CRC Project No. CM-138-17-1

COMPUTER CONTROLLED POOR DRIVEABILITY ON DEMAND TRAINING VEHICLE

October 2018

COORDINATING RESEARCH COUNCIL, INC.
5755 NORTH POINT PARKWAY SUITE 265 · ALPHARETTA, GA 30022

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FINAL REPORT

CRC Project No. CM-138-17-1

SwRI® Project No. 03.23291

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POWERTRAIN ENGINEERING DIVISION

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EXECUTIVE SUMMARY

Southwest Research Institute (SwRI) modified a 2014 Ford Fusion vehicle to perform driveability events on-demand in accordance with procedures detailed in Coordinating Research Council (CRC) Cold-Start and Warmup E85 Cold Ambient Temperature Driveability Program.

Four driveability events at three different severity levels as shown in Table 1 were enabled by intercepting the accelerator pedal and ignition timing signals of the stock vehicle's engine control module. Real-time software enabling the driveability events was written in LabVIEW language and deployed on a National Instruments (NI) Compact RIO (cRIO) 9035 controller.

A Graphical User Interface (GUI) was deployed on a Microsoft Surface tablet to communicate with the controller. Driveability raters recommended by CRC helped calibrate and validate the system on-site at SwRI and at an external test track over a period of 2 weeks. The raters were pleased with the overall system performance. The primary project objectives were met successfully.

In addition to the required scope of work, SwRI performed a repeatability study to draw statistically significant conclusions. Data was collected over 2266 events and a correlation study was performed comparing triggered driveability events versus events reported by the raters.

The study revealed accuracy at an event level was about 95%. This means, for example, if a hesitation event was triggered, the raters would identify it as a hesitation 95% of the time. Differences in average sensitivity of raters contributed to lower severity accuracies. Quantification of various driveability events performed as part of this project would enable building a "gold" standard for training future raters. Results from the testing and conclusions are detailed in this report.

1.0 INTRODUCTION

The CRC has developed a system and nomenclature to discriminate between different driveability events. The task of scoring these events utilizes trained raters. The raters perform a pre-set series of maneuvers on a test vehicle and determine the type of driveability event along with its severity.

This rating method has been used for decades, but unfortunately no new replacement raters have been trained to replace the current trained CRC raters once they retire. The availability of a vehicle where the driveability events can be created and controlled on demand would facilitate several CRC projects including training new raters, evaluating new methods for measuring vehicle driveability, and correlating trained rater evaluations of driveability with real world driving.

Final report of the CRC Cold-Start and Warmup E85 Cold Ambient Temperature Driveability Program, 2008 describes the driveability events. The five driveability events that were tested as a part of this program are:

1. Hesitation – a temporary lack of vehicle response to a pedal command
2. Stumble – a short, sharp reduction in acceleration
3. Surge – cyclic power fluctuations
4. Stall – engine is stopped with ignition ON
5. Idle Quality – degree of smoothness while idling

Driveability events along with the severity levels calibrated and tested in this program are captured in Table 1. A stall event does not categorize into the severity levels as mentioned in Table 1 since the event results in a stopped engine.

Table 1 Driveability Events and Severity Level

EVENT	SEVERITY		
Hesitation	Trace	Moderate	Heavy
Stumble	Trace	Moderate	Heavy
Surge	Trace	Moderate	Heavy
Idle Quality	Trace	Moderate	Heavy

2.0 OBJECTIVES

1. Develop engine control hardware and software to cause driveability events at different severities on the vehicle on command
2. Develop an easy to use interface to communicate with the controller

3.0 TERMINOLOGY

Based on further inputs from driveability raters and CRC members over the course of the project, the following terminology is used for the rest of this report:

- Clear – No driveability event was caused by SwRI controller
- Trace – Low intensity driveability event was caused by SwRI controller
- Moderate – Medium intensity driveability event was caused by SwRI controller
- Heavy – High intensity driveability event was caused by SwRI controller
- Extreme – Very high intensity driveability event was caused by SwRI controller

4.0 VEHICLE & CONTROLLER SELECTION

CRC recommended a test vehicle with the following requirements:

1. Vehicle manufacturer is one of the CRC consortium members - GM, Ford, FCA, Honda, Toyota, Nissan, Volkswagen, and Mercedes-Benz
2. Vehicle must be a Gasoline Direct Injection (GDI) vehicle
3. No auto-stop feature. If it exists on the vehicle, the feature should be easily disabled without altering the vehicle's calibration
4. Five-passenger sedan around $20,000 to $25,000

SwRI performed a comprehensive search of vehicles that would satisfy the above requirements. The different vehicles considered along with features are summarized in Table 2. The Ford Fusion and Ford Taurus were promising candidates.

Table 2. Vehicle Selection Preliminary Research

Brand	Model	Year	Engine	Auto-Stop	Transmission
Chevy	Malibu	2014-2015	2.5 GDI	Yes	Auto
Chevy	Malibu	2016-2017	1.5T GDI	Yes	Auto
Chevy	Impala	2014-2017	2.5 GDI	Yes	Auto
Chevy	Cruze	2016-2018	1.4 GDI	Yes	Auto
Cadillac	ATS	2014-2018	2.0 GDI LTG	Yes	Auto
Ford	Focus (sedan)	2018	2.0L Ti-VCT GDI	No	Auto-Manual
Ford	Fusion	2014-2016	1.5T/1.6T/2.0T GDI	No/Button Disable	Auto
Ford	Taurus	2013-2017	2.0T GDI	No/Button Disable	Auto
Jeep	Grand Cherokee	2016	3.6 Pentastar GDI	Button Disable	Auto
Chrysler	300	2016-2017	3.6 Pentastar GDI	Button Disable	Auto
Chrysler	200	2015-2017	All PFI	Button Disable	Auto

The Ford Fusion SE 2014 vehicle shown in Figure 1 was selected based on availability and approval from CRC. The vehicle specifications at a high level are listed below:

- 1.5 L Turbocharged
- Inline 4-cylinder engine
- 6 speed automatic transmission
- Front wheel drive
- Gasoline Direct Injection
- No "auto-stop" system

The VIN number of the vehicle was shared with a CRC representative from Ford Motor Company, who confirmed that the vehicle does not have auto-stop feature. The vehicle manufacturer build sheet is provided in Appendix 1, which confirmed the same. The odometer mileage of the vehicle at time of purchase was 35,901 miles (vehicle title in Appendix 4).

Figure 1. Ford Fusion 2014 Vehicle used for the Program

A NI cRIO 9035 controller was used as a platform to write software to cause the various driveability events. The CompactRIO or cRIO shown in Figure 2 is a combination of a real-time controller, Reconfigurable IO Modules (RIO), FPGA module and an ethernet expansion chassis. It is an open controller running on a Linux real time operating system. The cRIO controller running software developed by SwRI as part of this program will be referred to as the SwRI intercept controller for the rest of this report.

In addition to the base controller, the following input and output modules were procured:

1. NI 9411 – high speed digital input module for reading crank and cam signals
2. NI 9220 – high speed analog input module for reading pedal, spark and injector currents
3. NI 9862 – CAN bus module for interfacing with the OBD-II port of the vehicle
4. NI 9263 – high speed analog output module to override pedal signal
5. NI 9401 – high speed digital output module to override ignition timing signal

Figure 2. Controller Programmed to cause Driveability Events on Vehicle

SwRI also developed an interface, see Figure 3 to communicate with the controller. The interface was written using LabVIEW language. It was deployed on a Microsoft Surface tablet running Windows 10. The interface in Figure 3 shows the various calibration parameters and triggers for the driveability events programmed in the controller. More details on the calibration parameters are described in the later part of the report.

