

Timing and Synchronization of the Event Data Recorded by the Electronic Control Modules of Commercial Motor Vehicles - DDEC V

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ABSTRACT

It is well recognized that Heavy Vehicle Event Data Recorder (HVEDR) technology has been incorporated in the Electronic Control Modules (ECMs) on many on-highway commercial motor vehicles. The dynamic time-series data recorded by these HVEDRs typically include vehicle speed, engine speed, brake and clutch pedal status, and accelerator pedal position. With specific respect to Detroit Diesel ECMs, data are recorded surrounding certain events at a rate of 1.0 Hz. In this research, controlled testing was conducted to determine the time differences between the values being generated by the sourcing sensors and the interpreted data being broadcast on the vehicle's SAE J1939 controller area network (CAN). To accomplish this, raw sensor data as provided to the ECM was monitored, as were the subsequent J1939 CAN transmissions from the ECM. Several of the monitored parameters were then simultaneously changed through the use of a switch to determine timing between state change, receipt by the ECM, and J1939 CAN broadcast. Testing with the switch that simultaneously changed the states of four of the five monitored parameters established the time lags that exist between when the sourcing signal was generated and when the value for this signal was broadcast on the vehicle's J1939 CAN and reported by the HVEDR function of the DDEC V ECM. Testing with the switch also established that the data reported by the HVEDR function of the DDEC V ECM are asynchronous. Finally, the timing and synchronicity of the Electronic Engine Controller #2 (EEC2) and Cruise Control/Vehicle Speed (CCVS) Application Layer Parameter Group Numbers that are broadcast by the DDEC V ECM over the vehicle's J1939 CAN was determined. In addition, the Electronic Engine Controller #1 (EEC1) Application Layer Parameter Group Number was determined to broadcast asynchronously over the vehicle's J1939 CAN.

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INTRODUCTION

Published research concerning the use of Heavy Vehicle Event Data Recorders (HVEDRs) in collision reconstruction applications goes as far back as the late 1990s [1]. The primary source of such HVEDR data is the Electronic Control Module (ECM) used by the engine to monitor and control various aspects of the motor's operation. With respect to Detroit Diesel ECMs, data may be recorded surrounding a "hard brake" situation or the last time the wheel speed reached zero km/h. Captured data include, but are not limited to, brake pedal status (on/off), clutch pedal status (on/off), percent accelerator pedal position, engine speed (Revolutions per Minute - RPM), and vehicle speed (mph or km/h) at a rate of 1.0 Hz. These data are obtained by accessing the ECM using DDEC Reports software available from the Detroit Diesel Corporation.

The ECMs used with Detroit Diesel Engines are designated by the acronym DDEC, which refers to "Detroit Diesel Electronic Controls" [2]. Specific controllers are then further referenced by a numerical model, such as DDEC IV (circa 1998 to 2004), DDEC V (circa 2004 to 2007), DDEC VI (circa 2007 - 2010) and DDEC 10 (circa 2010 - present). This research focused on the DDEC V controller as employed by a Class 8 heavy vehicle currently in active use. A sample Detroit Diesel DDEC V ECM is shown in [Figure 1](#).



Figure 1. Sample Detroit Diesel DDEC V ECM

Although much of the currently available research concerns the accuracy of speed data under specified conditions, limited testing has been performed with a focus on the timing and synchronization of the various recorded parameters for on-highway commercial motor vehicles [3]. It should be noted that research has been conducted on the timing and synchronization on the HVEDRs installed in the airbag control modules of General Motors passenger vehicles [4, 5]. Another research study focusing on a Detroit Diesel DDEC IV ECM, observed inconsistencies of the timing of the reporting of the brake switch status to when the brake was actually applied [6]. ECMs receive raw voltage or frequency

data from various sensors on the engine and throughout the vehicle, including the accelerator pedal or Throttle Position Sensor (TPS) and Vehicle Speed Sensor (VSS). The raw data are then interpreted by the ECM and broadcast over the vehicle's communication network for use by other systems requiring these data as addressed CAN data. With respect to heavy vehicle systems, information is generally transmitted by the ECM via a J1587 data bus (older vehicles) or a J1939 CAN (newer vehicles). In the case of Detroit Diesel, the ECM also records the interpreted sensor signals as part of its HVEDR functionality.

