Error (%)
Chrysler	12	64.50	63.29	-0.99	2.27	2.96	-1.54%	3.53%	4.62%
Ford	6	65.72	64.72	-1.01	1.21	1.77	-1.54%	1.84%	2.72%
GM	7	64.01	60.71	-3.29	4.09	4.82	-5.15%	6.42%	7.61%
Honda	5	66.20	59.60	-6.60	7.25	10.51	-9.85%	10.85%	15.70%
Mazda	1	66.19	51.00	-15.19	15.19	15.19	-22.95%	22.95%	22.95%
Toyota	9	65.33	58.30	-7.03	7.03	8.65	-10.79%	10.79%	13.29%
Volvo	1	64.58	63.00	-1.58	1.58	1.58	-2.45%	2.45%	2.45%
Overall	41	65.03	60.92	-4.14	4.67	6.87	-6.33%	7.15%	10.48%

**Figure 8. (a) Illustration of hypothetical clipping at 50 G and (b) the corresponding effect on velocity in a 56kph frontal crash test**

maximum ΔV value, as listed on the Bosch report, against the test maximum ΔV . Due to the similarity of the single CDR reported maximum to the maximum found from the time series data, the accuracy metrics are also similar. The average absolute error between the reference instrumentation and the EDR was 4.67 kph (7.2% error).

In 39 of 41 cases, EDR recording duration was clearly sufficient to capture the entire crash pulse. In the remaining 2 cases (test 7622, a Honda CR-Z, and test 7732, a Honda CR-V), the ACM deployment algorithm appears to have gone back to sleep and stopped recording new values at 130ms and 100ms respectively. While the reference crash pulse in these two cases appears to be complete, the ACM algorithm crash pulse does not appear to be complete at the time that the ACM stopped recording.

DISCUSSION

One possible explanation for the EDR underreporting the reference instrumentation is clipping. In the Association of Automobile Manufacturers petition for reconsideration, dated February 28, 2008, they note that 50 G accelerometers are commonly used for airbag deployment decisions. They also note EDR acceleration data is filtered at 400 Hz (design dependent) versus the 60 Hz filter commonly used in NHTSA crash test analysis. The NHTSA signal processing software allows selection of 60, 180, 600, or 1000 Hz pre-defined

filters. The authors selected the 180 Hz filter as the closest measure of a 400 Hz filter and in 26 of the 41 tests (63%) reviewed the reference accelerometer data was greater than 50 G with the 180 Hz filter. This means that clipping of EDR acceleration data that the ΔV is calculated from is likely in many of the tests. Figure 8a conceptually illustrates the effects of hypothetical clipping at 50 G in a 56 kph full-frontal crash test. Figure 8b shows that clipping of this magnitude would result in underreporting of ΔV by 6 kph (9.5%).

Because the authors do not have access to either the exact range of each manufacturer's accelerometers, or the specific filtering used by each manufacturer, the exact amount of clipping cannot be ascertained for each of the NHTSA tests.

Nine of the 41 EDRs (22%) recorded acceleration data in addition to ΔV - five Honda, three GM, and one Mazda vehicles. In two vehicles the recorded peak was 50 G, the remainder were under 50 G, even though the reference accelerometers filtered to 180 Hz exceeded 50 G in 4 of the 9 tests where EDR acceleration was reported.

A third potential explanation of the ΔV error is an acceleration bias or offset built into their modules, that several studies have shown that some manufacturers appear to have. One possible strategy is that this bias could serve as a safeguard against inadvertent deployment of the airbags. Any EDRs with this bias would underreport ΔV . A module