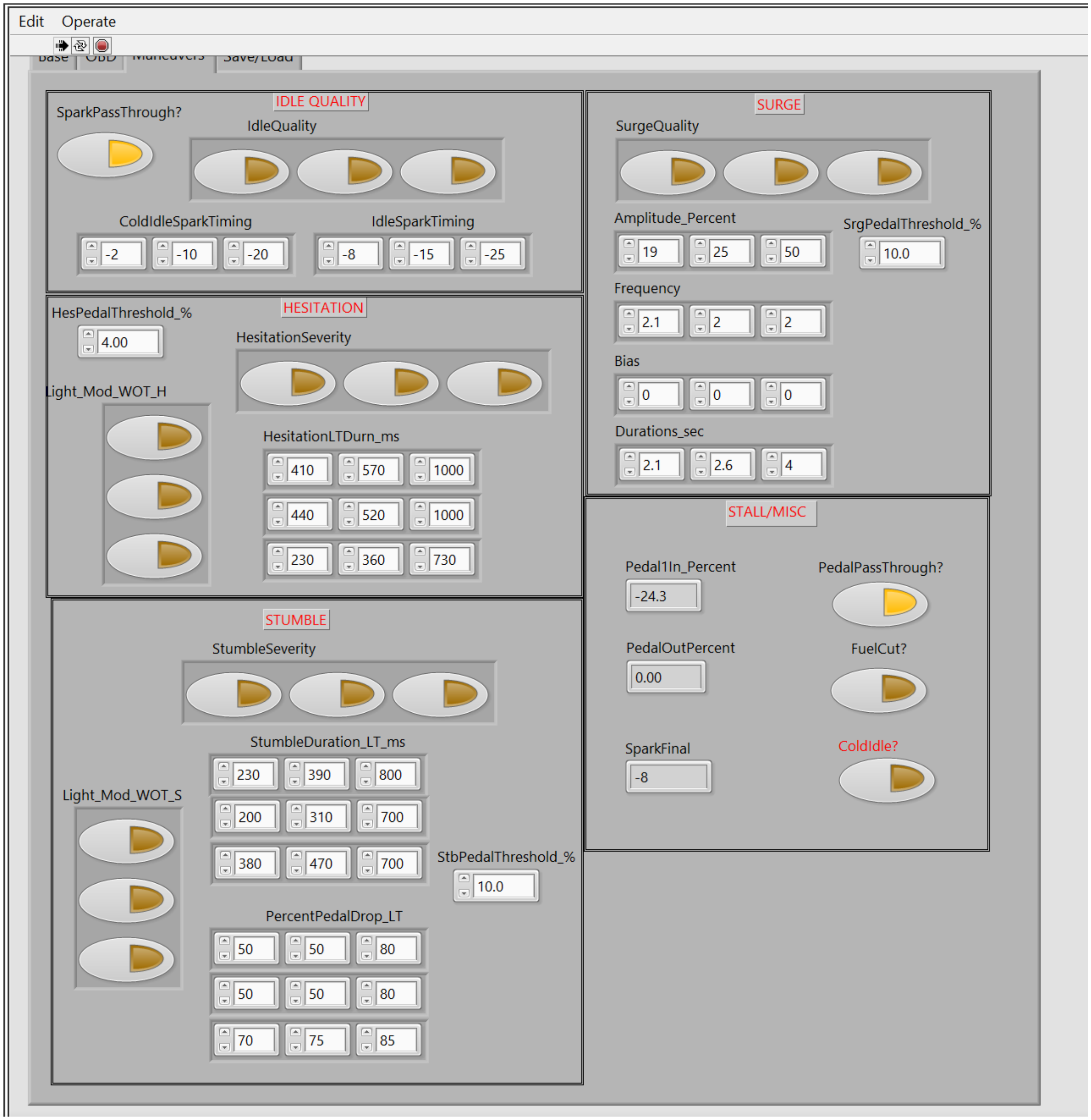


Figure 3. Interface Built by SwRI to Communicate with the Controller

5.0 IMPLEMENTATION STRATEGIES – INITIAL

As the first step, the stock vehicle's crank and cam signals were spliced and wired into the SwRI intercept controller. Logic was written in the SwRI intercept controller to synchronize with the engine in crank angle domain to override ignition timing signal as needed.

Figure 4. Crank (Yellow), Intake Cam (Blue) and Exhaust Cam (Red) Signals as Measured using an Oscilloscope

Ignition timing commands on all four cylinders were intercepted and controlled via the SwRI intercept controller. Two modes of operation were set-up:

1. *Pass-through*: Stock ignition commands are relayed to the coils as if in normal operation. Delay was measured to be about 100 nanoseconds. This pass-through delay is small and expected to have no measurable effect on vehicle operation. Even at 6000 rpm, the delay is less than 0.1 crank angle degrees.

2. *By-pass*: Custom ignition commands sent to the coils, as requested.

Impedance matching was done to prevent over-current faults. No fault codes were detected by the vehicle On-Board-Diagnostic (OBD) system. Figure 5 shows the intercept logic for spark timing and custom command by the SwRI intercept controller. Spark timing reported by the vehicle engine control module (ECM) over OBD was used to derive stock ignition timing command.

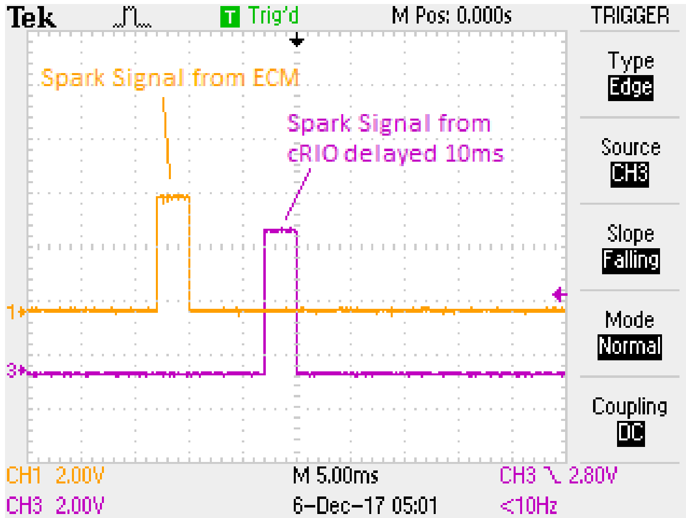


Figure 5. Spark Signal Intercept and Custom Command from SwRI Intercept Controller

Figure 6 shows the stock ignition timing being read into the cRIO controller. The timing info is measured in Degrees Before Top Dead Center (DBTDC) and pulse width is measured in milliseconds (msec). SOI in Figure 6 refers to Start of Injection timing for fuel.