While data in DDEC Reports files are given as one data point per second, information is broadcast over the J1939 CAN at higher rates. For example, vehicle speed, brake, and clutch data are transmitted at 10 Hz, percent accelerator pedal position is broadcast at 20 Hz, and the transmission rate for engine speed is dependent on the engine speed itself [7]. It was the goal of this testing to look at issues of timing and synchronicity by comparing the timing between the raw sensor signal being sent to the ECM, the J1939 CAN broadcast of the interpreted signal, and the recorded DDEC Reports event file.

METHODOLOGY

To evaluate the timing and synchronicity as described previously, comprehensive testing was performed with a 2006 Freightliner Columbia tandem axle truck-tractor (1FUJBCK56LV78618) having a Detroit Diesel Series 60 engine (Engine Serial Number 06R0859430) controlled by a DDEC-V ECM (software version 3.010). The vehicle was owned by Fox Valley Technical College (FVTC) and has been used for on-highway driving instruction. The unit was inspected by the Wisconsin State Patrol's Motor Carrier Section and found to be within Commercial Vehicle Safety Alliance (CVSA) regulatory specifications. For safety purposes, the testing was completed on a closed driving course at the College's J.J. Keller Transportation Center in Appleton, Wisconsin. The test vehicle is shown in [Figure 2](#).



Figure 2. 2006 Freightliner Columbia Test Vehicle

Prior to testing, the Freightliner was instrumented with Racelogic VBOX III 100 Hz GPS Data Logger and Video VBOX data acquisition systems. A list of the data acquisition instrumentation used in this research is contained in [Appendix A](#). The VBOX III 100 Hz GPS Data Logger was set to record parameters from the J1939 CAN data broadcast by the DDEC V ECM concerning the positions of the brake and clutch pedals (on/off), the percent accelerator pedal position, engine speed (RPM), and vehicle speed (km/h). In addition, raw data from the individual sensors from which these parameters are initially interpreted by the ECM were also recorded by a VBOX Mini Input Module, which was connected to the VBOX III 100 Hz GPS Data Logger. This was accomplished by recording the information directly from the sensors at the same time the voltage or a frequency was being sent to the ECM for processing. This allowed for the raw sensor signal as well as the subsequent J1939 CAN data to be compared for timing purposes. Finally, a tape switch was installed on the brake pedal that interfaced with the VBOX units to document when pressure was applied by the driver to the brake pedal.

According to Racelogic, the VBOX III 100 Hz GPS Data Logger records speed and other GPS related parameters at 100 Hz and that all of these parameters are sampled simultaneously. The VBOX III 100 Hz GPS Data Logger contains an internal module that is capable of recording data that is broadcasted over a vehicle's J1939 CAN. All of the parameters that are being sampled by the internal module that is recording the J1939 CAN data are being sampled simultaneously. In addition, all of the raw data from the individual sensors being recorded by the VBOX Mini Input Module are all sampled simultaneously. According to Racelogic, the GPS related parameters, the J1939 CAN data sampled by the internal module, and the raw sensor data sampled by the VBOX Mini Input Module, are not sampled simultaneously and the latency between all of these modules would be less than 6 ms (e.g. the time difference between when the J1939 CAN data were sampled and the raw sensor data were sampled would be less than 6 ms).

