

Accuracy of Event Data Recorder in 2010 Ford Flex During Steady State and Braking Conditions

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ABSTRACT

The accuracy of the Restraint Control Module (RCM) Event Data Recorder (EDR) was tested on a 2010 Ford Flex during both straight line steady state and maximum ABS braking. Six runs were made starting from 48 kph (30 mph), six runs starting from 80 kph (50 mph), and six runs starting from 113 kph (70 mph). Nondeployment events were artificially induced after a period of steady state driving followed by maximum braking for the last 2.5 seconds prior to creating the event, intended to simulate braking just prior to a crash. Following each run data was collected from the RCM EDR using the Bosch Crash Data Retrieval system. A Racelogic VBOX SL3 20 Hz differential GPS speed data recorder also served as a data acquisition system for vehicle CAN bus speed, accelerator position, RPM, and brake tape switch data. Graphs of RCM speed/brake/accel pedal data versus VBOX speed and other data over time are presented. The differences between RCM and VBOX speed are plotted and fitted to linear model using the method of least squares. Under steady state conditions the RCM EDR average under-reporting error was 1.4% at 113 kph (70 mph), and the 99% confidence interval was within 2.5% at 113 kph (70 mph). During hard braking the EDR under reports an average of 3 kph (1.9 mph) compared to VBOX GPS, with a worst case of 6.8 kph (4.2 mph) at approximately 60 kph (37.2 mph), due to the expected wheel slip during hard braking.

INTRODUCTION

PURPOSE

The 2010 Ford Flex Restraint Control Module EDR is one of the first EDR's to give 11 data points at 0.5 second intervals

spanning 5 seconds per the intent of the Code of Federal Regulation, Title 49, Part 563 EDR rule that becomes effective in September 2012, and hence it is a glimpse into the usefulness of that type of data to accident reconstruction into the near future. The module is manufactured by Autoliv and is known within Ford and Autoliv as the "RC6". Per the Part 563 intent, it is also designed to have sufficient reserve power to complete recordings even when battery power is lost during a crash, so it increases the likelihood of getting reliable and complete recording even in severe impacts when compared to previous airbag control module families. Previous GM EDR's had 5 speed data points at 1 second intervals, or 5 data points at 0.5 second intervals, and prior Ford Restraint Control Modules that did have precrash speed data recorded had 5 data points at 1 second intervals. This EDR does not have as much data as some new Chrysler models which may record as many as 50 data points at 0.1 second intervals spanning 5 seconds before the crash.

In addition, the 2010 Ford Flex Autoliv RC6 it is the most recent Ford EDR released to the Bosch CDR system, and was first introduced in the 2009 Escape. The RC6 marks the consolidation of what have been two separate event data recorders in some Ford vehicles, the Restraint Control Module and the Powertrain Control Module. When Ford introduced the PCM data recorder in 2003 in models with Electronic Throttle Control (ETC), the RCM's were recording only acceleration data and had no precrash speed data. Ford began to phase in speed data recording into RCM's in some 2005 models, but typically 5 data points or less at 1 second intervals, and there are still some RCM modules with no precrash speed data in them. The second EDR in the ETC PCM's typically recorded 127 speed data points at 0.2 second

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intervals spanning 25.4 seconds, but only locked the data if there was a restraint deployment signal. Data was typically overwritten by post crash data in non-deployment crashes. With the installation of the Restraint Control Module approaching Part 563 intent, Ford is removing the separate EDR function in the PCM. This evolution will result in a reduction in the number of data points in models that had PCM recorders but is more than made up for by the increased likelihood of getting complete recordings reliably in both low severity and high severity collisions, and the additional data available in the RC6. Ford has added information from the stability control system yielding longitudinal acceleration, lateral acceleration, steering angle, and roll rate at 0.1 second intervals for 5 seconds before a crash. This will assist reconstructionists in determining changes in approach angle from swerves before impact.

The added benefit of this study is the expanded use of the VBOX as a vehicle CAN data acquisition system. Since precrash data in the EDR originates as values being transmitted on the vehicle CAN bus, the EDR data can be synchronized to the VBOX data via matching EDR CAN data to VBOX data acquisition system CAN data.

