Accuracy of Powertrain Control Module (PCM) Event Data Recorders

Richard R. Ruth
Ruth Consulting LLC

Orrin West and Jim Engle, Timothy J. Reust
Ford Motor Company, Accident Sciences, Inc.

ABSTRACT
The primary purpose of this paper is to evaluate the accuracy of speed data recorded in the Ford PCM under steady state conditions. The authors drove 3 different test vehicles at 5 different steady state speeds from 48 to 113 kph (30 to 70 mph), making 6 runs at each speed. The authors collected PCM data after each run. For the first vehicle a GPS based Racelogic VBOX III was used to measure speed. For the second and third vehicle a purpose built speed trap with .0001 second resolution was used. The authors compare the readings and calculated differences and statistical limits. The secondary purpose is to deliberately create conditions that could result in errors of speed measured, document the conditions, and to quantify the error.

INTRODUCTION
Prior papers have assessed the accuracy of pre crash speed data in automotive event data recorders such as General Motors Sensing and Diagnostic Modules (SDM’s). Chidester (1999) stated the accuracy was 4%. Lawrence (2003) tested vehicles using a 5th wheel and found SDM speed to be over reported by 1.5 kph at low speeds and under reported by 3.7 kph at high speeds up to 150 kph. Niehoff (2005) reported on 28 crash tests from 40 to 64 kph and determined the average error in pre-impact speed was 1.1% with a maximum error of 3.7%. Reust (2006) reported accuracy under dynamic conditions within +/- 2.4 kph (1.5 mph) from 1 to 122 kph (76 mph) in light acceleration and +/- 2.4 kph (1.5 mph) in heavy acceleration from 1 to 143 kph (89 mph), and +0.8/-3.2 kph (0.5/-2.0 mph) during coasting. To the author’s knowledge, the accuracy of pre crash speed data in Ford Powertrain Control Modules has not yet been reported.

FDA began installing an event data recorder function in the Powertrain Control Modules of 2003 and later vehicles equipped with Electronic Throttle Controls on gasoline engines. Like GM speed data, the source of speed data is the transmission output shaft speed sensor, and the speed is calculated in the Powertrain Control Module. The key differences with possible effects on speed data accuracy calculations include:

1. Ford speed data is recorded in binary to the nearest 1/128 (0.0078) mph. (vs. rounded to nearest 1 mph for GM). Speed data was rounded to the nearest 0.01 mph in this research.

2. Ford data is continuously recorded real time to an EEPROM in the PCM and locked by a deployment event (versus GM sending the data on a class 2 serial bus from the PCM to the SDM, buffering it in SDM RAM, then writing to an EEPROM only in the event of a nondeploy or deployment event).

The latter difference may affect dynamically changing speed data but should have little effect on steady state speed measurements.

METHODS
The original concept was to drive the vehicle through a speed trap consisting of a pair of electric eyes spaced a known distance apart, and using the time between breaking the beams to calculate a precise vehicle speed through the trap. This value would then be compared to the speed being recorded in the data recorder. The intent was to drive through the trap at a stabilized speed, then apply the brake and use the brake light switch signal to identify when the trap was passed. Speed was
initially measured using the commercially available Farmtek Polaris wireless electronic sports timer. The electric eyes were placed at a known spacing of 0.91 meters (3 feet), and measured the time between breaking the first beam and the second beam. Speed was calculated by dividing the distance between the beams by the time. The Farmtek Polaris timer resolution is to the nearest .001 seconds. This equipment was initially used in a series of test runs. At 113 Km/hr (70 mph) a vehicle should take .029 seconds to pass through the trap. The limited resolution of +/- .001 seconds corresponded to a measurement limitation of +/- 3.6 kph (2.2 mph) or 3.2%. The authors determined that the resolution was insufficient for the differences being measured, and have not relied upon the Farmtek Polaris data in reaching their conclusions.

The initial rear wheel drive 2005 Crown Victoria Police Interceptor test vehicle was also equipped with an available Racelogic VBOX III sampling at 100 times per second. The VBOX records the GPS position of the vehicle to a resolution of 0.0001 seconds of latitude/longitude and claims to measure speed to within 0.1km/hr when averaged over 4 samples. The VBOX was also set up to record brake light switch voltage on a data channel, allowing synchronization between the PCM brake light on signal and the VBOX brake light voltage measurement. The authors have relied upon the VBOX data for accuracy measurements in the Crown Victoria test series.