The particular Freightliner used in the testing was not equipped with other systems using the J1939 communications protocol for communication. Therefore, it was necessary to construct a J1939 CAN "backbone" with appropriate twists in the data bus wires, proper terminating resistors at either end, and of an appropriate length to meet SAE standards [8]. Literature from Detroit Diesel indicates that the DDEC V does broadcast the desired parameters using J1939 CAN, and was therefore equipped with a three-pin J1939 connector near and wired to the DDEC V ECM for this purpose [9]. A backbone was subsequently built and connected to the described plug. The parameters that were recorded during this testing that were transmitted over the vehicle's J1939 CAN were the brake and clutch switch statuses, vehicle speed, engine speed, and percent accelerator pedal position. According to this Detroit Diesel literature, engine speed is transmitted as part of the Electronic Engine Controller #1

(EEC1) Application Layer Parameter Group Number and its transmission rate is engine speed dependent. This Detroit Diesel literature also states that throttle pedal position sensor (TPS) is transmitted as part of the Electronic Engine Controller #2 (EEC2) Application Layer Parameter Group Number and its transmission rate is 50 ms (20 Hz). Furthermore, this Detroit Diesel literature states that vehicle speed, clutch switch, and brake switch are transmitted as part of the Cruise Control/Vehicle Speed (CCVS) Application Layer Parameter Group Number and its transmission rate is 100 ms (10 Hz).

To assist in determining timing and synchronicity issues, a 4PDT (Four Pole Double Throw) switch was used to simultaneously change the state of signals from the VSS, TPS, brake switch, and clutch switch. With respect to the brake and clutch, opening or closing the 4PDT switch would cause the ECM and VBOX units to observe a state change of "on" to "off" or "off" to "on" as desired. At the same time, the interpreted VSS frequency would change between that for the actual non-zero speed of the vehicle and that for zero km/h. The 4PDT switch also changed the TPS signal between one that would relate to an actual value of the pedal being depressed and a set lower absolute value of five to six percent. These specific positional percentages were used to prevent any fault conditions from occurring, including that for Detroit Diesel's Idle Validation programming. A schematic showing the operation of the 4PDT switch by changing the states of vehicle speed, percent accelerator pedal position, and brake and clutch switch status from OFF to ON (e.g. from released to applied) is shown in [Figure 3](#).

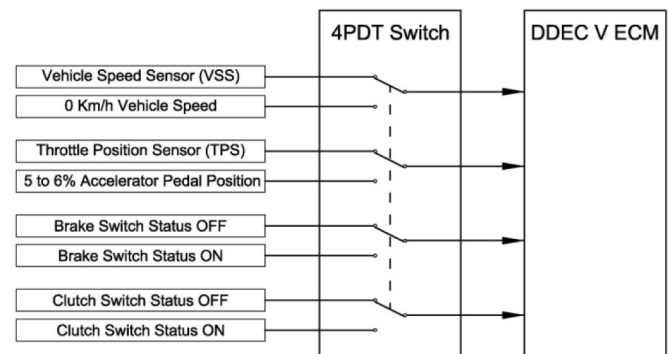


Figure 3. Schematic Showing Operation of 4PDT Switch

In testing the described DDEC V ECM, a total of 30 driving runs were performed with the Freightliner Columbia wherein raw sensor data and J1939 CAN broadcasts were monitored. Following each of these tests, Last Stop Record (LSR) and Hard Brake (HB) event data were imaged from the ECM using DDEC Reports software version 7.02 through the in-cab diagnostic connector. This allowed for a later comparison to be made between the sensor information, J1939 CAN transmissions, and HVEDR data with respect to timing and synchronization.

Specific testing protocol called for data to be recorded after the ignition was first turned on in order to monitor systems prior to the engine being started. The clutch and accelerator pedals were then manipulated by the driver in a set order, followed by the starting of the engine. The Freightliner was then accelerated from the stopped position to constant speed, followed by a brake application that would bring the vehicle to a stop. Test runs ranged from approximately 78 to 115 seconds, and braking ranged from light to hard pedal applications.

In 20 of the 30 test runs, the 4PDT switch was engaged to change the parameters previously described. For five of these runs, the VSS signal was excluded from the switch to determine if the sudden drop in vehicle speed caused by applying the switch had any effect in the reporting of the remaining parameters (brake, clutch, TPS). It should be noted that individual test runs had multiple applications of the 4PDT switch at specified times.