LITERATURE REVIEW

The accuracy of various event data recorders has been documented in various vehicle models and model years, and under some varying conditions including straight ahead steady state driving and under braking and yaw conditions. Accuracy has been expressed in absolute terms and as a percentage. The chart below summarizes the published findings to date - and if the original authors did not express the data as a percentage, where possible these authors have converted the data to a percentage. Not all the research is done at the same speed, but if multiple speed ranges were tested, the authors have cited accuracy at highway speeds. Consult the individual papers for more specific results. Since the first (1999) publication stated EDR speed data accuracy was within $\pm 4\%$, the vast majority of published test data has shown EDR's to be more accurate than 4%, and many show it to be within 1%. There is one exception in the 2008 Gabler paper that reported a single data point with a 22% error.

Chidester (1) in 1999 jointly with General Motors authors which, while unstated, is believed to apply to steady state conditions. Lawrence (2) tested early 2000 decade GM EDR's and published steady state speed data accuracy was ranged from over reporting 1.5 kph (0.8 mph) at low speed to underreporting 3.7 kph (2.3 mph) at higher speeds. Niehoff (3) reported GM EDR speed accuracy during barrier crash test conditions (typically 48 kph (30 mph), some as high as 56 kph (35 mph)) was within 1.1% on average and 3.7% worst case in 2004. Ruth (4) reported that the 2005 Crown Victoria PCM EDR tested from 48 kph (30 mph) to 113 kph

(70 mph) had a maximum steady state under-reporting error of 0.9% at 48 kph (30 mph) and an average under reporting error of 0.1%. The 2007 Lincoln Town Car PCM had a maximum over-reporting error of 0.4% and an average over-reporting error of 0.25%. The 2007 Ford 500 PCM had a maximum under-reporting error of 0.7% and an average under-reporting error of 0.3%. Ruth (5) reported that the 2008 Ford Edge RCM speed data at 113 kph (70 mph) had a maximum under reporting error of 0.6% and an average under reporting error of 0.2%, and the PCM speed data had a maximum under reporting error of 0.7% and an average under reporting error of 0.3%. In the same paper the 2008 Ford Focus RCM speed data at 113 kph (70 mph) had a maximum under reporting error of 1.0% with an average under reporting of 0.8%, and the PCM had the same values. Ruth and Reust (6) reported the 2008 Jeep Commander airbag control module EDR accuracy at 113 kph (70 mph) was a maximum under reporting of 1.0% with an average under reporting of 0.2%, and the 2008 Dodge Dakota at 113 kph (70 mph) had a maximum under reporting difference of 2.3% and an average under reporting difference of 1.8%. Ruth and Brown (7) reported the 2009 Ford Crown Victoria PCM EDR speed data at 97 kph (60 mph) had a maximum under reporting error of 0.8% and an average under reporting error of 0.2%. Bortolin (8) reported that the 2008 Dodge Grand Caravan minivan EDR had a maximum under reporting of 1.79 kph (1.1 mph) and an average under reporting error of 1.1 kph (0.7 mph). They further noted that the EDR speed data had fractions truncated to the next lower whole speed. However, wheel rpm data was reported to a resolution of 1rpm, and when converted to speed, the maximum error was reduced. Gabler (12) reported that in NHTSA full system crash tests between 40 and 56 kph (25 to 35 mph) of GM, Ford, and Toyota models that EDR reported speed prior to impact was within $\pm 3\%$, with one exception that was under reported by 22%. All the data cited above is under steady state operating conditions.

Accuracy during heavy braking conditions was first reported by Ruth and Reust (9) & (10). The 2005 Ford Crown Victoria PCM EDR under-reported ground speed by a maximum of 8mph at 60 mph, and showed a graph of all data that suggested the lower the speed, the less the error, but did not give a linear mathematical relationship.

