

# Validation of Event Data Recorders in Side-Impact Crash Tests

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## ABSTRACT

This study evaluated the accuracy of 75 Event Data Recorders (EDRs) extracted from model year 2010-2012 Chrysler, Ford, General Motors, Honda, Mazda, and Toyota vehicles subjected to side-impact moving deformable barrier crash tests. The test report and vehicle-mounted accelerometers provided reference values to assess the EDR reported change in lateral velocity (delta-v), seatbelt buckle status, and airbag deployment status.

Our results show that EDRs underreported the reference lateral delta-v in the vast majority of cases, mimicking the errors and conclusions found in some longitudinal EDR accuracy studies. For maximum lateral delta-v, the average arithmetic error was -3.59 kph (-13.8%) and the average absolute error was 4.05 kph (15.9%). All EDR reports that recorded a seatbelt buckle status data element correctly recorded the buckle status at both the driver and right front passenger locations. For equipped vehicles that reported side torso, side curtain, and frontal airbag deployment information, all vehicles recorded the correct status. Although only model year 2013 and later EDRs must meet Code of Federal Regulations Title 49 Part 563, seatbelt buckle status and frontal airbag deployment time are required data elements.

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## INTRODUCTION

Event Data Recorders (EDRs) are now installed in 96% of the model year (MY) 2013 U.S. fleet according to National Highway Traffic Safety Administration (NHTSA) estimates [1]. These devices offer a unique opportunity to understand the vehicle crash performance as they are capable of recording the characteristics of an automotive crash, e.g. velocity changes (delta-v), airbag deployment, and seatbelt use. As a result, EDR data has become an invaluable tool for law enforcement, researchers, and government agencies. However, before using EDRs to study crash performance, it is important to first establish their accuracy.

Many EDR validation studies have evaluated the accuracy of delta-v. These studies have focused on frontal crashes, utilizing the longitudinal data integral to algorithms that determine frontal airbag deployment. Most early EDRs computed and recorded longitudinal delta-v using the frontal airbag accelerometer data [2]. Vehicles with early EDRs were typically not equipped with lateral accelerometers or side airbags; and hence did not record lateral acceleration. However, with the increased prevalence of side airbags in recent model years, there has been a parallel increase in lateral accelerometers. EDRs from these vehicles can now compute and record lateral delta-v, providing an opportunity to validate EDRs in side crashes.

This study presents the results of a methodical evaluation of MY 2010-2012 EDR accuracy extracted from vehicles subjected to the NHTSA Side-Impact New Car Assessment Program (SINCAP) Moving Deformable Barrier (MDB) crash tests. These crash tests include Chrysler, Ford, General Motors (GM), Honda, Mazda, and Toyota vehicles, several of which are assessed in this crash mode for the first time.

## OBJECTIVE

The objective of this study was to establish the accuracy of EDR measurements recorded during side-impact crash tests.

## APPROACH

The dataset utilized in this study was composed of EDRs extracted from MY 2010-2012 passenger vehicles subjected to SINCAP MDB crash tests conducted by NHTSA. SINCAP MDB tests involve a stationary test vehicle that is perpendicularly impacted on the driver side by the MDB at 62 kph (39 mph). The protocol for this crash test specifies a crabbed MDB angle of 27° to simulate an impact where both vehicles are moving [3]. The MDB has a crushable face of aluminum honeycomb structure to simulate the stiffness of the front end of a striking vehicle. In this crash test two dummies are seated in the driver and left rear (or middle) row passenger positions, depending upon the vehicle type. The right front passenger seat is usually unoccupied and unbuckled.

The EDR delta-v data were compared to the NHTSA accelerometers mounted within the crash test vehicles and data elements were compared to the laboratory test reports. The following EDR report data elements were analyzed in this study:

- Maximum Delta-V, Lateral
- Seatbelt Buckle Status, Driver
- Seatbelt Buckle Status, Passenger
- Torso Airbag Deployment Status, Left Side
- Curtain Airbag Deployment Status, Left Side
- Frontal Airbag Deployment Status, Driver
- Event Recording Status Complete

Additionally, if the time to deploy was available in the EDR report, those data elements were also reported in this study.

## Development of the EDR Dataset

Table 1. Composition of the analyzed EDR dataset.

| Variable               | Number of Tests |
|------------------------|-----------------|
| <b>Vehicle Make</b>    |                 |
| Chrysler               | 16              |
| Ford                   | 17              |
| GM                     | 16              |
| Honda                  | 4               |
| Mazda                  | 2               |
| Toyota                 | 20              |
| <b>Model Year</b>      |                 |
| 2010                   | 12              |
| 2011                   | 28              |
| 2012                   | 35              |
| <b>EDR Module Type</b> |                 |
| CHRY0000               | 2               |
| CHRY0305               | 7               |
| CHRY0403               | 3               |
| CHRY4005               | 2               |
| CHRY4101               | 1               |
| Epsilon2006            | 1               |
| FordAB10               | 1               |
| FordRC6_2010           | 6               |
| FordRC6_2011           | 5               |
| FordRC62011CGEAB       | 1               |
| FordRC62011CGEAC       | 2               |
| FordRC62011CGEAD       | 2               |
| HONDA001               | 4               |
| MAZDA001               | 1               |
| MAZDA002               | 1               |
| SDM10                  | 12              |
| SDM10P                 | 1               |
| SDM11_AUTOLIVNEW       | 1               |
| SDMC2008V              | 2               |
| TOYOTA001              | 20              |
| <b>Total</b>           | <b>75</b>       |

The analysis was based on 75 EDRs from NCAP vehicles in SINCAP MDB tests. The EDR reports were downloaded from the NHTSA Vehicle Crash Test Database [4]. All of the EDR reports in our sample were generated using the publicly

available Bosch Crash Data Retrieval (CDR) system v.11.1. The reports indicated that the data was collected using the Bosch CDR tool from versions 4.2 to 10.0. Six (6) crash tests were excluded because the EDR did not report lateral delta-v data. Additionally, 3 tests were excluded because 2 or more of the 4 chosen reference sensors displayed unusual behavior. Note, although only MY 2013 and later EDRs must meet Code of Federal Regulations Title 49 Part 563 (Part 563), lateral delta-v is a data element in Table II.