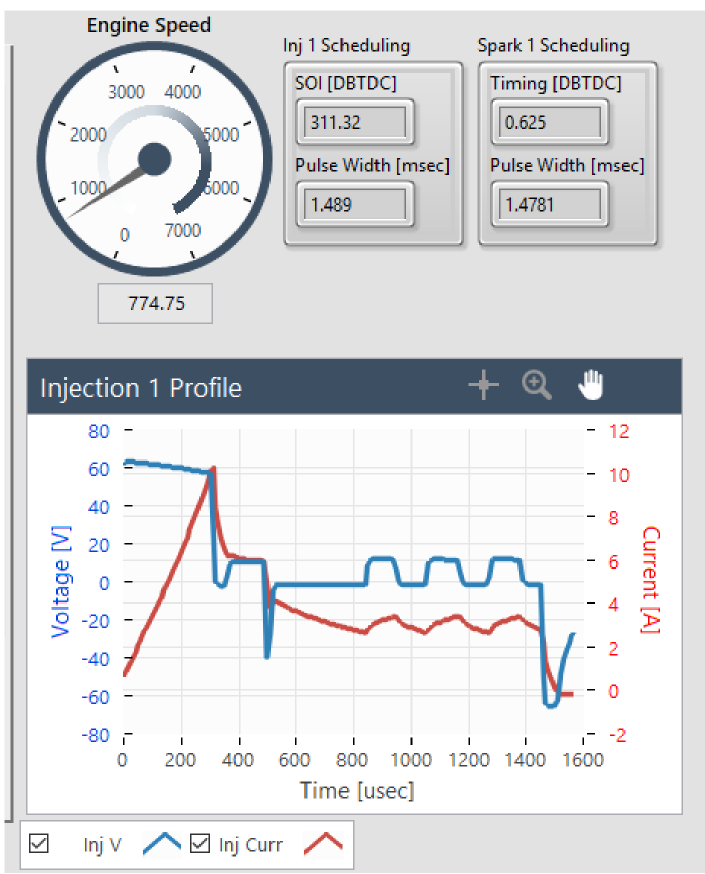


Figure 6. Synchronization Logic and Fuel Injection/Spark Timing Detection

The pedal signal was also intercepted and controlled via the SwRI intercept controller. Similar to ignition command, pass-through and by-pass modes were set-up and tested without the vehicle ECM being aware of the override.

Fuel injection intercept and control was also programmed in the SwRI intercept controller. A direct injection driver was procured and configured to mimic the stock injector current profile, as shown in the bottom half of Figure 6. Typical injector firing consists of two phases: first is the injector “opening” phase which requires a high-current, high-voltage actuation (60V in this case). This opens the injector tip against the fuel rail pressure. Once the injector tip is open, the injector is in the “hold” phase. This phase requires a lower current and is typically operated at 12V battery voltage. As seen in Figure 6, the injector opening phase of the stock injector pulls in a current of 10 A at 60 V. The hold phase draws about 6 A at battery voltage.

Dummy resistive loads with similar impedances as the stock injectors were wired to the stock ECM to mimic a true injector. The real injectors were wired to the custom direct injection driver which is commanded via the SwRI intercept controller. Figure 7 shows injector operation in pass-through mode. The SwRI intercept controller reads the stock injection commands via the voltage across the dummy injectors. This voltage should nominally read 60 V during the pull-in phase and 12 V during the hold phase. The analog input in the SwRI intercept controller was not rated for 60V input. A simple voltage scaling circuit was built and installed on the vehicle to scale the voltage by a factor of 10. Therefore, the voltage changes from 6V to 1.2V as seen in left axis of Figure 7.

The intercept ECM detects this desired injector firing by the stock ECM and sends a digital command to the custom injection driver. The injector driver modulates voltage and current like the stock injection driver for the desired duration. Similar to ignition, the injection command is phase lagged by 100 nanoseconds in pass through mode. This delay is insignificant with respect to normal vehicle operation. The intercept ECM command to the custom injector driver is shown in the right axis of Figure 7. The custom injection command and the stock ECM command are synchronous with no noticeable phase lag. This test ensured that the vehicle could be successfully driven with the custom injection driver by just mirroring the stock ECM commands for a given pedal position.

When a driveability event needs to be created via fuel injection override, the SwRI intercept controller would switch to by-pass mode. In by-pass mode, the SwRI intercept controller could provide a custom command to the injection driver.

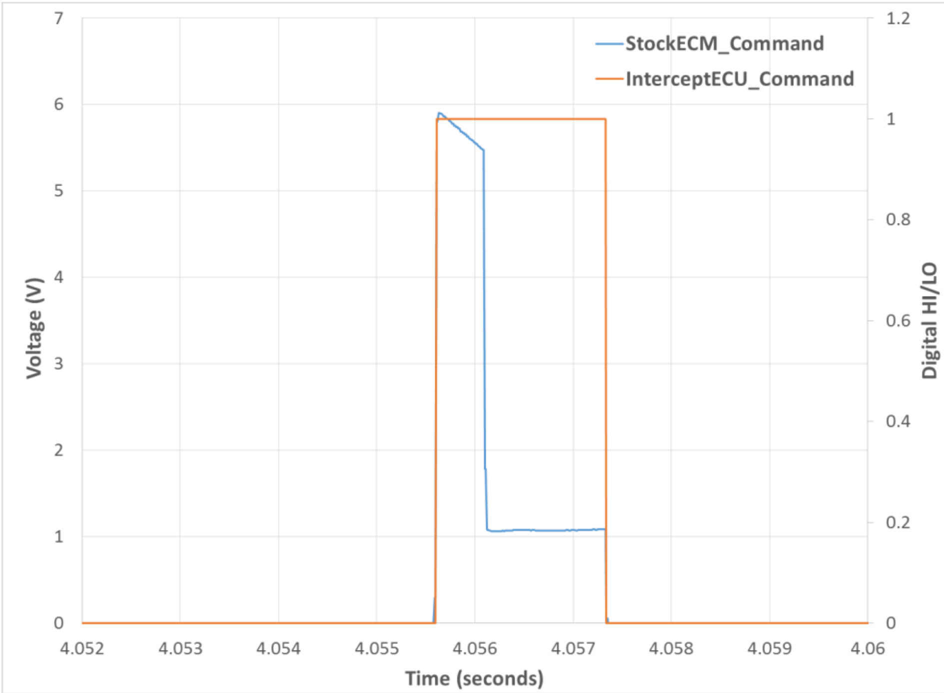


Figure 7. Injector Operation in Pass-through Mode, Left Axis Corresponds to Scaled Voltage Measured across Dummy Injector and Right Axis is the TTL Output from Intercept ECM to the Direct Injection Driver

An OBD scan tool was used to confirm that there were no active or pending fault codes. There were no fault codes present on the vehicle display either. Figure 8 shows the SwRI intercept controller mounted in the vehicle glove box. It was carefully installed in this manner to ensure five people could comfortably ride in the vehicle during the rating process.

Figure 8: SwRI Intercept Controller Mounted in the Vehicle Glove Box

Figure 9 shows the custom direct injection driver mounted near the stock ECM under the hood of the vehicle.

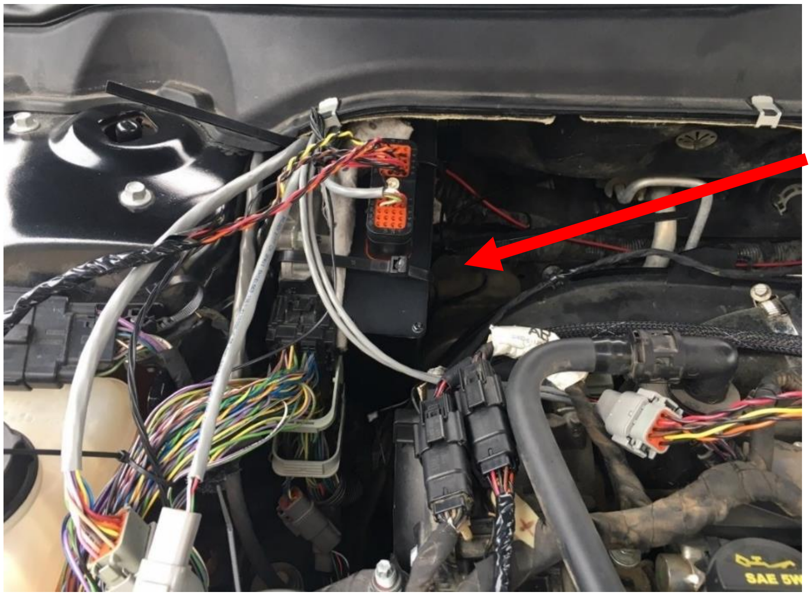


Figure 9. Direct Injector Driver Mounted near the Vehicle ECM under the Hood

In addition to the pedal, spark, and fuel injection command, the SwRI intercept controller also interfaced with the vehicle's OBD port. The following parameters were acquired by the data acquisition system:

- Pedal position
- Throttle position
- Coolant temperature
- Vehicle speed
- Intake air temperature
- Engine rpm
- Spark timing
- Pending fault codes

Monitoring these parameters helped identify outliers in data acquired during track testing.