Ruth and Reust (11) reported that for the 2008 Jeep Commander, during the initial application of brakes, the brake may significantly slow the wheel before ABS activates and relieves the brake pressure, leading to a significant under-reporting at initial brake application. After the initial application period was over, the average under-reporting speed difference between EDR and actual ground speed could be described by the best fit equation of $-0.55 - 0.48(\text{Speed in mph})$. For the 2008 Dodge Dakota they reported the best fit equation after initial engagement was $-0.48 - 0.046(\text{Speed in mph})$.

Table 1

<u>Author</u>	<u>EDR Type</u>	<u>Avg. Error</u>	<u>Max. Error</u>
Chidester (1)	GM SDM		4%
Lawrence (2)	GM SDM		over 1.5 kph low speed under 3.7 kph hi speed
Niehoff (3)	GM SDM & various	1.1%	3.7%
Ruth/Engle/Reust (4)	Ford PCM - 05 Cr Vic	under 0.1%	under 0.9%
	Ford PCM - 07 500	under 0.3%	under 0.7%
	Ford PCM - 07 Tn Cr	over 0.1%	over 0.25%
Gabler (12)	GM, Ford, Toyota ACM	within 3%	under 22%
Ruth/West/Nasrallah (5)	Ford RCM - 08 Edge	under 0.2%	under 0.6%
	Ford PCM - 08 Edge	under 0.3%	under 0.7%
	Ford RCM - 08 Focus	under 0.8%	under 1%
Ruth/Reust (6)	Chrysler ACM - 08 Commander	under 0.2%	under 1%
	Chrysler ACM - 08 Dakota	under 1.8%	under 2.3%
Bortolin (8)	Chrysler ACM - 08 Caravan	under 1.1 kph	under 1.8 kph
Ruth/Brown (7)	Ford PCM - 09 Cr Vic	under 0.2%	under 0.8%

mph). This was further described in more approximate terms as 0.5 mph plus 5% of speed.

Bortolin (8) reported that during braking the 2008 Dodge Caravan had a maximum under-reporting of 2.49 mph at 34 mph and an average error of 0.76 mph over the 20-60 mph speed range tested. Bortolin did not attempt to describe the error as a function of speed.

Ruth (7) reported the 2009 Ford Crown Victoria underreported during braking and gave an average best fit relationship of speed underreporting error equal to $-0.85 - 0.0397 * (\text{Speed in kph})$. While the intercept did not go through zero, Ruth suggested that this equated to a nominal 5% at highway speeds.

TEST PROCEDURE

DESCRIPTION OF THE TEST VEHICLE

The test vehicle was a front wheel drive 2010 Ford Flex, VIN 2FMGK5CC9ABA49768, with approximately 23,000 miles on its Goodyear P235/60R18 tires. Tires were inflated to the factory recommended 35 psi. The test driver accelerated the vehicle to a predetermined speed of 113 kph (70 mph), 80 kph (50mph) or 48 kph (30 mph) and then stabilized the speed for a minimum of 5 seconds. The driver gave a slight blip to the accelerator pedal to assist in identifying event timing. Then the driver released the accelerator pedal as quickly as practical and applied the brake with the intention of achieving maximum ABS braking. Approximately 2.5 seconds after braking was initiated, a nondeployment event was artificially induced into the RCM to create a recording.

The event was induced by mounting the RCM on a slide mechanism held by multiple strong springs against one end of the test fixture (see photo in [appendix](#)). The slide travel was marked on the fixture every 1" to allow the operator to pull the slide back to approximately the same point for each test run. Pre-testing was done to establish the minimum pull necessary to reliably set a non-deployment event. This travel marker does not rise to the level of delivering a "calibrated" hit, and no effort was made to match the crash pulse shape to that representative of a real world crash. The intent was simply to create an event that would meet the precrash data recording threshold. The operator would manually pull the slide back to a travel of approximately 16 cm (6.5") and release it after the 2.5 seconds of braking. The driver continued braking until the vehicle stopped.

At the end of each run and the RCM EDR data was obtained using the Bosch Crash Data Retrieval system, software version 3.51, using the provided Ford RCM adaptor and a cable connecting directly to the RCM.