As shown in Table 1, EDRs from MY 2010-2012 Chrysler, Ford, GM, Honda, Mazda, and Toyota vehicles were included in the analysis. EDRs are designed to capture and record data in crashes like the SINCAP MDB test, and lock the data in its memory in the case of an airbag deployment. At least one type of side airbag deployed in all of the crash tests. Table 1 also presents the distribution of EDR module types using the nomenclature by which modules are identified in Bosch \*.CDRx files.

## Event Recording Complete Status

Each EDR report contained a data element that described whether the overall event recording was completed successfully. In addition, some EDR reports provided additional recording statuses for subsections or pages of the report. The recording status for each EDR was examined to ensure data quality. If the EDR recorded unusual delta-v behavior, an incorrect airbag deployment status, or an incorrect seatbelt buckle status the recording status was consulted.

## Crash Test Instrumentation Selection

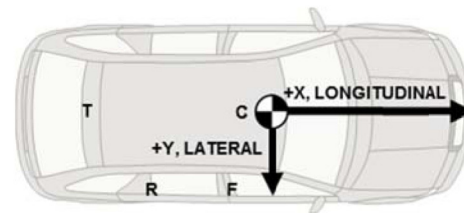


Figure 1. Vehicle-fixed reference frame orientation with approximate accelerometer locations: (F) right front sill, (R) right rear sill, (T) trunk floor center, and (C) vehicle center of gravity.

The reference delta-v values were obtained from crash test accelerometers. The data for each accelerometer were acquired from the NHTSA Vehicle Crash Test Database [4] using Signal Browser v.1.3.6.2, the publicly available NHTSA signal analysis software. Sensors were limited to tri-axial accelerometers that were mounted to the vehicle. All vehicles were struck on the left side. Sensors mounted to the struck side of the vehicle were not considered in our analysis in order to avoid impact damaged accelerometers or compromised signals caused by localized crush. After these constraints were applied, four accelerometers were considered in our analysis: the right front sill, right rear sill, center trunk floor, and vehicle center of gravity (CG). Figure 1 gives the approximate mounting location of these accelerometers within the test

vehicle. The data quality of the longitudinal and lateral channels, relative to the vehicle, was manually scrutinized. If unusual behavior was observed, the channel was not used in the proceeding analysis.

### Delta-V

Two (2) EDR lateral delta-v values were compared to the reference delta-v: (a) maximum delta-v as determined from the delta-v versus time data and (b) the maximum delta-v data element.

In a frontal crash test, the reference accelerometers can be simply integrated to obtain velocity that can be compared to the EDR velocity. Direct integration of this acceleration, however, is not immediately comparable to the vehicle-fixed EDR velocity if the vehicle experiences post-impact yaw motion. In SINCAP MDB crash tests, the vehicles experience yaw rotation as illustrated in [Figure 2](#). This rotation causes the velocity to be dependent on the location of the sensor, as seen in [Figure 3](#). Although these effects could be overcome by a vehicle CG located accelerometer, the crash tests in our sample did not install an accelerometer at the true CG.

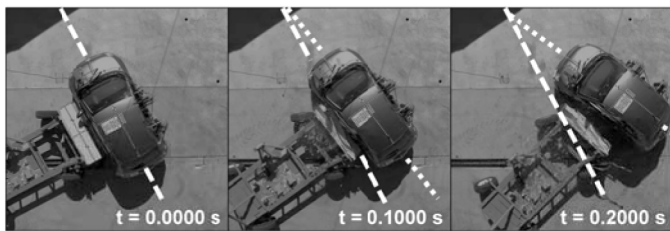


Figure 2. Still frames from an overhead video indicating rotation of a MY 2012 Fiat 500 (test no. 7507) during a side-impact new car assessment program moving deformable barrier test.

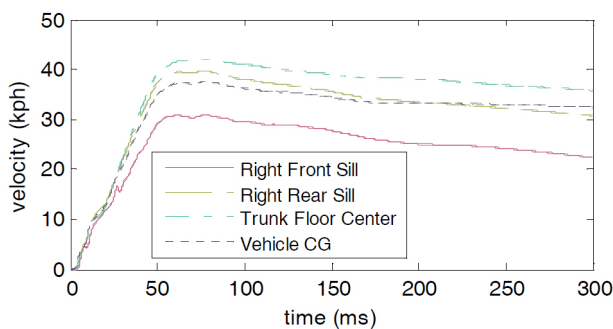


Figure 3. Directly computed velocity from accelerometers vary by sensor location in a rotating vehicle.

Most EDRs in our dataset provided delta-v measured from one sensor, however, Toyota EDRs report lateral delta-v from 3 sensors: the airbag ECU (electronic control unit), the B-pillar, and the C-pillar. [Figure 4](#) shows the lateral velocity measured from these sensors contrasted with reference velocity. The airbag ECU sensor was used for all Toyota EDRs in this study as it was unknown which side the pillar sensors are found.

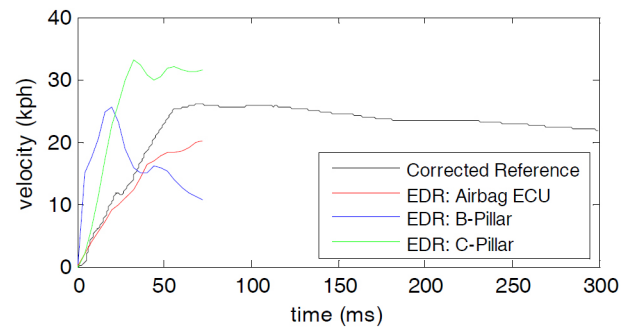


Figure 4. Three (3) lateral channels offered by Toyota EDRs shown in comparison to the rotation corrected reference velocity.