Following the testing procedures, the data recorded by the VBOX III GPS 100 Hz Data Logger was imported into a spreadsheet. This data consisted of the GPS data, the tape switch on brake pedal, the raw sensor signals, and the J1939 CAN transmissions. This allowed for a comparison to be made between the raw voltage or frequency signals from the given sensors to be compared with information broadcast by the ECM over the J1939 CAN. Additionally, the HVEDR data was imported into the spreadsheet and had to be aligned to the data recorded by the VBOX III GPS 100 Hz Data Logger. One of the parameters recorded by the HVEDR (e.g., vehicle speed, engine speed, brake and clutch pedal status, and accelerator pedal position) needed to be selected to align the HVEDR data to the data recorded by the VBOX III GPS 100 Hz Data Logger. A review of the results, which will be discussed in the Results section, showed that both engine speed and accelerator pedal position both reported changes, over the vehicle's J1939 CAN, in the values of these parameters in as little as 0.01 seconds for engine speed and 0.05 seconds for accelerator pedal position. Also, results from the testing using the 4PDT switch showed that the DDEC V ECM is monitoring accelerator pedal position frequently and is updating the value for percent accelerator pedal position in the LSR and HB event of DDEC Reports as these changes occur. Although not directly tested, based on the update rates for the engine speed, it is likely that DDEC V ECM is monitoring the engine speed frequently and is also updating the value for engine speed in the DDEC Reports LSR and HB events as these changes occur. For this research, it is assumed that the DDEC V ECM is updating the value for engine speed in the DDEC Reports LSR and HB events as these changes occur. For this research, engine speed was used to align the two data sets by using the first non-zero engine speed value upon starting the engine. Using engine speed to align the two data sets, [Figure 4](#) is a graph of engine speed obtained from the vehicle's J1939 CAN, the raw (analog) engine speed sensor, and from DDEC Reports versus time for one of the testing runs. [Figure 4](#) shows that as the engine is started and

engine speed changes rapidly that there is a good correlation between the DDEC Reports engine speed and the analog engine speed.

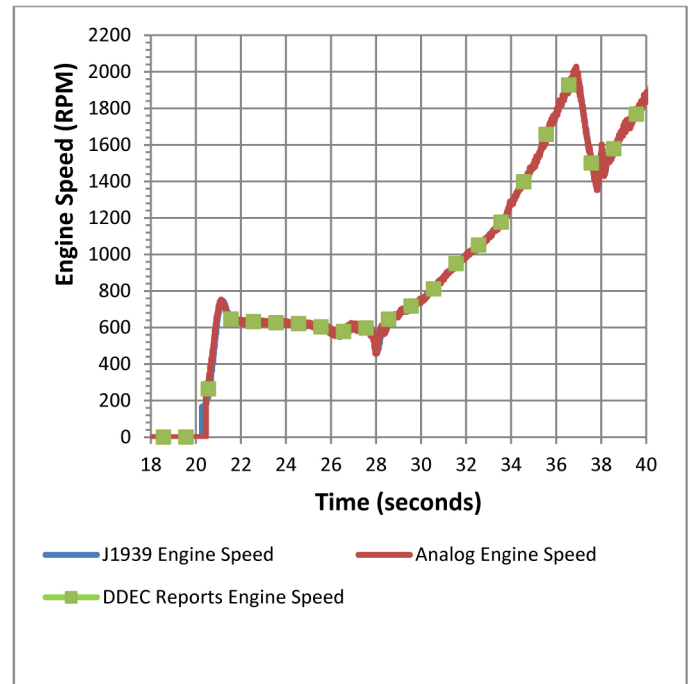


Figure 4. Engine Speed versus Time Showing the Correlation between the Analog and DDEC Reports Engine Speeds

RESULTS

Brake Pedal Time Lag

The first portion of this testing consisted of an analysis of the time lags between the driver's application of the brake pedal, the raw signal being sent to the ECM, the ECM's subsequent broadcasting of the pedal status over the J1939 CAN, and the HVEDR data from DDEC Reports. The results of these time lags or differences are shown in [Table 1](#), in Appendix B, which shows the results obtained when the brake switch status was changed from "off" (not applied) to "on" (applied). [Table 2](#), in Appendix B, shows values observed when changing the brake status from "on" (applied) to "off" (not applied).