Occasionally, due to the strength required to operate the fixture and the extreme nature of the braking, the fixture would tip slightly and in some cases set a rollover deployment event. The EDR has two event registers. The first nondeployment goes in the first register, the second into the second, the third overwrites the first, the fourth overwrites the second, etc. When a deployment occurs it locks in the second register but the tester can continue to set nondeployment events in the first register. When a second deployment event occurs then both registers are locked and no additional events can be recorded.

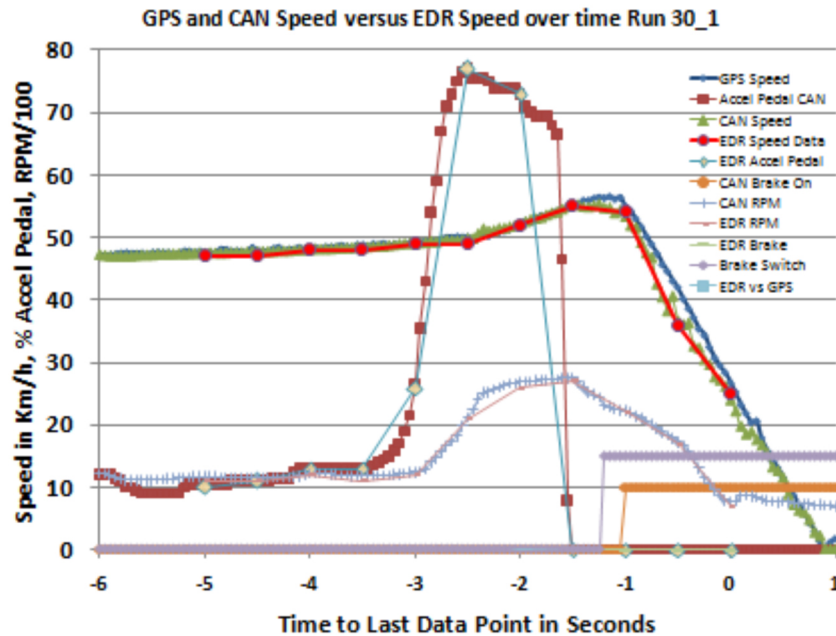


Figure 1.

SYNCHRONIZING DATA SOURCES

The EDR data was synchronized to the VBOX GPS speed by matching both accelerator pedal and speed data from the EDR to the vehicle CAN bus accelerator pedal and speed data.

The synchronized VBOX GPS, Vehicle CAN speed, and EDR data are plotted side by side as well as accelerator pedal position and RPM. The external brake tape switch status is plotted as 0=Off, 15=On, and the EDR brake status is plotted as 0=Off, 10 = On. A representative graph is shown in [Figure 1](#).

Graphs from all 18 hard braking test runs are shown in the [appendix](#). The brake tape switch did not operate properly in runs 70_4, 70_5, or 70_6. The switch was not secured adequately and worked its way out of position during numerous hard pedal applications.

During the analysis of the data from the first 18 test runs, the authors explored the possibility that the error between the EDR and GPS signal may be dependent not just on speed but also on the de-acceleration rate. All the data in the 18 test runs was at maximum de-acceleration, and some data at intermediate levels of de-acceleration was needed. By this time the authors had a good understanding that the EDR was recording a truncated version of the Vehicle Speed Sensor (VSS) data that was on the vehicle CAN bus. The authors decided that VBOX GPS and CAN bus VSS data alone was sufficient for the purpose of understanding the relationship between de-acceleration rate and GPS to vehicle speed sensor data. 26 additional test runs were made braking from

approximately 80 kph (50 mph) to a stop at a wide variety of braking rates, using only the VBOX data acquisition system, without setting EDR events. This generated a large amount of data, perfectly synchronized because it was all within one data acquisition system on the same time base. This second data set was used for some of the model development and validation.

DATA ANALYSIS AND RESULTS

For each run, the data were broken into two phases: 1) without braking and 2) with braking. Since the tests were for maximum braking on the same surface, the deceleration phase of the test activated the ABS system. This gave the most difference in the wheel slip because of the aggressive braking action.