### Rotation Correction

Marine and Werner [5] applied rotational concepts from rigid body dynamics using two bi-axial accelerometers to solve for the test vehicle's angular velocity ( $\omega$ ) and angular acceleration ( $\alpha$ ). This method can be used to determine the acceleration of the CG within the vehicle-fixed coordinate system. This method ignores pitch and roll motion. Beyond the need for longitudinal and lateral accelerations from two sensors ( $A$  and  $B$ ), the relative distance of these accelerometers ( $r_A$  and  $r_B$ ) was also needed with respect to the true vehicle CG. Sensor locations, as well as the location of the true vehicle CG, were given in the test reports.

$$\alpha = \frac{(a_{A_x} - a_{B_x})(r_{B_y} - r_{A_y}) - (a_{A_y} - a_{B_y})(r_{B_x} - r_{A_x})}{(r_{B_x} - r_{A_x})^2 + (r_{B_y} - r_{A_y})^2} \quad (1)$$

$$\omega^2 = \frac{(a_{A_x} - a_{B_x})(r_{B_x} - r_{A_x}) - (a_{A_y} - a_{B_y})(r_{B_y} - r_{A_y})}{(r_{B_x} - r_{A_x})^2 + (r_{B_y} - r_{A_y})^2} \quad (2)$$

The components of acceleration at the true vehicle CG can then be solved from the addition of [Equation 1](#) and [Equation 2](#):

$$a_{CG_x} = \frac{1}{2} \left[ a_{A_x} + a_{B_x} + \alpha(r_{A_y} + r_{B_y}) + \omega^2(r_{A_x} + r_{B_x}) \right] \quad (3)$$

$$a_{CG_y} = \frac{1}{2} \left[ a_{A_y} + a_{B_y} - \alpha(r_{A_x} + r_{B_x}) + \omega^2(r_{A_y} + r_{B_y}) \right] \quad (4)$$

Prior to applying this approach, each channel was digitally filtered with a class 180 filter. The SINCAP crash tests had 4 NHTSA sensors on the non-struck side yielding 6 possible accelerometer pairs. The velocity at the CG was then obtained through trapezoidal integration of these accelerations for each of the 6 accelerometer pairs, as shown in [Figure 5](#). If all velocities exhibited normal behavior, then those with the 2 highest and 2 lowest maximum delta-v were discarded and the remaining 2 velocities were averaged. For some tests only 3

sensors were available, yielding 3 accelerometer pairs. If there was a range of maximum delta-v, only the middle pair was chosen. However, if two velocity pairs were similar, then they would be averaged and the third was discarded.

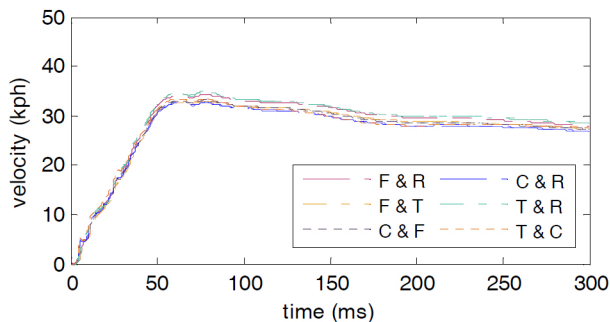


Figure 5. Six velocity pairs computed after rotation correction of four sensors: (F) right front sill, (R) right rear sill, (T) trunk floor center, and (C) vehicle center of gravity.

### Time Zero Alignment

The time zero for the reference data was measured by a constant switch closure, intended to capture the instant of vehicle-MDB first contact. For EDRs, the time zero may either be the time of algorithm wakeup or some other estimated time after impact, e.g. time of deployment. Thus, the velocity data of the reference and EDR may not occur over the same time scale.

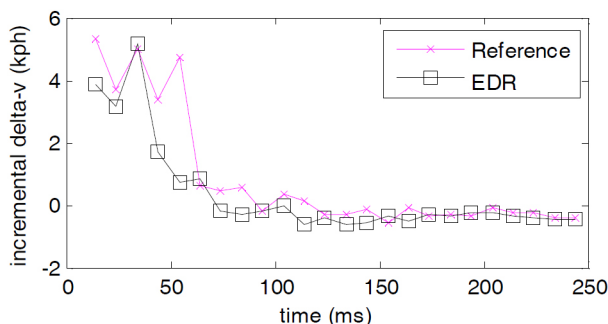


Figure 6. Initial calculation of incremental delta-v prior to time shift

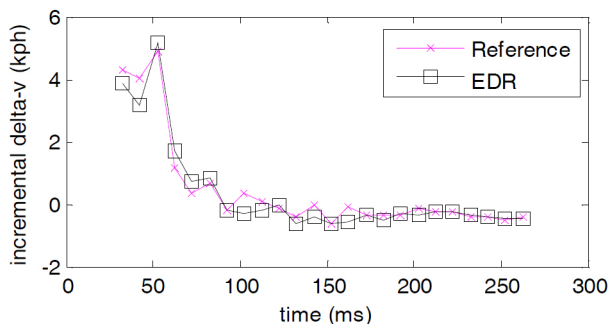


Figure 7. Optimized incremental delta-v with a time shift of 12.5ms

Time-zero alignment first involved calculating the change in velocity between each of the time steps, referred to here as incremental delta-v, over the entire range of EDR and averaged reference values. To find the time when the EDR and reference

incremental delta-v were most similar, the EDR incremental delta-v was shifted in time by the reference time step (i.e. 0.1ms, 0.05ms, or 0.08ms). The reference incremental delta-v was then summed in segments such that the time data matched the EDR incremental delta-v time data, shown in Figure 6. With the EDR and reference incremental delta-v data lined up, an array of differences were summed and squared to get a metric of best fit. This time shift allowed the EDR incremental delta-v to shift from -10ms to 30ms. An optimized time shift of incremental delta-v is shown in Figure 7. The original and time shifted EDR data is shown in Figure 8. The time shift was included only for visualization of lateral velocity reference and EDR overlay, seen in Table A-4, and had no effect on the analysis of delta-v accuracy presented in this paper. The authors 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 was 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 study.

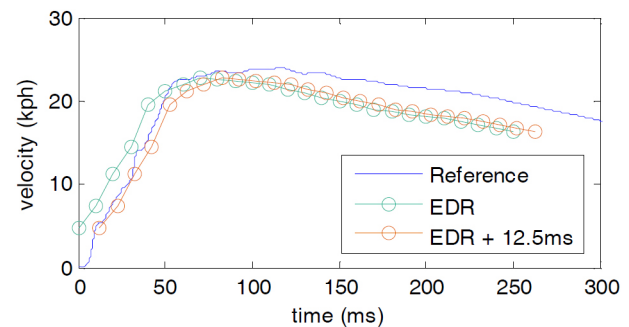


Figure 8. Sample time zero alignment shift where an EDR shift of 12.5ms resulted in the smallest sum of squares

### Seatbelt Buckle Status

This portion of the study examines seatbelt buckle status accuracy. The study asked two questions: (a) whether seat belt buckle status was recorded and (b) if recorded, whether the status was correct.