Six runs were made each at 48.3 kph (30 mph), 64.4 kph (40mph), 80.5 kph (50mph), 96.6 kph (60mph), and 112.7 kph (70mph) in the baseline vehicle condition. An additional (7th) run was made at 30 mph and included in the data set.

Subsequently, in an effort to quantify the effects of low tire pressure, the tire pressure in both rear wheels was reduced from the baseline normal 35psi to 20psi. Three additional runs each were conducted at 48.3 kph (30 mph) and 96.6 kph (60 mph).

Following this, in an effort to quantify the effects of changing tire size, the passenger side rear tire was removed and replaced with the oversize T145/90R17 60 psi spare tire from a 2007 Escape. This tire was visibly larger than the base tire. The driver side rear tire was returned to 35 psi. Three test runs were conducted at 48.3 kph (30mph) and three at 96.6 kph (60mph).

Following the Crown Victoria test series, the authors decided to test additional vehicles but did not have ongoing access to the Racelogic VBOX III. The authors decided that a more accurate speed trap was necessary, and not finding any more accurate speed trap equipment available for purchase within the project budget, the authors decided to design and build a speed trap capable of measuring to the nearest .0001 seconds, or ten times the precision of the commercially available Farmtek Polaris equipment. The timer is based upon a 1 MHz crystal. The crystal frequency was divided by 10's down to tenths of a second. Counters were used and attached to 7 segment displays so that 4 digits displayed from .0001 to .9999 seconds. Two pairs of photo emitters and receptors made up the two beams that were monitored. The clock was started and stopped by the signals from two photo receptors as the test vehicle passed through the trap. The timer circuit diagram is attached at the end of the paper.

Because the clock is digital and not analog, it does not require calibration – the accuracy is controlled by the crystal frequency which has a specified accuracy of 50 ppm. This crystal frequency potential error is negligible. Wave forms were verified with oscilloscopes at each stage of the clock. Considering only the resolution of the timer, being ten times more precise than the Farmtek Polaris, the timer resolution error of +/- .0001 seconds would be expected to translate to speed measurement errors of +/- 0.36 kph (0.22 mph) or 0.32% at 113 kph (70mph). The authors considered that there could also be error introduced by flaws in the spacing of the photo receptors during fabrication. The spacing could be measured to the nearest 0.8mm. Maximum error due to spacing is 0.8mm/0.91m = 0.09%. Combining the 0.32% maximum timer error and the maximum spacing measurement error of 0.09% on a root mean square basis yields 0.33% maximum error. For a single data point, test equipment measurement error will average half of this, and when all the data samples are considered as a group, because the errors are all independent any test equipment measurement error will be minimized. The timer resolution error has proportionally less effect on measured speeds at lower test speeds as the time period to pass through the trap increases.

When the new .0001 resolution timer was initially tested, the infra red photo receptors were sometimes activated by strong reflected daylight. Testing was conducted after dusk to eliminate any risk of false triggering of the timer. If the timer had been falsely triggered, the timer measurement would be expected to be significantly different than the expected values and immediately obvious. The next series of tests were conducted with the .0001 second resolution speed trap using a rear wheel drive 2007 Lincoln Town Car, which is a sister vehicle to the 2005 Crown Victoria. Six runs were conducted at each chosen speed of 48.3 kph (30mph), 64.4 kph (40mph), 80.5 kph (50mph), 96.6 kph (60 mph), and 112.7 kph (70 mph). Two additional runs were made at 112.7 kph (70 mph) which were included in the data set.

The final series of tests were conducted with the .0001 second resolution speed trap using a front wheel drive 2007 Ford 500. Six runs were conducted at each chosen speed of 48.3 kph (30mph), 64.4 kph (40 mph), 80.5 kph (50 mph), 96.6 kph (60 mph), and 112.7 kph (70 mph).

RESULTS
1. Crown Victoria PCM vs. Racelogic VBOX III.

The PCM vs. VBOX data shown in Figure 1 shows the correlation between the two and that the differences are relatively small in proportion to speed being measured. For this reason the authors have chosen to display the difference between PCM and VBOX speed at various speeds instead of the absolute speed. The data in Figure 2 is the same information as that displayed in Figure 1, but the differences are more visible.

The maximum difference between the Vbox and the PCM was -0.40 kph (-0.25 mph) or -0.9% at 48.3 kph (30 mph). The average difference was -0.03 kph (-0.02 mph) or -0.08%. The standard deviation was 0.21 kph (0.13 mph) and the 3 Sigma range was -0.68 kph (-0.42 mph) to +0.61 kph (+0.38 mph).