Useful information was shared by raters regarding driveability events. A few examples are highlighted below. Figure 10 describes a hesitation event using vehicle speed response. Typical operation of the accelerator pedal would have resulted in vehicle speed as indicated via the black line. Vehicle speed during a hesitation event is shown by the red line in Figure 10. There is no increase in vehicle speed for a certain period initially, after which the vehicle speed overshoots and then converges back to the typical line. Figure 11 and Figure 12 similarly describe vehicle speed response during surge and stumble events respectively.

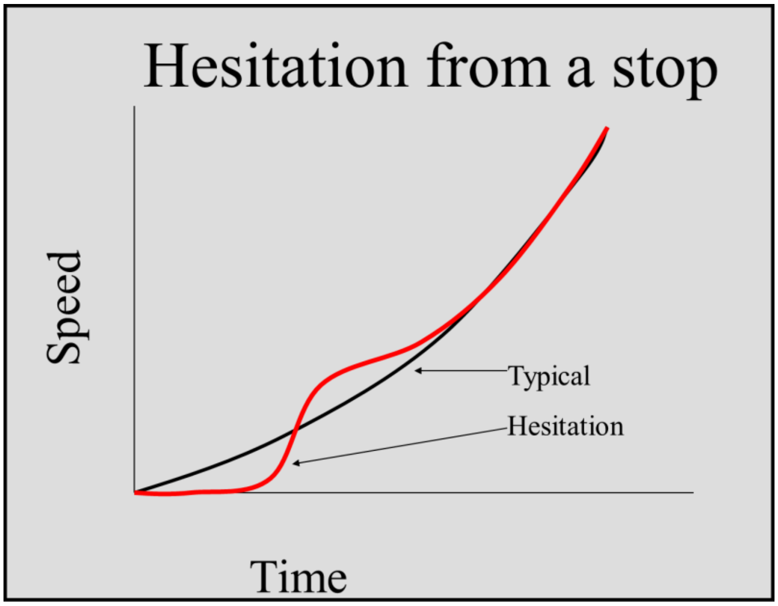


Figure 10. Rater Description for Hesitation from a Stop

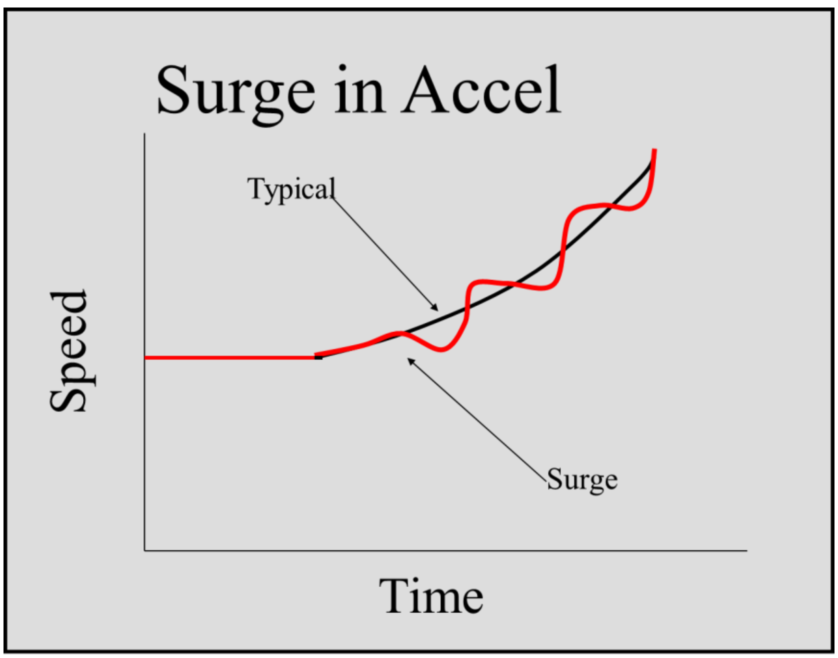


Figure 11. Rater Description for Surge in Acceleration

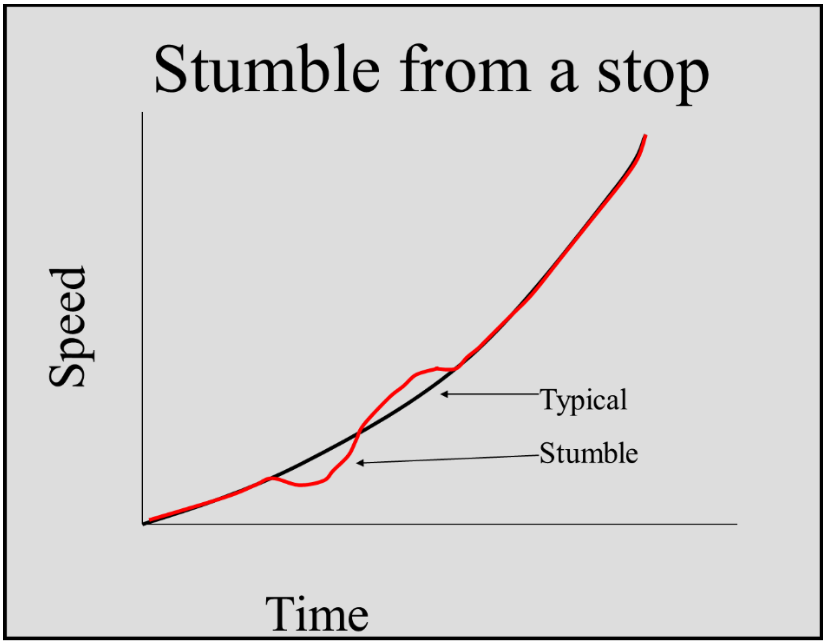


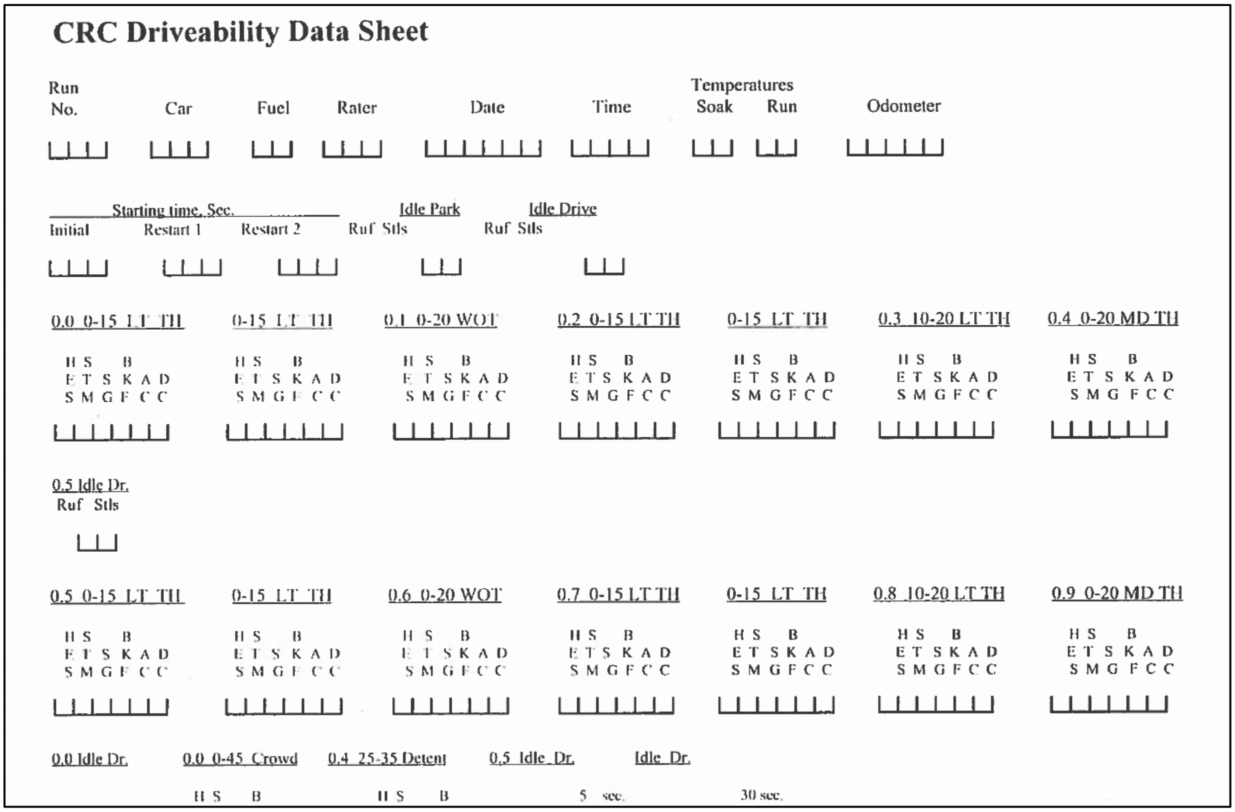
Figure 12. Rater Description for Stumble from Stop

6.0 TESTING WITH RATERS – WEEK 1

Driveability raters (Figure 13), previously approved by CRC, were on site at SwRI during the week of March 5-9, 2018 to help calibrate and fine-tune the system built by SwRI.

Figure 13. Testing with Driveability Raters at SwRI (From Left: Beth Evans, Harold Archibald, Sankar Rengarajan, Phil Krysinski, and James Fritz)

The raters followed driveability test procedures at the SwRI test track where they began calculating demerits for the system. The rater who performed the rating was the driver, and a SwRI operator sat in the back seat triggering the driveability events. The other rater sat in the front passenger seat and noted the reported event on the driveability sheet (sample shown in Figure 14). The vehicle electrical harness was modified in a manner such that switching between stock ECM operation and SwRI intercept controller was easy. The SwRI intercept controller was completely disconnected and the raters performed the driveability maneuvers on the vehicle with stock ECM operation to quantify baseline performance.


CRC Driveability Data Sheet

Run No. | Car | Fuel | Rater | Date | Time | Temperatures Soak | Run | Odometer

Starting time, Sec. Initial | Restart 1 | Restart 2 | Idle Park Ruf Stls | Idle Drive Ruf Stls

0.0 0-15 LT TH | 0-15 LT TH | 0.1 0-20 WOT | 0.2 0-15 LT TH | 0-15 LT TH | 0.3 10-20 LT TH | 0.4 0-20 MD TH

H S B
E T S K A D
S M G F C C

0.5 Idle Dr.
Ruf Stls

0.5 0-15 LT TH | 0-15 LT TH | 0.6 0-20 WOT | 0.7 0-15 LT TH | 0-15 LT TH | 0.8 10-20 LT TH | 0.9 0-20 MD TH

H S B
E T S K A D
S M G F C C

0.0 Idle Dr. | 0.0 0-45 Crowd | 0.4 25-35 Detent | 0.5 Idle Dr. | Idle Dr.

H S B | H S B | 5 sec. | 30 sec.

Figure 14. Sample Driveability Sheet

The remainder of this section describes various driveability events that were calibrated. Initial strategy and refinement of strategy based on rater feedback is described for individual events. Three levels of severity captured were Trace, Moderate, and Heavy.

6.1 Idle Quality

The initial strategy for idle quality was to retard ignition timing. Retarding ignition timing would deter combustion stability enough to worsen idle quality of the test vehicle. Fuel injection and pedal were controlled via the stock ECM.