The SINCAP MDB tests were conducted with both the driver and left rear (or middle) row passenger belted. Post-crash photographs from the test reports were manually inspected to confirm the seatbelt buckle status and used as the reference value. The EDRs in our sample only recorded buckle information for the front occupants, i.e. seatbelt buckle status was only determined for the driver and right front passenger. In the tables which follow, a check mark indicates observed seatbelt use and an empty box indicates no seatbelt use during the crash test.

The EDR reports were manually examined for seatbelt use. In the tables which follow, a check mark indicates the report recorded that the seatbelt was buckled. An empty box indicates that the report recorded the seatbelt was not buckled. If the EDR was not configured to record seatbelt use, it was assigned the value "NC". If no seatbelt buckle status information was given within the report, it was marked as "NR".

## Airbag Deployment

This portion of the study examines airbag deployment accuracy. The study asked two questions: (a) whether airbag deployment status was recorded and (b) if recorded, whether the status was correct.

Post-crash photographs from the test reports were inspected manually to determine whether the curtain and/or torso airbags had deployed. Additionally, the driver frontal airbag deployment was also inspected. In the tables which follow, a check mark indicates that airbag deployment was observed in the photographs and an empty box indicates no airbag deployment. This information was checked against test report deployment tables. All tests deployed at least one type of side airbag. If the vehicle was not equipped with an airbag it was marked "NE" in the results.

Most EDRs indicated side airbag deployment status (Yes/No). Some EDRs recorded the time to deployment or time to criteria met for deployment, which is also included in the results. A non-zero number was assumed to imply an airbag deployment. The Honda Fit (7576) and the Honda Civic IMA (7713) EDR reports recorded a zero time to deployment without any accompanying data elements that specifically indicated deployment status. Honda was contacted regarding these cases and Honda determined that the EDR recorded a deployment after analysis of the HEX data.

In the following tables a check indicates that the EDR recorded a deployment and an empty box indicates the EDR recorded a non-deployment. The test reports described the side airbags as either torso airbags or side curtains. The EDR reports, however, sometimes used different terminology. "Thorax" airbags and "seat" airbags were included in the "torso" airbag classification. If a report only provided a "side airbag" deployment data element this was assumed to apply to all side airbags, *i.e.* "torso" and "curtain" airbags if equipped.

## RESULTS

Of the 75 EDRs in our dataset, 70 had an event recording complete flag. All 70 indicated that the event was successfully recorded, as shown in [Table A-1](#). Five (5) Toyota EDRs did not have recording status flags: the 2011 Tacoma (7103), 2011 Tundra Double Cab (7343), 2011 Corolla (7353), 2012 Tundra (7586), and 2012 Corolla (7749). None reported any diagnostic trouble codes which would indicate EDR recovery problems. However, the EDR reports did indicate that much of the HEX data was not imaged from the EDR into the report. Additionally, the report identified these modules to be from the "02EDR" ECU generation, among one of the oldest EDR families offered by Toyota. In addition to not reporting a recording status flag, these modules did not report any information regarding seatbelt buckle status or frontal airbag deployment. The remaining Toyota EDRs

in this analysis contain modules from later generations ("04EDR" and "06EDR"), suggesting that these data elements were either not recorded or not reported in these early modules.

## Delta-V

Of the 75 extracted EDRs, all 75 recorded lateral delta-v and 55 recorded longitudinal delta-v. The remaining 20 EDRs that did not record longitudinal delta-v were Toyota modules; none of the Toyota EDRs in this study recorded longitudinal delta-v.

The sensor pair used to compute the velocity at the CG, as well as the velocity at the CG, are reported in [Table A-3](#). Likewise, the time shifts are shown in that same table. For 6 EDRs, the final time shifts were negative: 2011 Toyota Camry (6952), 2011 Toyota Tacoma (7103), 2011 Ford Edge (7151), 2011 Buick Lucerne (7363), 2011 Toyota Scion tC (7364), and 2012 Dodge Journey (7473).

[Table 2](#) shows several error metrics by vehicle make for a comparison between the reference and maximum EDR lateral delta-v taken from the time series data. GM showed the lowest average absolute error with 2.07 kph (8.9%) and Toyota showed the greatest average absolute error with 6.34 kph (24.4%). As shown in [Table A-1](#), Toyota modules also represent the OEM with the shortest EDR recording duration, less than 100ms, with rarely more than 70ms recorded after algorithm enable.

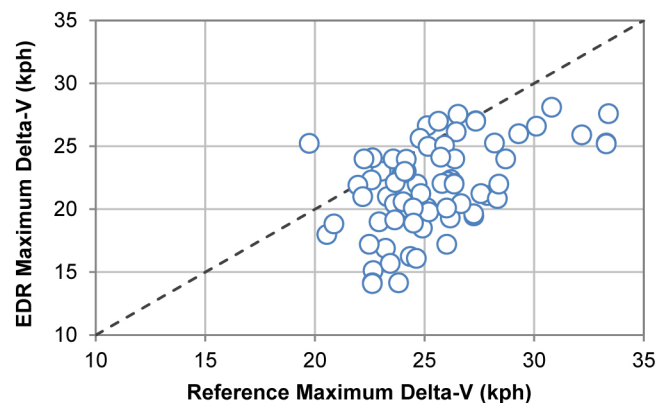


Figure 9. Distribution of EDR maximum delta-v with respect to the reference maximum delta-v, where the dotted line represents identical maximum values

Overall, the average absolute error was 4.05 kph (15.9%). Considering the EDRs individually, the 2011 Ram 1500 Crew (7111) showed the greatest lateral absolute error 8.5 kph (37.6%). The 2012 Toyota Tundra (7586) and the 2012 Scion iQ (7733) also showed absolute errors greater than 35%. The 2010 Chevrolet Camaro (6746), 2011 Jeep Grand Cherokee (7036), 2012 Ford Explorer (7492), and 2012 Chrysler 300 (7593) showed the smallest lateral arithmetic errors, less than 1%. Out of the 75 EDR reports that provided lateral delta-v, 66 under-predicted the rotation-corrected reference velocity, shown in [Figure 9](#).