The Vbox to PCM average difference on a percentage basis was -0.08%, with a standard deviation of 0.32% for a 3 sigma range of -1.02% to +0.87%. See Figure 3 below.


As displayed in Figure 4, there was no discernable difference in recorded speed between the original Crown Victoria series with 35 psi tire pressure, and the additional test series done at 20psi. The average difference PCM to VBOX data with 20 psi tires was -0.03 kph (-0.02 mph), the same as for the baseline sample. This is consistent with reports by other researchers that an even more significant change in air pressure is required to affect the revolutions per mile of the tire significantly. A reference line from zero difference at zero speed to +/- 0.8 kph (0.5 mph) at 112.8 kph (70 mph) was added to show the envelope most data points fell within.


Three data points at 48.3 kph (30mph) and three at 96.6 kph (60mph) were collected and are also shown in
Figure 5. At 96.6 kph (60mph) the PCM reported approximately 3.2 kph (2.0 mph) or 3.5% lower than the actual speed. At 48.3 kph (30mph) the PCM reported an average of 1.5 kph (0.9 mph) or 3.0% lower than the actual speed.

The difference in percentage terms is shown below in Figure 6.

Figure 6

4. 2007 Lincoln Town Car PCM vs. .0001 second resolution speed trap.

The maximum difference between the measured time trap speed and the last data point recorded before brake application was 0.92 kph (0.57 mph) at 48.3 kph (30mph), a difference of 1.9%. The average difference was 0.24 kph (0.15 mph) or 0.29%. Data is shown in Figure 7.

The standard deviation was 0.25 kph (0.156 mph) and the 3 Sigma range was from -0.51 kph (-0.32 mph) to +0.98 kph (+0.61 mph). This was an average of 0.27% with a 3 Sigma range of -0.90% to +1.43%.

The intent of the testing was to accelerate to a steady speed, engage the speed control, and pass through the speed trap with the speed control engaged, and then apply the brake as soon as possible after passing through the trap. This particular vehicle had a speed control engagement button which only intermittently engaged the speed control. During the available run up distance, the speed control could only be engaged about 50% of the time. It was observed that if the speed control did not engage that the test driver had to concentrate on maintaining the speed through the trap, and then he did not brake as quickly after passing through the trap as when the speed control was engaged. The data was therefore sub-divided between speed control engaged and not engaged in Figure 8. The standard deviation of the total data was 0.156, but the subset with speed control used had a standard deviation of 0.087 versus 0.195 for the subset without speed control. The additional scatter induced into the test procedure by the failure of the speed control to engage resulted in measuring error not attributable to the PCM recording accuracy. For this reason the data where speed control did not engage will not be considered further, and results after this point are only for the runs where speed control did engage.
The maximum difference with the subset of data where speed control engaged is shown in Figure 9. It was 0.43 kph (0.27 mph) or 0.4%. The average difference was 0.19 kph (0.12 mph) or 0.23%.

The speed control mean of 0.19 kph (0.12 mph) and its standard deviation of 0.14 kph (0.087 mph) yield a +/- 3 Sigma range of -0.24 kph (-0.15 mph) to 0.63 kph (0.39 mph) difference.

The foregoing was all done on an absolute difference basis, but examining the best fit trend line, it appears the average difference is higher at higher speeds. The data can also be looked at on a percentage basis, as in Figure 10. The average percentage error was 0.23% with a standard deviation of 0.13% for a 3 sigma range of -0.15% to +0.61% difference between the PCM reading and the .0001 second resolution speed trap.

5. 2007 Ford 500 PCM data vs. .0001 resolution speed trap. The data is displayed in Figure 11.

The maximum difference observed was -0.61 kph (-0.38 mph) at 96.6 kph (60 mph) or -0.7%. The average error was -0.26 kph (-0.16 mph) or -0.31%. The standard deviation was 0.16 kph (0.10 mph) for a 3 sigma range of -0.74 kph (-0.46 mph) to +0.26 kph (+0.16 mph).

Since the differences may be more relevant on a percentage basis, they are also displayed below in Figure 12 in percentage terms:
The average percentage error was -0.31%. The standard deviation was 0.17% for a 3 sigma range of -0.82% to +0.19%.

**DISCUSSION**

VBOX Data Synch The authors had to synchronize the Racelogic VBOX III data to the PCM data. Since the PCM only reported every 0.2 seconds vs. the VBOX every .01 seconds, the PCM last data point before brake light switch engagement was set at 0.1 seconds before the first change in brake light switch voltage in the VBOX. In a few runs, the VBOX did not record the brake switch voltage change, but another data channel was observed to change values at brake application and was used instead.