EDR TO GPS SPEED DIFFERENCES

The EDR reported speed was subtracted from the GPS speed recorded by the VBOX. This difference is plotted against the EDR speed for the case when brakes were on and when they were off. A linear speed model was proposed for both sets of data based on previous. The linear model can be written as $y = mx + b$ where $y = \text{GPS speed} - \text{EDR speed}$ in kph and $x = \text{EDR speed}$ in kph. This gives a unitless slope and an intercept with units of kph.

Once the values of the slope and intercept are found based on the method of least squares, bounds for future values of the speed difference can be calculated. So long as conditions are similar to the testing conditions, the prediction of a future value for y is

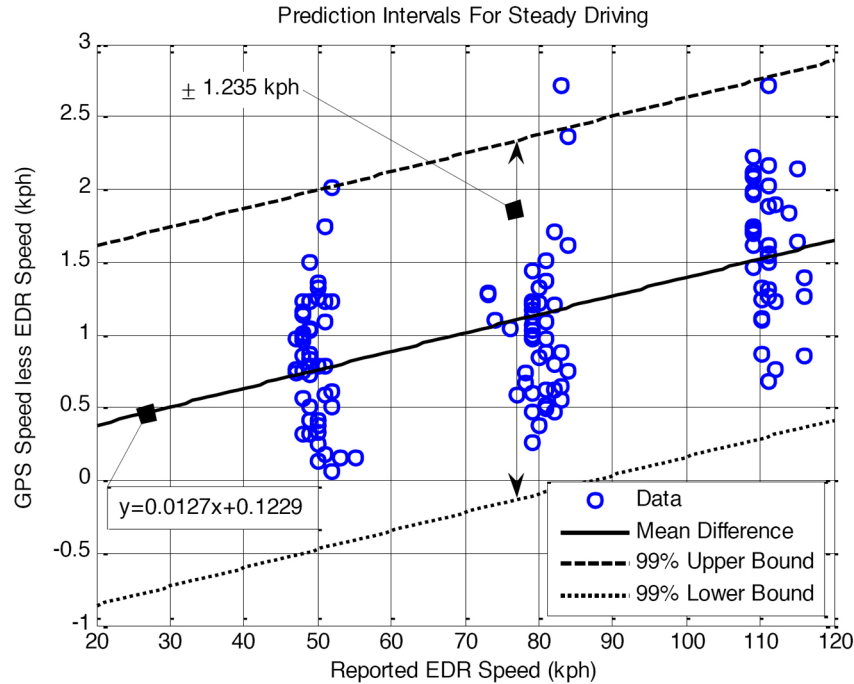


Figure 2. Difference of GPS reported Speed and EDR reported Speed for data without the brakes applied. Note that all the EDR reported speed data was lower than the GPS data since no data fell below zero.

$$y_{predict} = (mx + b) \pm t_{\alpha/2} s \sqrt{1 + \frac{1}{n} + \frac{(x - \bar{x})^2}{SS_{xx}}}$$

where x is a future value of the EDR speed, m is the slope, b is the intercept, $t_{\alpha/2}$ is the student-t statistic for the $(1 - \alpha)$ prediction interval, n is the number of data points, $\bar{x}$ is the mean value of the EDR speeds reported, and $SS_{xx} = \sum_{i=1}^n (x_i - \bar{x})^2$. These values are reported in Table 2 and the bounds are plotted in Figures 1 and 2. Since the bounds have dependence on x , the prediction intervals have curved boundaries. Therefore, a minimum interval can be calculated at the average EDR speed (i.e. when the $(x - \bar{x})$ term is zero). The minimum prediction interval is reported at the bottom of Table 2.

Steady Driving

There were three different speeds from which the driving tests were conducted. Therefore, there are three groups of speed difference data shown in Figure 2. A best fit line in a least-squares sense is plotted on the data along with the 99% confidence bounds. These data show all data were within the range of 0 to 3 kph (0 to 1.9 mph), which means the EDR for this vehicle was always underreporting the GPS speed data. It is important to note that there was no significant acceleration during these tests and wheel slip was not suspected. Therefore, these data represent a baseline for EDR accuracy at highway speeds.