Clutch Pedal Time Lag

Timing involving the clutch pedal was completed by evaluating when the signal was sent from the sensor to the ECM and the ECM's broadcasting of the pedal status on the J1939 CAN. The positional data was then compared to its recorded status change in the imaged DDEC Reports files. The results of these time lags or differences are shown in [Table 3](#), in Appendix B, which shows the results obtained when the switch status was changed from "off" (not applied) to "on" (applied). [Table 4](#), in Appendix B, shows values

observed when changing the clutch status from “on” (applied) to “off” (not applied).

Accelerator (Throttle) Pedal Time Lag

The accelerator pedal position sensor or TPS employed by the Freightliner was such that an application of the pedal causes an increasing voltage (analog signal) to be sent from the sensor to the ECM. The ECM then interprets this voltage as a percentage of pedal application. Detroit Diesel Diagnostic Link (DDDL) software was used to monitor the given percentage in order to determine the relationship between the TPS voltage output and the percentage of accelerator pedal reported by the ECM. With the accelerator pedal fully released, the voltage from the TPS was approximately 0.50 Volts. Depressing the accelerator pedal to a TPS output voltage of 3.2 Volts equated to a 100% reading from the ECM. Further depression of the accelerator pedal to the floor increased the TPS voltage approximately 3.5 Volts; however the reported percentage did not increase beyond 100%. A review of the TPS voltage and ECM percent accelerator pedal position values showed that there was a linear relationship between 5% and 100% application (Linear Regression slope = 41.6 %/Volt and $R^2 = 0.9996$). The relationship between percent accelerator pedal position and TPS voltage for applications below 5% was not determined.

With the voltage/percent accelerator pedal relationship being established, an evaluation of timing from the analog signal being sent from the TPS to the ECM and the ECM's subsequent broadcasting of the pedal position over the J1939 CAN was completed by observing sudden changes in the analog signal and recording when these changes occurred in the J1939 CAN broadcast data. The timing from the original signal source was not compared with its reporting in DDEC Reports files due to not being able to determine when the value recorded in DDEC Reports was generated. The results of these time lags or differences are shown in Table 5, which shows the results obtained both when the accelerator pedal was increased (depressed) and when it was decreased (released). The data showed that when the accelerator pedal was increased (depressed), that there could be a substantial lag between when the voltage from the TPS increased to when the DDEC V ECM reported a non-zero percent accelerator pedal position over the vehicle's SAE J1939 CAN. This time lag was found to be as long as 0.73 seconds.

Vehicle Speed and Engine Speed Time Lag

The frequency signals from the vehicle speed sensor (VSS) and engine speed sensor were sampled by the frequency inputs to the VBOX Mini Input Module. With respect to VSS data, a scaling factor was required to align the raw frequency signals to actual wheel speed. This factor was determined by driving the Freightliner at a constant speed and calculating the ratio between analog frequency and the actual vehicle speed as reported over the J1939 CAN and the VBOX's GPS reported speed. A graph showing these three

speed data sources is shown in Figure 5. While there was good correlation between the sensor values, J1939 CAN data, and the GPS indicated speed, the analog VSS signal had periods where the signal was “noisy” and/or had random fluctuations, even though the wiring leads connecting to the Vehicle Speed and Engine Speed sensors were twisted. No filtering of the signal was attempted, and a comparison to the J1939 vehicle speed broadcasts was not conducted during this research. The engine speed signal also had periods where the signal was “noisy,” and, again, a comparison to the J1939 engine speed was not attempted.