Table 2. Comparison of reference instrumentation and EDR time series maximum lateral delta-v by vehicle make

| Vehicle Make   | n         | Avg. EDR Delta-V (kph) | Avg. Test Delta-V (kph) | Avg. Arithmetic Error (kph) | Avg. Absolute Error (kph) | RMS Error (kph) | Avg. Arithmetic Error (%) | Avg. Absolute Error (%) | RMS Error (%) |
|----------------|-----------|------------------------|-------------------------|-----------------------------|---------------------------|-----------------|---------------------------|-------------------------|---------------|
| Chrysler       | 16        | 20.59                  | 25.31                   | -4.73                       | 4.73                      | 5.45            | -18.6%                    | 18.6%                   | 21.6%         |
| Ford           | 17        | 23.23                  | 25.44                   | -2.21                       | 2.61                      | 3.37            | -8.4%                     | 9.9%                    | 12.6%         |
| GM             | 16        | 23.09                  | 23.84                   | -0.75                       | 2.07                      | 2.54            | -2.7%                     | 8.9%                    | 11.2%         |
| Honda          | 4         | 22.84                  | 25.89                   | -3.05                       | 3.05                      | 3.76            | -12.0%                    | 12.0%                   | 14.8%         |
| Mazda          | 2         | 24.54                  | 26.84                   | -2.29                       | 2.29                      | 3.04            | -8.7%                     | 8.7%                    | 11.6%         |
| Toyota         | 20        | 20.06                  | 26.40                   | -6.34                       | 6.34                      | 6.66            | -24.4%                    | 24.4%                   | 25.9%         |
| <b>Overall</b> | <b>75</b> | <b>22.14</b>           | <b>25.77</b>            | <b>-3.59</b>                | <b>4.05</b>               | <b>4.88</b>     | <b>-13.8%</b>             | <b>15.9%</b>            | <b>19.1%</b>  |

Table A-3 shows the arithmetic error for both delta-v comparisons. Table A-4 shows the overlay of corrected, averaged reference and EDR velocity and Table A-5 shows the overlay of incremental delta-v at the optimized time shift.

### Seatbelt Buckle Status

In all cases, if the driver seatbelt buckle status was recorded, then it was reported correctly. For the driver position, 70 out of 75 EDRs reported seatbelt buckle information. The remaining 5 EDRs did not report any information about seatbelt status. Of the 70 EDRs, 65 reports correctly recorded that seatbelt buckle status for the driver was buckled. The 5 remaining EDRs indicated that the module was not configured to record seatbelt buckle status for the driver.

Similarly, in all cases, if the right front passenger seatbelt buckle status was recorded, then it was recorded correctly. Out of the 75 EDR reports, 69 recorded seatbelt buckle information and 6 did not report any information. Sixty-four (64) of the 69 EDRs that reported passenger seatbelt buckle information correctly identified the seatbelt status: 63 were unbuckled and 1 was buckled (2011 Ford Range, test no. 7341). The 5 remaining EDRs indicated that the module was not configured to record seatbelt buckle status for the driver.

Of the 6 EDRs that did not report any information regarding seatbelt buckle status, 5 were Toyota EDRs: the 2011 Tacoma (7103), 2011 Tundra Double Cab (7343), 2011 Corolla (7353), 2012 Tundra (7586), and 2012 Corolla (7749). The remaining EDR was a 2012 Ford F250 Super Crew (7650). For the EDR reports that did not provide a seatbelt buckle status, 3 did not report for both the driver and the passenger, 2 reported only the driver status, and 2 reported only the passenger status. These results are shown in Table A-1. Although the MY 2010-2012 EDRs are not required to meet Part 563, seatbelt buckle status is a data element that must be recorded by MY 2013 and later EDRs.

### Airbag Deployment

For vehicles that reported frontal, side torso, or side curtain airbag deployment information, all vehicles recorded the correct status. Of the 75 vehicles analyzed in this study, all were equipped with a frontal airbag. All 75 vehicles were also

equipped with either a side torso bag or side curtain bag, where 64 were equipped with both, 5 were equipped with only the curtain airbag, and 6 were equipped with only the side torso airbag. These results are shown in Table A-2.

The side torso airbag deployed in all 70 equipped test vehicles. Of these, 66 EDRs offered a deployment status and 4 did not offer any deployment information regarding side torso airbags. These 4 vehicles were the 2011 Toyota Tacoma (7103), 2011 Toyota Tundra Double Cab (7343), 2011 Scion tC (7364), and 2012 Mazda Mazda3 (7448). Thirty-five (35) out of 66 EDRs reported side time to deployment, a data element in Table II of Part 563. Although the regulation does not apply to the vehicles in this analysis, Part 563 requires "side airbag" time to deploy in MY 2013 EDRs "if the data is recorded in non-volatile memory for the purpose of subsequent downloading."

The side curtain airbag deployed in all 69 equipped test vehicles. Sixty-five (65) out of 69 EDRs reported a deployment status. The remaining 4 EDRs did not offer any deployment information regarding curtain airbags. These 4 EDRs were the same modules that also did not report side torso airbag information even though they were equipped and deployed. Time to deploy was reported by 30 out of 65 EDRs that offered curtain airbag information. Curtain airbag time to fire is also a Part 563 Table II data element for MY 2013 vehicles.

For both the torso and curtain airbags, the Honda Fit (7576) and the Honda Civic IMA (7713) reports recorded 0ms for the time to deployment data element. The Honda reports did not contain a specific data element describing deployment. It was unclear from the report whether 0ms time to deployment meant that the airbag did not deploy or that the airbag deployed at time zero (T0). The Bosch CDR report data limitations for Honda EDRs 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).*

Honda looked at the report HEX data and Honda determined that both driver side airbags, *i.e.* torso and curtain, were deployed and that T0 in these tests was the time at which the airbag deployed.