Aggressive Braking

All EDR braking data is aggregated and shown in Figure 3. These data may include points where the brakes had been applied for only a short time and brake pressure had not been built. Also included are points that could be considered part of an “initial engagement” period where the wheel slip builds before the ABS systems engages. In prior studies, points before full braking were achieved and during initial engagement were excluded before looking for a mathematical relationship during braking after initial engagement. Those prior studies all dealt with EDR's that report at more frequent intervals than the RC6. Due to the reduced number of data points collected at the half second intervals, initial engagement data was not discarded.

In all cases during braking, the EDR reported speed was less than the VBOX GPS reported speed. The average difference was 2.75 kph (1.7 mph), with the worst case of 6.74 kph (4.2 mph) at approximately 60 kph (37 mph). A 99% tolerance band is shown surrounding the best fit line in Figure 3.

Regression Analysis Results

The data summary listed in Table 2 shows the summary statistics of the overall speed differences and the statistics of the applied linear model. A Lilliefors test [14] was applied to the distribution of the residuals to test whether the residuals followed a normal distribution. For both the braked and non-braked data, the Lilliefors test suggested that distribution of the residuals indeed followed a normal distribution, thus satisfying an assumption of linear regression.

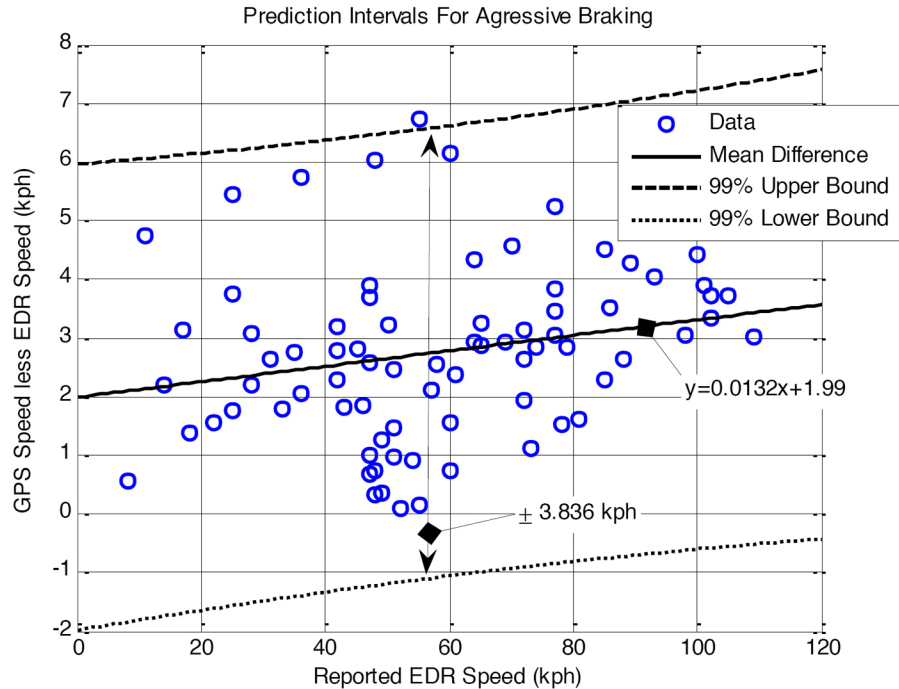


Figure 3. Difference in EDR Speed as a function of EDR speed. The EDR underreported all speeds.

Particularly interesting results from the regression analysis are the confidence bounds for the slope and intercept terms. For the case of no braking (shown in [Figure 2](#)), the confidence interval for the intercept includes zero. This means the numerical value of the intercept is due only to the scatter of the data. Therefore, the intercept term is insignificant and can be treated as zero. Also, for the braking data shown in [Figure 2](#), the slope term has a confidence interval that includes zero. This means the data does not support the idea that there is speed dependence on the difference between the EDR and the GPS speed. This observation is contrary to some of the prior research. If speed dependence is suspected, then more data is needed to reduce the uncertainty of the slope of the line in [Figure 3](#).