Induced Errors Knowing that the source of the PCM reported speed signal is the transmission output shaft and the original vehicle-as-built relationship between the transmission speed sensor, the axle ratio, and the tire size in revolutions per mile, changes “downstream” of the speed sensor should result in differences between the PCM reported speed and the VBOX actual speed. The main point of the test was to show that the PCM recorded speed would be affected by the change in tire diameter, and it did. The authors had hoped to show that the precise amount the reading was affected could be predicted, but the authors lacked the proper test equipment to measure the revs per mile of the mini spare versus the baseline tire directly. Without test equipment, the authors examined theoretical differences. For the oversize spare tire test runs, the P145/90R17 tire has a calculated revs/mile of 739 versus the calculated baseline P225/60R16 of 757 revs per mile, a difference of 2.4%. The Tire and Rim Association specifications allow up to 4% difference between the two different tire sizes. Since the mini spare was only placed on one side, the right side, the error induced at the speed sensor would be expected to be half that of an individual tire difference. This rev/mile data or Tire and Rim Association specifications did not fully explain the average 3.3 % difference measured in the authors’ testing.

**CONCLUSIONS**

Vehicle speeds recorded in the Ford Powertrain Control Module Event Data Recorder are consistent with reference Racelogic VBOX III speed measurements in rear drive 2005 Crown Victoria vehicles to within a 3 sigma range of -0.68 kph (-0.42 mph) to +0.61 kph (+0.38 mph). The maximum difference measured between the Vbox and the PCM was -0.40 kph (-0.25 mph) or -0.9% at 48.3 kph (30 mph). The average difference was -0.03 kph (-0.02 mph) or -0.08%. The 3 sigma percentage difference was -1.02% to 0.87%.

Reducing tire pressure from 35 psi to 20 psi produced negligible changes in measured vehicle speeds.

Changing one tire size did cause the PCM to under-report speed by an average of 3.3% versus the Racelogic VBOX III reference measurements. Underreporting was expected and consistent with the change in tire diameter.

Vehicle speeds recorded in the Ford Powertrain Control Module Event Data Recorder are consistent with reference .0001 second resolution speed trap measurements in the rear drive 2007 Town Car with speed control engaged, to within a 3 Sigma range of -0.24 to 0.63 kph (-.15 mph to +.39 mph). The maximum difference recorded was 0.43kph (0.27 mph) or 0.4%. The average difference was 0.19 kph (0.12 mph) or .0.23%. The 3 sigma percentage range was -0.15% to +0.61%.

Vehicle speeds recorded in the Ford Powertrain Control Module Event Data Recorder are consistent with reference .0001 second resolution speed trap measurements in the front wheel drive 2007 Ford 500 to within a 3 Sigma range of -0.74 kph to +0.26 kph (-.46 mph to +.16 mph). The maximum difference reported between the speed trap and the PCM was -0.61 kph (-0.38mph) or -0.7% at 97 kph (60mph). The average difference was -0.26 kph (-0.16 mph) or -0.31%. The 3 sigma percentage range was from -0.82% to +0.19%.

The Ford PCM speed reporting resolution to within 0.01 mph allows more precise comparisons to reference speed measuring devices than was available on previously tested Event Data Recorders which had a reporting resolution of 1 mph. Of the 3 different vehicles tested, The largest 3 sigma difference calculated was less than 0.8 kph (0.5 mph) and the 3 sigma worst case percentage was -1.02%.

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REFERENCES


CONTACT


Richard R. Ruth P.E. spend 33 years in engineering and planning at Ford Motor Company, the last 10 years as a manager in Environmental and Safety Engineering, Design Analysis, which conducted field investigations of vehicle performance in crashes. Mr. Ruth was instrumental in releasing the ability to read Ford event data recorders to the Bosch/Vetronix Corporation so that safety researchers, law enforcement and accident reconstructionists would have access to this data. He is now a private consultant.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

EDR – Event Data Recorder
EEPROM – Electrically Erasable Programmable Read Only Memory
GPS – Global Positioning System
PCM – Powertrain Control Module (Ford term)
RAM – Random Access Memory
SDM – Sensing and Diagnostic Module (GM term)
Appendix
APPARATUS

Speed Trap Setup

Beam Loss Detection Circuit

Speed Trap Circuit Board

Timer Circuit