While retarding ignition timing did result in degraded combustion stability, the stock controller would quickly adjust throttle and fuel injection to increase engine rpm to idle set point. Also, there was inconsistency between the events reported by raters. The raters would call out a “Trace” severity and a “Heavy” severity for the same ignition timing during different parts of the test.

To mitigate this compensation by the stock controller, random white noise was added onto the adjusted ignition timing. The randomness bounds were a function of the desired severity level. This randomness ensured that the stock controller cannot learn the adjustment in ignition timing. After implementation of the strategy, the “triggered” severity level had better correlation with what was reported by the raters. Figure 15 shows the variation in spark timing during a triggered idle quality event. As seen, the random noise for a trace severity is bit more constrained than a moderate severity idle quality event.

Figure 15. Data Sample – Idle Quality Event (Top: Spark Timing Command to ECM; Bottom: Button Push Corresponding to Idle-Trace or Moderate Event Trigger)

6.2 Hesitation

The initial strategy for causing a hesitation event involved intercepting pedal signal and forcing pedal to zero for a specific duration. The desired event severity would dictate duration for which the pedal was held at zero.

While the initial strategy worked well, the maneuver performed significantly affected reported severity. For example, if 100 milliseconds duration worked well for "Trace" severity at 0-15 mph light throttle, the same setting would result in the rater reporting "Heavy/Extreme" severity for 0-20 wide open throttle (WOT).

The final solution was simply an added dimension to the calibration table. In addition to duration, throttle setting was added for the final strategy. The calibration table format is shown in Table 3.

Table 3. Calibration Table Format Based on Severity and Maneuver Type

		Severity		
		Trace	*Moderate*	*Heavy*
Throttle	*Light*			
	Moderate			
	Wide Open			

Also, a trigger was set on the pedal signal based on its position. This pedal-based trigger helped with repeatability and coordination. Once the pedal position crossed a threshold value of 4%, the pedal command would be set to 0% for a specified duration. The 4% threshold was selected because the vehicle ECM does not respond to pedal values below this threshold, but it was sufficient to detect actuator movement. Once the specified duration was complete, the pedal would be set to pass-through mode. Pedal manipulation during a hesitation event is shown in Figure 16. The blue dashed line shows the pedal input corresponding to actuator movement by the rater. Pedal out corresponds to manipulation by the SwRI intercept controller to the vehicle ECM. The red dashed line indicates the pedal threshold (4%) at which the intercept controller recognizes the pedal movement and forces the pedal output to zero.