Only 5 driver frontal airbags were deployed in all 75 side impact tests. All 5 were Toyota vehicles. Of these 5, only the 2010 4Runner (6861) and 2012 4Runner (7753) offered information about the frontal airbag. Both 4Runner modules reported a frontal airbag status correctly identified as deployed and a 2ms time to deployment. The remaining 3 vehicles did not offer any frontal airbag deployment information: 2011 Tacoma (7103), 2011 Tundra Double Cab (7343), and 2012 Tundra (7586). Note, although the EDRs in this analysis do not need to meet Part 563, frontal airbag time to fire is a [Table 1](#) required element.

## DISCUSSION

Niehoff *et al* (2005) [6] evaluated MY 2000-2005 primarily GM EDRs extracted from the Insurance Institute for Highway Safety (IIHS) and NHTSA crash tests across several impact configurations. For lateral crash tests alone ( $n=3$ ) they reported an average delta- $v$  error of 18.56% and 15.43% for the full crash pulse and at 100ms, respectively. The Niehoff study did not correct for vehicle rotation, but did note that vehicle yaw was a source of error. Comparatively, this study reported average maximum delta- $v$  errors of -2.7% (arithmetic) and 8.9% (absolute) for GM EDRs. These findings were more aligned with the errors Niehoff reported for frontal crashes: 5.82% error for the full crash pulse and 5.50% error at 100ms [6].

A more recent study by Gabler *et al* (2008) [7] also evaluated MY 2004-2007 EDRs that were primarily extracted from GM and Toyota vehicles from an array of crash modes. For EDRs that succeeded in recording the full crash pulse, Gabler reported that the absolute maximum longitudinal delta- $v$  error for side-impacts ( $n=3$ ) was 10.8%. This value was slightly higher than the 8.9% absolute error reported in this study for GM EDRs, which each recorded more than 250ms. Although the Toyota EDR findings in this study greatly exceed (24.4%) the side-impact error results by Gabler, more than half of their modules recorded more than 100ms [7].

Across a greater array of OEMs, the average errors of this study were consistent with the results of longitudinal delta- $v$  errors. A study by Tsoi *et al* (2013) [8], conducted on only MY 2012 frontal NCAP crash tests for 7 OEMs reported an average arithmetic error of -3.83 kph and an average absolute error of 4.32 kph for maximum longitudinal delta- $v$  [8]. In comparison, this study showed an average arithmetic error of -3.59 kph and an average absolute error of 4.05 kph.

The EDRs analyzed in this study were also susceptible to the many error sources highlighted in previous studies. For instance, accelerometer saturation has been acknowledged by NHTSA [9] and identified in the data limitations for some Bosch

EDR reports (*i.e.* Honda). Unfortunately the range of each manufacturer's accelerometers was not available to the authors; however, the Alliance of Automobile Manufacturers [10] and the Association of International Automobile Manufacturers [11] indicated that 50G accelerometers were commonly used in the fleet. Among the 75 crash tests, 20 (27%) lateral reference accelerations exceeded 50Gs after digital filtering and rotation correction ([Table A-3](#)): 2 Chrysler, 3 Ford, 2 GM, 2 Honda, and 11 Toyota. In this study, Toyota had the greatest error in lateral delta- $v$  due to underreporting.

As discussed by Gabler *et al* (2008) [7], underreported delta- $v$  also occurs in EDRs that record for a short duration, not sufficiently long enough to capture the entire crash pulse. This was evident among the Toyota EDRs in this study, as these modules reported the greatest inaccuracies, recording less than 100ms with rarely more than 70ms recorded after algorithm enable ([Table A-1](#)). Along the same lines, Comeau *et al* (2004) [12] discussed the initial delta- $v$  lost in the interval between the time of impact and the onset time of EDR recording. These findings were confirmed by Wilkinson *et al* (2013) [13] in MY 2005-2008 Toyota EDRs. For a low-speed rear-end crash, Wilkinson created a model incorporating a 2G trigger threshold and 0.4Gs bias. With these adjustments, the reference qualitatively recreated the EDR recorded values for longitudinal delta- $v$  [13]. Evidence of a 1G bias was additionally addressed by Chidester *et al* (1999) [2].

The EDR was not mounted on the true test vehicle CG and was susceptible to the same rotational effects that were corrected for in the reference. Although the Bosch CDR Tool provided make-, model-, and model year-specific information describing the occupant compartment region where the EDR can be found, an improved method would be to incorporate the exact EDR location into the rotational correction process. However, only 1 vehicle EDR was not located in the center tunnel or console. Thus, the authors expected this to make little difference in the results. As seen in [Table A-1](#), the 2012 Chevrolet Impala (7486) EDR was located under the right front seat. The absolute error for this vehicle was 4.8%, double the observed average for GM vehicles and slightly higher than average for all vehicles analyzed.

The authors would like to emphasize that the rotation correction indicated in this study was applied to the reference instrumentation. Relative to the vehicle reference frame in which the EDR reports its delta- $v$ , the average maximum lateral delta- $v$  was within 4 kph (15.9%) of the corrected sensor data. It is important to note that the presented accuracy results were based upon crash tests and only extend to real-world crashes similar to the SINCAP configuration. This limitation extends to side-impacts of the far side. Although it is tempting to assume symmetry of EDR accuracy, Wilkinson *et al* (2013) [13] showed discrepancies between front and rear-end crash modes in low-speed impacts. Wilkinson found EDR longitudinal delta- $v$  to be underreported in front impacts, but overreported in rear-end impacts [13].