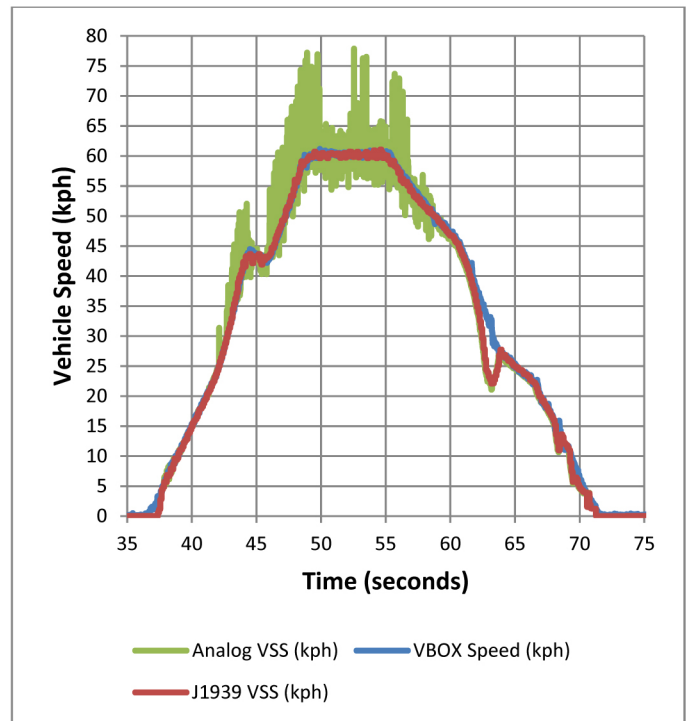


Figure 5. Analog Signal from Vehicle Speed Sensor (VSS) Compared to VBOX Speed and J1939 Vehicle Speed versus Time

4PDT SWITCH TESTING

During 20 of the 30 test runs, a 4PDT (Four Pole Double Throw) switch (referred to as the switch) was used to simultaneously change the state of the signals from the VSS, the brake and clutch switches, and the TPS. The state of the brake and clutch switch statuses were changed either from not depressed to pressed (e.g. OFF to ON) or from pressed to not depressed (e.g. ON to OFF). The signal from the VSS was changed either from a non-zero speed (typically well above 20 km/h) down to zero km/h. The signal from the TPS was changed either from a high percent accelerator pedal position (typically well above 20%) down to about a 5-6% accelerator pedal position or from the 5-6% accelerator pedal position to a higher percent accelerator pedal state. The value of 5-6% accelerator pedal position was chosen instead of 0% accelerator pedal position so that an Idle Validation Fault was

not set. For each test run, the switch was thrown from OFF to ON and then after approximately two seconds was thrown from ON to OFF while the vehicle was accelerating, traveling at constant speed, and while decelerating. For five of the testing runs, the signal from the VSS was not changed when the switch was thrown. The purpose of excluding the VSS signal from the switch was to see if the large change in vehicle speed had any effect on the time differences of the other parameters (brake and clutch switches and TPS) when the switch was thrown.

For each testing run, the data from the analog signals for the brake and clutch switches, the TPS, and the VSS were reviewed to determine the time for when the switch was thrown from OFF to ON and from ON to OFF. Time differences between when the switch was thrown to when the changes were detected and reported over the vehicle's SAE J1939 CAN and to when the changes were reported in the LSR of DDEC Reports. The results of these time lags or differences for all switch throws (from OFF to ON and from ON to OFF) between when the switch was thrown to when the changes were reported over the vehicle's SAE J1939 CAN are shown in [Table 6](#), in Appendix B. The results of these time lags or differences for all switch throws (from OFF to ON and from ON to OFF) between when the switch was thrown to when the changes were reported in the LSR of DDEC Reports are shown in [Table 7](#), in Appendix B.

Furthermore, the time differences between when the changes reported over the vehicle's SAE J1939 CAN and when the changes were reported in the DDEC Reports LSR was determined. The results of these time lags or differences for all switch throws (from OFF to ON and from ON to OFF) between when the changes were detected reported over the vehicle's SAE J1939 CAN to when the changes were reported in the LSR of DDEC Reports are shown in [Table 8](#). Negative times reported for the Minimum Time Lag in [Table 8](#) mean that the change was reported first in the LSR of DDEC Reports before it was reported over the vehicle's SAE J1939 CAN. The negative time values seem to indicate that the function of sampling and recording of event data in the HB or LSR of DDEC Reports is separate from the function of broadcasting this data over the vehicle's SAE J1939 CAN in the DDEC V ECM.