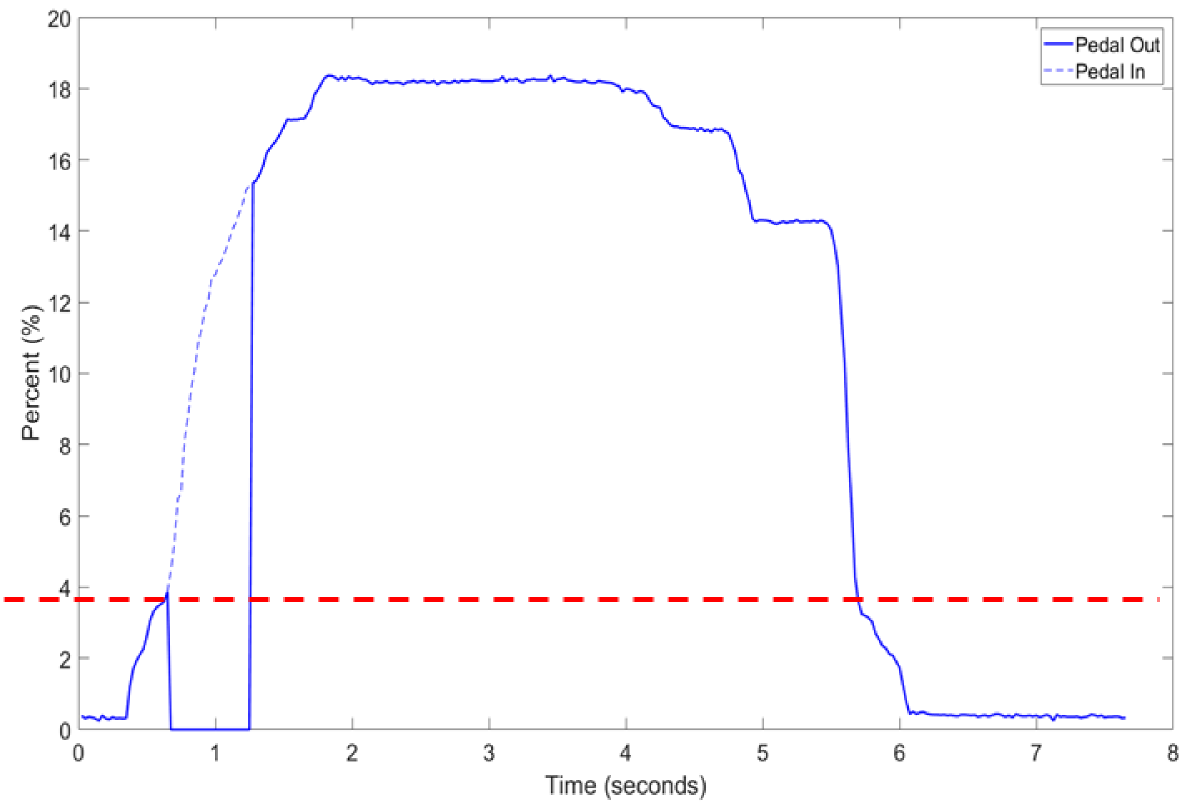


Figure 16. Pedal Manipulation during a Hesitation Event

6.3 Stumble

The initial strategy for stumble was similar to hesitation. The strategy was to intercept pedal signal and force pedal to slightly lower value for a specific duration. Desired event severity would dictate duration as well as reduction in commanded pedal. Like hesitation, the commanded throttle significantly affected severity. The final solution was similar to hesitation. The primary difference was that two tables were used for stumble calibration, one for duration of power drop and one for magnitude of power drop. The calibration tables look like Table 3 but with two dimensions – throttle and severity desired.

Pedal manipulation during a stumble event is depicted in Figure 17. Pedal-in corresponds to actual movement of the pedal actuator and pedal-out is the manipulation of the signal by the SwRI intercept controller. While the true pedal movement corresponds to about 27%, the signal to the ECM is held at about 16% for around 300 milliseconds. This causes the sharp power drop experienced by the user.

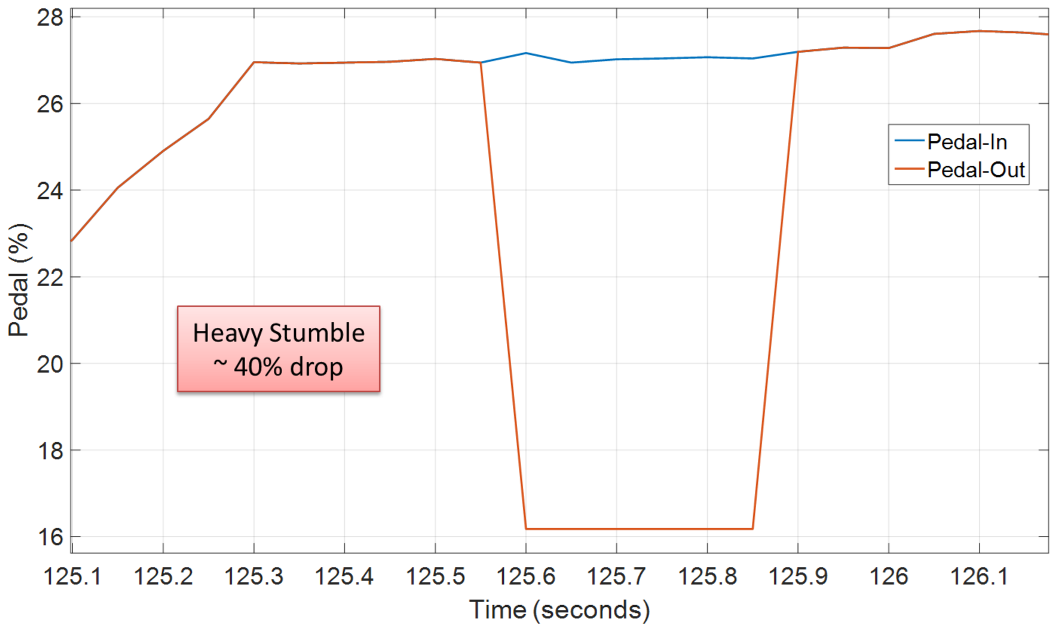


Figure 17. Pedal Manipulation during a Stumble Event

6.4 Surge

The initial strategy for surge was to intercept pedal or fuel injection and attenuate a sine wave on top of the stock ECM command. The pedal was initially attenuated. The raters commented that the pedal attenuation did mimic the surge event accurately. Therefore, fueling was left untouched and commanded by stock controller. The custom injection driver was removed from the vehicle and fuel injection harness was hooked up in the stock configuration.

One rater focused more on duration of the surge event and the other focused more on amplitude of the attenuated sine wave. The final solution that worked well involved four parameters – (1) frequency of the sine wave (2) amplitude of the sine wave (3) duration of total event and (4) pedal threshold below which no surge was performed. The parameters, see Figure 18 dictate the characteristics of the sinusoidal variation in pedal signal during a surge event.

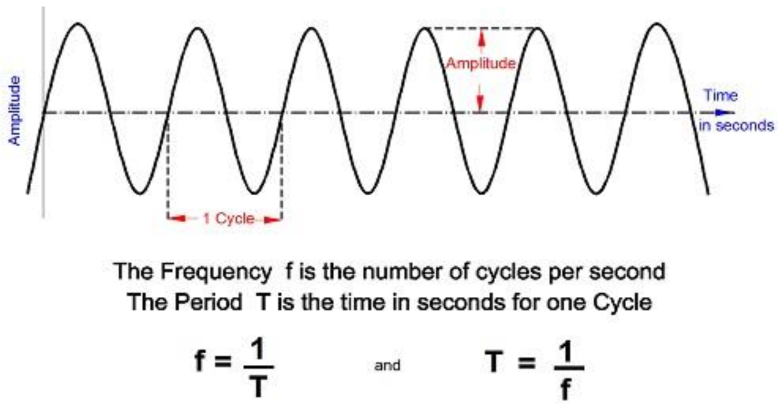


Figure 18. Sine Wave Parameters (source: Google)

Pedal manipulation during a surge event is shown in Figure 19. While the pedal input corresponding to actuator movement is constant around 15%, the output is a sinusoidal wave with frequency, amplitude and duration that are set via calibrations. The pedal threshold below which no surge was performed was set to 10%. This was necessary because manipulation at very low pedal values would not yield any noticeable fluctuations in engine power. The raters also commented that surge event does not happen at wide open throttle conditions. SwRI's understanding is that for a surge event, the power needs to cycle up and down along a mean power line. If throttle is already at wide open condition, it is only possible to drop power. The feel might resemble a stumble more than a surge.