EDR TO CAN SPEED DIFFERENCES

The expected EDR value can be derived from the individual parameter CAN data. Once the relationship of EDR data to individual parameter CAN message data is known, it may no longer be necessary to set events in the EDR to test EDR accuracy. This is true for speed, accelerator pedal position, RPM, and brake on off data. This section describes the relationship of the CAN data to the data stored in the EDR.

Data Truncation

The 2010 Ford RC6 designers created a unique “EDR data” CAN bus message from to go from the Powertrain Control Module to the Restraint Control Module. This special CAN bus message is designed to meet the intent of the U.S. CFR, Title 49, Part 563 Table III recorded data element format. For

example, speed is reported in whole kph, accelerator pedal position to a whole percent, and RPM in whole hundreds. The special CAN message is sent every one-half second. These same parameters may exist in the vehicle and in other CAN messages to a greater precision, and are updated on the bus at a greater frequency. For example, Vehicle Speed Sensor (VSS) data is transmitted as a separate CAN message with a precision of 0.01 kph at nearly 30 times per second. Accelerator pedal position is transmitted with a precision of 0.5%, and RPM is transmitted with a precision of 0.25 RPM. By comparing the individual CAN message data to the EDR data it is clear the EDR truncates data and reports the next lower whole value. Because the EDR speed data is truncated, it introduces a random error uniformly distributed from 0 to -1 kph (0 to 0.6 mph). This means the reported values in an EDR are, on average, 0.5 kph (0.3 mph) lower than the values reported on the CAN bus VSS signal. The truncation effect is illustrated for EDR vehicle speed and the CAN Vehicle Speed Sensor (VSS) message as shown below in [Figure 4](#).

Data Timing

The CAN VSS update rate is approximately 30 Hz, but the VBOX sampling rate is only 20 Hz. The VSS data may change in between VBOX samples, and it is possible for an EDR data point to be a truncation of one of these VSS values not captured by the VBOX. The authors did, on occasion, observe an EDR data point that was slightly different than the VSS truncation, which is due to the slower VBOX sampling rate. The slower VBOX sampling rate means some of the intermediate VSS data was not captured.

Table 2. Summary statistics for the linear speed model for EDR speed differences.

<i>Parameter</i>	<i>No Braking Figure 1</i>	<i>With Braking Figure 2</i>
Number of Runs	18	18
Number of Data Points, n	129	77
Average EDR Speed, $\bar{x}$ (kph)	78.8	57.85
Sum of Squares of x , SS_{xx}	8124	4537
Mean overall difference, $\bar{y}$ (kph)	1.125	2.751
Standard Deviation of y (kph)	0.5675	1.468
Maximum difference (kph)	2.716	6.738
Minimum difference (kph)	0.0625	0.0970
Slope, m	0.0127	0.0132
Intercept, b	0.1229	1.9884
Sum of Squares of the Residuals, SSE	28.09	155.82
Estimate of the Variance of the Residuals, s^2	0.2212	2.0776
Coeff. of Determination, $R^2 = 1 - \frac{SS_y}{SSE}$	0.3186	0.0482
Standard Error of m	0.00165	0.00677
Standard Error of b	0.136	0.4245
Student-t value for 99%, $t_{\alpha/2}$	2.6154	2.6439
99% Confidence Bounds on m	(0.0084, 0.0170)	(-0.0047, 0.0311)
99% Confidence Bounds on b	(-0.2340, 0.4798)	(0.8660, 3.1108)
99% Prediction Interval for y at $\bar{x}$ (kph)	+/- 1.235	+/- 3.836

GPS Speed Data and CAN Speed Data

To reduce the effects of random variation in the VBOX GPS based speed, the five data points surrounding the synchronized point were averaged before the difference to the EDR reported speed was taken. VBOX claims 0.1 kph (0.06 mph) accuracy when 4 data points are averaged; however, 5

points gave a symmetrical average with 2 on either side of the point being tested. See [Figure 5](#).

Dependence on Acceleration

Since wheel slip typically occurs when the tires transmit traction force to the road, it was surmised that the CAN Speed and GPS Speed difference may be attributable to the