## CONCLUSIONS

This study established the accuracy of EDR seatbelt buckle status, airbag deployment status, and delta-v measurements recorded during side-impact crash tests of MY 2010-2012 passenger vehicles. EDR values were compared with test reports and NHTSA accelerometers mounted to the non-impacted vehicle side. Following are our conclusions:

- Our results show that EDRs in SINCAP MDB crash tests underreported the reference lateral delta-v in the vast majority of cases. This is consistent with the error and conclusions found in some longitudinal EDR accuracy studies.
- For maximum lateral delta-v, the average arithmetic error was -3.59 kph (-13.8%), the average absolute error was 4.05 kph (15.9%), and the RMS error was 4.88 kph (19.8%).
- All EDR reports that offered a seatbelt buckle status data element correctly recorded the buckle status at both the driver and right front passenger locations.
- Six (6) EDRs did not offer any seatbelt buckle information for the driver and/or right front passenger. Seven (7) EDRs indicated that they were not configured to report information for one or both occupant seats. It should be noted that MY 2013 EDRs are required to indicate seatbelt buckle status for both front occupants by Part 563.
- For equipped vehicles that reported side torso, side curtain, and frontal airbag deployment information, all vehicles recorded the correct status.
- Of 70 torso airbags deployments, 4 EDRs did not report deployment data and 31 did not report time to fire. Of 69 curtain airbag deployments, 4 EDRs did not report deployment data and 35 did not report time to fire. Of 5 frontal airbag deployments, 3 did not report any deployment data. Although the EDRs in this study do not need to meet Part 563, time to fire is a [Table I](#) required data element for frontal crashes and a [Table II](#) data element for both side airbags.

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## ABBREVIATIONS

**AE** - Algorithm Enable

**CDR** - Crash Data Retrieval

**CFC** - Channel Frequency Class

**Part 563** - Code of Federal Regulations Title 49 Part 563

**CG** - Center of Gravity

**Delta-V** - Change in velocity

**ECU** - Electronic Control Unit

**EDR** - Event Data Recorder

**GM** - General Motors

**IIHS** - Insurance Institute for Highway Safety

**kph** - Kilometers Per Hour

**MDB** - Moving Deformable Barrier

**mph** - Miles Per Hour

**MY** - Model Year

**NC** - Not Configured

**NCAP** - New Car Assessment Program

**NE** - Not Equipped

**NHTSA** - National Highway Traffic Safety Administration

**OEM** - Original Equipment Manufacturer

**RMS** - Root Mean Square

**RP** - Recommended Practice

**SINCAP** - Side-Impact New Car Assessment Program

**T0** - Time Zero

## APPENDIX

Table A-1. Description of dataset EDR and reference instrumentation parameters

| Test No. | Make & Model             | Model Year | EDR Recording Properties |      |        | Bosch CDR Tool EDR Module Type | Bosch CDR Tool EDR Indicated Location               | EDR Recording Complete Status |
|----------|--------------------------|------------|--------------------------|------|--------|--------------------------------|-----------------------------------------------------|-------------------------------|
|          |                          |            | Freq (Hz)                | t(0) | t(end) |                                |                                                     |                               |
| 6652     | Ford Mustang             | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6653     | Ford Mustang             | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6734     | Ford Mustang             | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6737     | Ford Mustang             | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6743     | Ford Fusion              | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6746     | Chevrolet Camaro         | 2010       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 6789     | Chevrolet Equinox        | 2010       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 6792     | Buick Lacrosse           | 2010       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 6798     | Ford Taurus              | 2010       | 100                      | 0    | 250    | FordRC6_2010                   | Center tunnel                                       | Complete                      |
| 6813     | Dodge Avenger            | 2010       | 500                      | 0    | 298    | CHRY0305                       | Center stack                                        | Complete                      |
| 6827     | Cadillac SRX             | 2010       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 6861     | Toyota 4Runner           | 2010       | 250                      | -23  | 69     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 6944     | Toyota Sienna            | 2011       | 250                      | -24  | 68     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 6952     | Toyota Camry             | 2011       | 250                      | -21  | 71     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 6988     | Chevrolet Traverse       | 2011       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 7000     | Chevrolet Malibu         | 2011       | 100                      | -70  | 220    | Epsilon2006                    | Center tunnel                                       | Complete                      |
| 7036     | Jeep Grand Cherokee      | 2011       | 500                      | 0    | 298    | CHRY0305                       | Center stack                                        | Complete                      |
| 7070     | Buick Lucerne            | 2011       | 100                      | -70  | 220    | SDMC2008V                      | Center tunnel                                       | Complete                      |
| 7103     | Toyota Tacoma            | 2011       | 167                      | -24  | 54     | TOYOTA001                      | Under center stack                                  | Not Supported                 |
| 7111     | Ram 1500 Crew            | 2011       | 500                      | 0    | 298    | CHRY0403                       | Under center front seat or console                  | Complete                      |
| 7117     | Ford Escape              | 2011       | 100                      | 3    | 253    | FordRC6_2011                   | Center tunnel                                       | Complete                      |
| 7129     | Ram 1500 Quad            | 2011       | 500                      | 0    | 298    | CHRY0403                       | Under center front seat or console                  | Complete                      |
| 7130     | Ford Fusion              | 2011       | 100                      | 8    | 258    | FordRC6_2011                   | Center tunnel                                       | Complete                      |
| 7138     | Toyota RAV4              | 2011       | 250                      | -24  | 72     | TOYOTA001                      | Under center console                                | Complete                      |
| 7146     | Lexus RX350              | 2011       | 250                      | -23  | 69     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 7151     | Ford Edge                | 2011       | 100                      | 7    | 257    | FordRC62011CGEAB               | Center tunnel                                       | Complete                      |
| 7160     | Chevrolet Cruze          | 2011       | 100                      | -70  | 220    | SDM10                          | Center tunnel                                       | Complete                      |
| 7177     | Toyota Venza             | 2011       | 250                      | -24  | 68     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 7181     | Toyota Highlander        | 2011       | 250                      | -23  | 69     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 7193     | Dodge Caliber            | 2011       | 500                      | 0    | 298    | CHRY0305                       | Center tunnel before/aft of shifter or center stack | Complete                      |
| 7259     | Toyota Camry             | 2011       | 250                      | -21  | 71     | TOYOTA001                      | Under center stack                                  | Complete                      |
| 7341     | Ford Ranger              | 2011       | 100                      | 0    | 250    | FordRC6_2011                   | Center tunnel                                       | Complete                      |
| 7343     | Toyota Tundra Double Cab | 2011       | 167                      | -24  | 54     | TOYOTA001                      | Under center stack                                  | Not Supported                 |
| 7352     | Ford F150 Super Crew     | 2011       | 100                      | 3    | 253    | FordRC62011CGEAC               | Center tunnel                                       | Complete                      |
| 7353     | Toyota Corolla           | 2011       | 167                      | -24  | 54     | TOYOTA001                      | Under center stack                                  | Not Supported                 |
| 7355     | Ford F150 Super Cab      | 2011       | 100                      | 8    | 258    | FordRC62011CGEAC               | Center tunnel                                       | Complete                      |