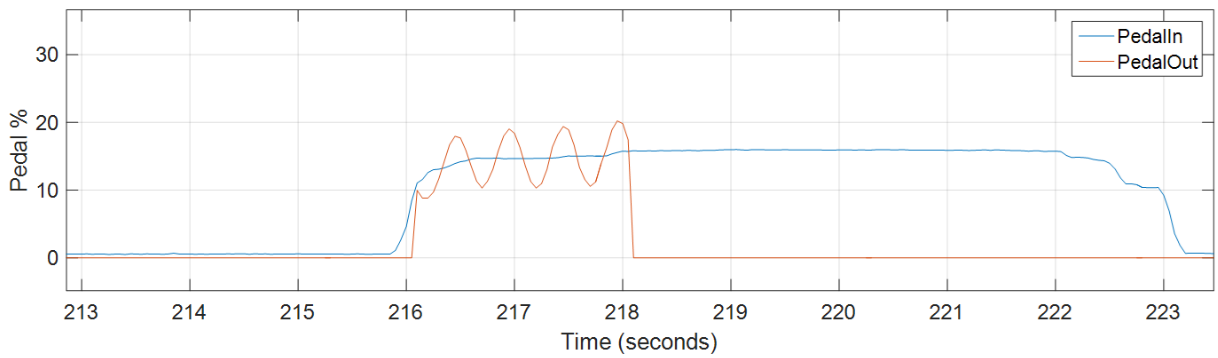


Figure 19. Pedal Manipulation during a Surge Event

6.5 Stall

The initial strategy implemented for a stall was fuel cut. Since the custom injection driver was removed and fueling made completely stock, stall was implemented and verified via ignition cut. No extensive testing was required for stall since it does not categorize in severity levels like other driveability events.

6.6 Testing with Raters – Week 1 Takeaways

Fueling override was not required to cause driveability events. Overall system performance was good. Track quality is important for driveability testing – raters mentioned the track at SwRI was not smooth enough to detect trace and moderate events in some cases. More testing was needed to generate data for drawing statistically significant conclusions. Improved post processing tools were needed for data analysis.

A conference call was held between SwRI and CRC members on March 21, 2018 to discuss the path forward. Members agreed with SwRI's assessment to bring the raters back for an additional week of testing. Members also agreed with SwRI that it was best to perform testing on an external test track to remove any variability associated with the original track. San Antonio Raceway, a drag strip located about 40 minutes from SwRI, was selected as the venue to perform the testing at SwRI's recommendation. The raters were in San Antonio between April 16-20, 2018.

7.0 ADDITIONAL CAPABILITIES BUILT PRIOR TO RATER TESTING-WEEK 2

7.1 Electronic Rating Sheet

As previously mentioned, the current test procedure with the SwRI driveability control system involved performing the maneuvers as mentioned in the CRC driveability data sheet. While the “triggered” event by the SwRI control system, along with corresponding effect on pedal and spark timing was logged electronically, the “reported” event by raters were noted on the driveability data sheet. This information was later manually entered in an electronic format for post processing. This method was laborious and prone to human error.

To overcome the above challenges mentioned, SwRI implemented an electronic CRC driveability data sheet on a second tablet. The rater tablet and the control tablet would communicate wirelessly through a router hub to a centralized data acquisition system. This enabled rater responses and controller info to be logged in a time synchronous fashion in a single data file. This would significantly speed-up post processing efforts of the incoming data. A flow chart of the updated data acquisition setup is shown in Figure 20.

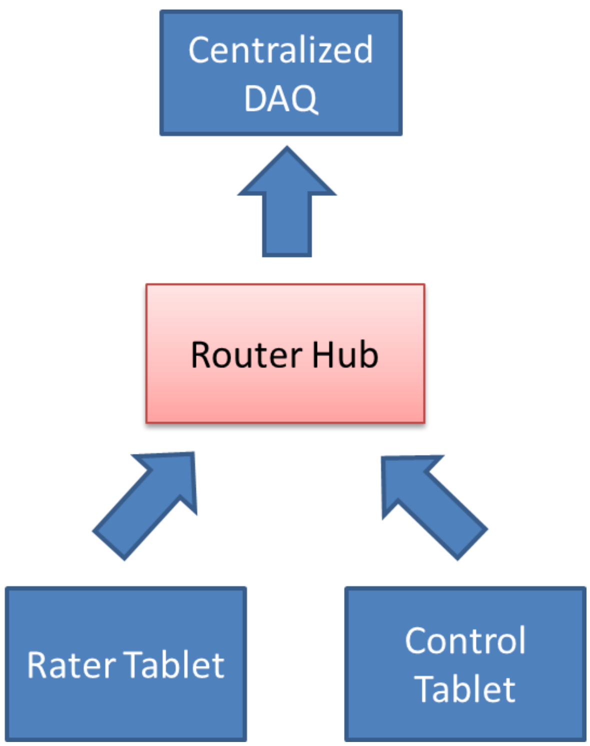


Figure 20. Data Acquisition Setup 2.0

The GUI of this “Rater Response Tablet” is shown in Figure 21 for idle rating and for all other events such as stumble and hesitation. The GUI displays the current date and time. Run number is displayed and controlled by the main test application. No action can be taken until the main test application confirms start of test. The current maneuver name and number is displayed prominently. For the maneuver displayed, the rater selects which rating is appropriate. The rater presses confirm to lock in their selection and transition to the next maneuver. At the end of a test, the application waits until the main program begins the new test. Raters were pleased with the electronic interface and had no issues with the set-up.

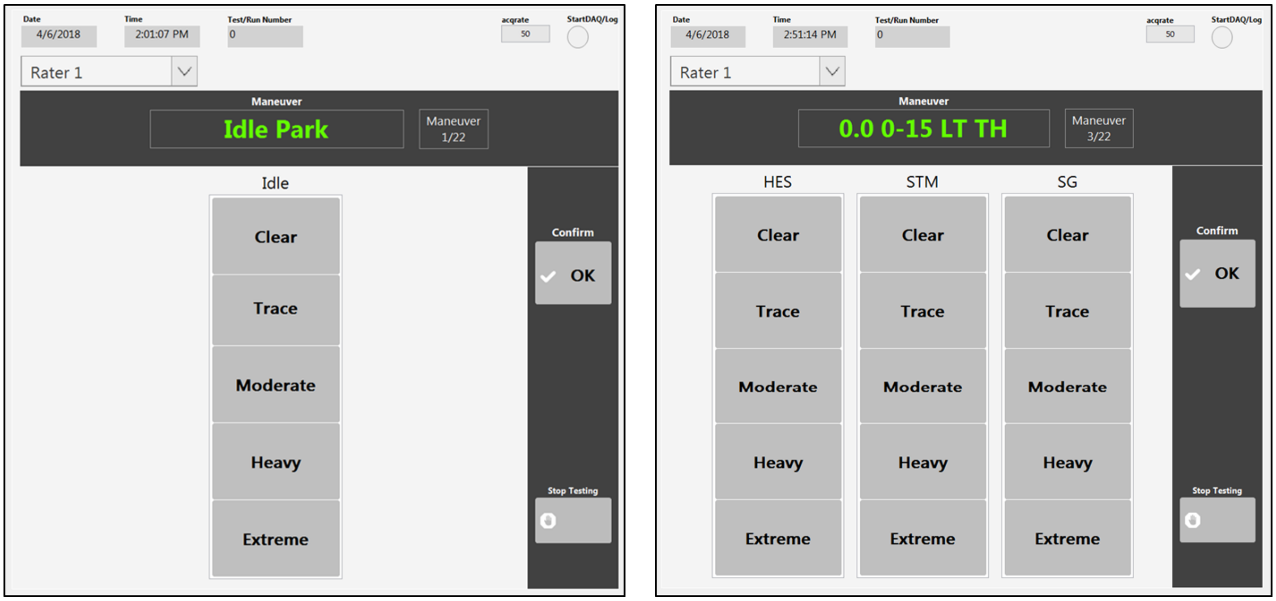


Figure 21. Rater Data Sheet Application GUI (Left: Idle Rating and Right: (Hesitation, Stumble, Surge Rating))