The switch throw data was separated and [Tables 9](#), [10](#), and [11](#), in Appendix B, include only the OFF to ON switch throws and [Tables 12](#), [13](#), and [14](#), in Appendix B, include only the ON to OFF switch throws. The results of these time lags or differences for only the OFF to ON switch throws between when the switch was thrown to when the changes were reported over the vehicle's SAE J1939 CAN are shown in [Table 9](#). The results of these time lags or differences for only the OFF to ON switch throws between when the switch was thrown to when the changes were reported in the LSR of DDEC Reports are shown in [Table 10](#).

The results of these time lags or differences for only the OFF to ON switch throws between when the changes were detected reported over the vehicle's SAE J1939 CAN to when

the changes were reported in the LSR of DDEC Reports are shown in [Table 11](#). Again, negative times reported for the Minimum Time Lag in [Table 11](#) mean that the change was reported first in the LSR of DDEC Reports before it was reported over the vehicle's SAE J1939 CAN.

The results of these time lags or differences for only the ON to OFF switch throws between when the switch was thrown to when the changes were detected reported over the vehicle's SAE J1939 CAN are shown in [Table 12](#). The results of these time lags or differences for only the ON to OFF switch throws between when the switch was thrown to when the changes were reported in the LSR of DDEC Reports are shown in [Table 13](#).

The results of these time lags or differences for only the ON to OFF switch throws between when the changes were detected reported over the vehicle's SAE J1939 CAN to when the changes were reported in the LSR of DDEC Reports are shown in [Table 14](#). Again, negative times reported for the Minimum Time Lag in [Table 14](#) mean that the change was reported first in the LSR of DDEC Reports before it was reported over the vehicle's SAE J1939 CAN.

All parameters, including the brake and clutch switch statuses, vehicle speed, engine speed, and percent throttle (or accelerator pedal position), are reported once per second (1 Hz) in the LSR of DDEC Reports. The time between when the switch was thrown to when the next row of parameters was reported in the LSR of DDEC Reports was random. In this paper, this time will be referred to as the "switch to DDEC Report parameters" time and this time is illustrated in [Figure 6](#).

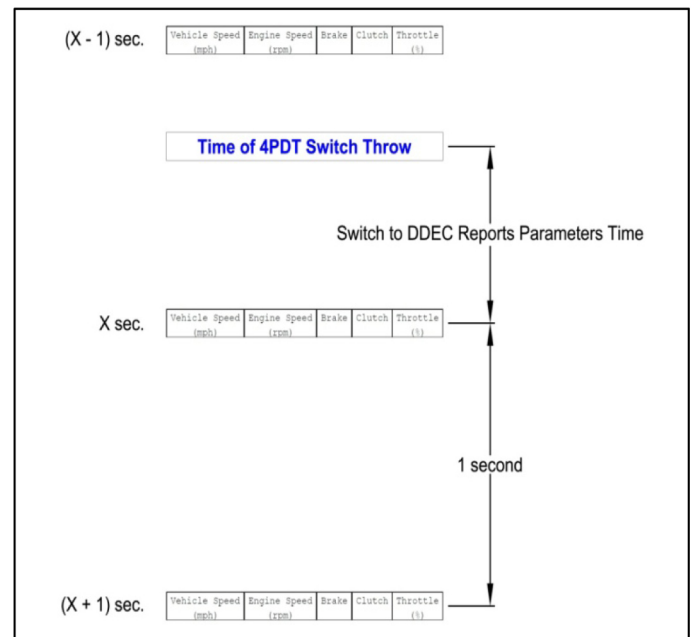


Figure 6. Illustration to Define "Switch to DDEC Reports Parameters Time"