Table A-1 (cont).

| Test No. | Make & Model            | Model Year | EDR Recording Properties |      |        |            | Bosch CDR Tool EDR Module Type | Bosch CDR Tool EDR Indicated Location | EDR Recording Complete Status |
|----------|-------------------------|------------|--------------------------|------|--------|------------|--------------------------------|---------------------------------------|-------------------------------|
|          |                         |            | Freq (Hz)                | t(0) | t(end) | total (ms) |                                |                                       |                               |
| 7363     | Buick Lucerne           | 2011       | 100                      | -70  | 220    | 290        | SDMC2008V                      | Center tunnel                         | Complete                      |
| 7364     | Toyota Scion tC         | 2011       | 250                      | -24  | 68     | 92         | TOYOTA001                      | Under center stack                    | Complete                      |
| 7367     | Buick Lacrosse          | 2011       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7392     | Chevrolet Volt          | 2011       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7448     | Mazda Mazda3            | 2012       | 100                      | 0    | 250    | 250        | MAZDA001                       | Center tunnel aft of shifter          | Complete                      |
| 7465     | Ford Mustang            | 2012       | 100                      | 8    | 258    | 250        | FordRC6_2011                   | Center tunnel                         | Complete                      |
| 7469     | Dodge Avenger           | 2012       | 500                      | 0    | 298    | 298        | CHRY0305                       | Center stack                          | Complete                      |
| 7470     | Ford Focus              | 2012       | 100                      | 0    | 250    | 250        | FordAB10                       | Center tunnel                         | Complete                      |
| 7473     | Dodge Journey           | 2012       | 500                      | 0    | 298    | 298        | CHRY4101                       | Center stack                          | Complete                      |
| 7484     | Chrysler 200            | 2012       | 500                      | 0    | 298    | 298        | CHRY0305                       | Center stack                          | Complete                      |
| 7486     | Chevrolet Impala        | 2012       | 100                      | -70  | 220    | 290        | SDM11_AUTOLIVNEW               | Under RF seat                         | Complete                      |
| 7492     | Ford Explorer           | 2012       | 100                      | 6    | 256    | 250        | FordRC62011CGEAD               | Center tunnel                         | Complete                      |
| 7493     | Chevrolet Camaro        | 2012       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7507     | Fiat 500                | 2012       | 500                      | 0    | 298    | 298        | CHRY0000                       | Center stack                          | Complete                      |
| 7510     | Chevrolet Suburban 1500 | 2012       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7517     | Toyota Camry            | 2012       | 250                      | -23  | 69     | 92         | TOYOTA001                      | Under center stack                    | Complete                      |
| 7519     | Cadillac CTS            | 2012       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7528     | Dodge Durango           | 2012       | 500                      | 0    | 298    | 298        | CHRY0305                       | Center stack                          | Complete                      |
| 7534     | Cadillac SRX            | 2012       | 100                      | 10   | 300    | 290        | SDM10P                         | Center tunnel                         | Complete                      |
| 7537     | Mazda Mazda6            | 2012       | 100                      | 0    | 250    | 250        | MAZDA002                       | Center tunnel, below instrument panel | Complete                      |
| 7541     | Ford Expedition         | 2012       | 100                      | 2    | 252    | 250        | FordRC6_2011                   | Center tunnel                         | Complete                      |
| 7563     | Chevrolet Sonic         | 2012       | 100                      | -70  | 220    | 290        | SDM10                          | Center tunnel                         | Complete                      |
| 7561     | Jeep Liberty            | 2012       | 100                      | 0    | 298    | 298        | CHRY0305                       | Center stack                          | Complete                      |
| 7576     | Honda Fit               | 2012       | 100                      | 0    | 298    | 298        | HONDA001                       | Under dashboard, center               | Complete                      |
| 7586     | Toyota Tundra           | 2012       | 166.7                    | 0    | 250    | 250        | TOYOTA001                      | Under center stack                    | Not Supported                 |
| 7593     | Chrysler 300            | 2012       | 500                      | 0    | 298    | 298        | CHRY4005                       | Center stack                          | Complete                      |
| 7602     | Toyota Yaris            | 2012       | 250                      | -21  | 71     | 92         | TOYOTA001                      | Under center stack                    | Complete                      |
| 7604     | Dodge Charger           | 2012       | 500                      | 0    | 298    | 298        | CHRY4005                       | Center stack                          | Complete                      |
| 7640     | Lexus ES350             | 2012       | 250                      | -23  | 69     | 92         | TOYOTA001                      | Under center stack                    | Complete                      |
| 7648     | Honda Civic             | 2012       | 100                      | 0    | 250    | 250        | HONDA001                       | Under dashboard, center               | Complete                      |
| 7650     | Ford F250 Super Crew    | 2012       | 100                      | 4    | 254    | 250        | FordRC62011CGEAD               | Center tunnel                         | Complete                      |
| 7713     | Honda Civic IMA         | 2012       | 100                      | 0    | 250    | 250        | HONDA001                       | Under dashboard, center               | Complete                      |
| 7733     | Scion iQ                | 2012       | 250                      | -24  | 68     | 92         | TOYOTA001                      | Under center console                  | Complete                      |
| 7738     | Toyota RAV4             | 2012       | 250                      | -24  | 72     | 96         | TOYOTA001                      | Under center console                  | Complete                      |
| 7745     | Ram 2500 Crew Cab       | 2012       | 500                      | 0    | 298    | 298        | CHRY0403                       | Under center front seat or console    | Complete                      |
| 7749     | Toyota Corolla          | 2012       | 166.7                    | -24  | 54     | 78         | TOYOTA001                      | Under center stack                    | Not Supported                 |
| 7750     | Honda CR-V              | 2012       | 100                      | 0    | 250    | 250        | HONDA001                       | Under dashboard, center               | Complete                      |
| 7753     | Toyota 4Runner          | 2012       | 250                      | -24  | 68     | 92         | TOYOTA001                      | Under center stack                    | Complete                      |
| 7768     | Fiat 500                | 2012       | 500                      | 0    | 298    | 298        | CHRY0000                       | Center stack                          | Complete                      |