7.2 Randomized Event Generator

A randomized event generation algorithm was created to ensure uniform distribution of events triggered by the SwRI operator. This was important to ensure that there was no bias towards a specific event in the final data-set. The algorithm needed to handle exceptions. It should differentiate between idle maneuvers and standard maneuvers and it should not command surge during wide open throttle maneuvers. A typical test in the CRC driveability sheet consists of 22 maneuvers. The algorithm would generate what event needs to be triggered by the SwRI operator for the given maneuver.

8.0 TESTING WITH RATERS – WEEK 2 OVERVIEW

With updated tools as described in Section 7, SwRI was ready to resume testing with raters during the week of April 16-20, 2018. Raters were pleased with the external test track and the facility's ideal conditions for driveability testing. The overall testing was performed for five days. Days 1 and 2 spent on fine-tuning calibration. Calibrations finalized and no changes from Day 3. Days 3 and 4 involved testing all maneuvers described in the CRC driveability data sheet. Day 5 involved performing fixed severity events.

The raters were happy with the system and stated that the car would be an extremely useful tool to train future raters. Written feedback from raters was requested after the testing. The raters did not have any access to the data and analysis described in the following section. Highlights of the raters' comments are shown below. Full write-up from raters is attached in Appendix 2.

<u>Rater 2 Comments Highlights (as-provided):</u>

In my opinion, this car will be an invaluable training tool in future Rater workshops. Nothing can overcome the difficulties in programming 100% consistency for individual (human) drivers.

<u>Rater 1 Comments Highlights (as-provided):</u>

A preprogrammed computer with software to create random malfunctions and severity levels without an operator may be useful. This would prevent cuing the driver/rater that someone is creating malfunctions.

8.1 Data Analysis

While the human feel of the system as evidenced by rater feedback was positive, the team focused on data-driven conclusions drawn from the testing. The overall data was structured in the manner shown in Figure 22.

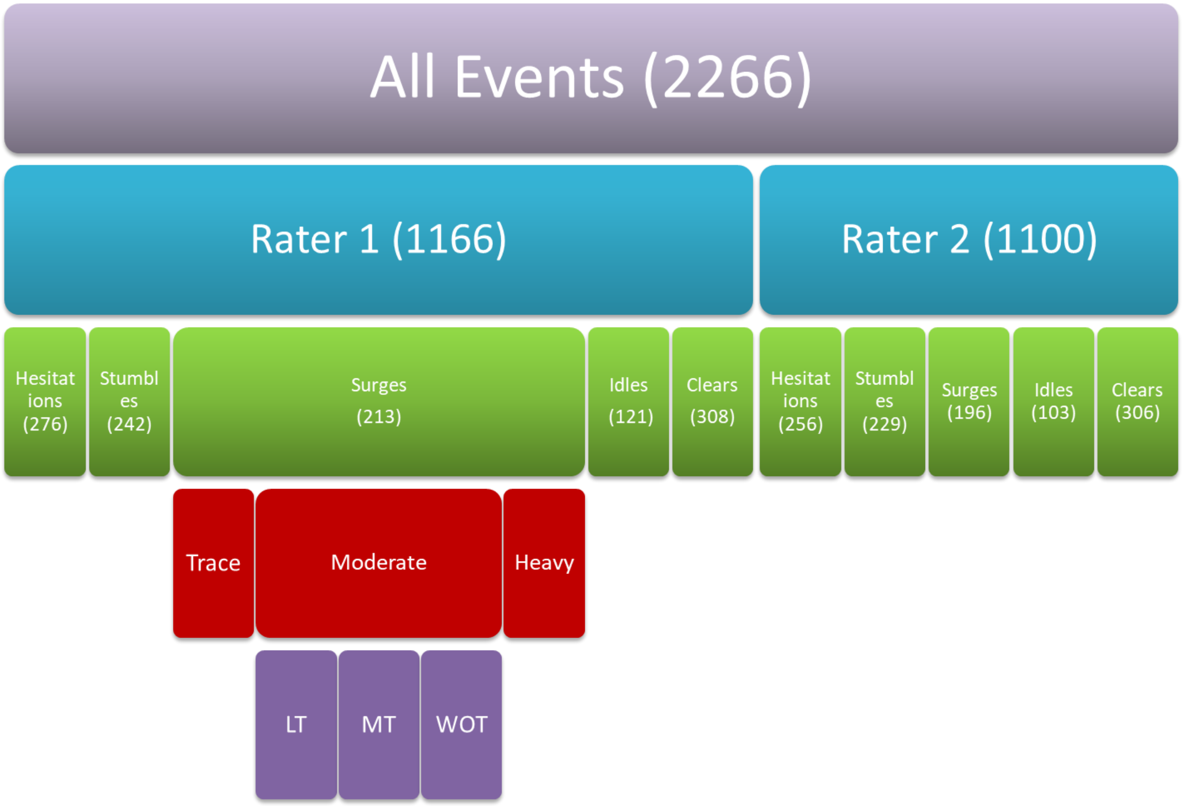
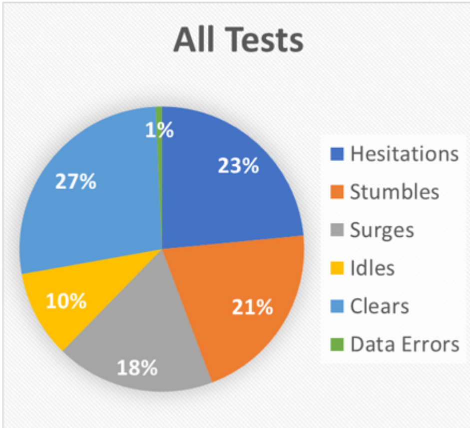


Figure 22. Schematic Showing Organization of the Acquired Data-Set

Data analyzed from a total of 2,266 events was rich in information. Figure 22 also describes the dimensionality of the data set. A specific event would need at minimum four dimensions to be uniquely identified – (1) What event was triggered (2) Who was the rater (3) What was the severity of the event and (4) What throttle maneuver was performed – light throttle (LT), moderate throttle (MT) or wide-open throttle (WOT). In addition to these four dimensions, there is also ambient temperature. While ambient temperature was not controlled, it was monitored by measuring the intake air temperature over the OBD port.

The total number of events were distributed as shown in Figure 23. The events were distributed evenly because of the random event generator algorithm described in section 7.2. With only 6 idle maneuvers out of the total 22 maneuvers in the CRC driveability data sheet, the percentage of idle events are slightly less.



Totals (All Severities)		
Hesitations	532	23%
Stumbles	471	21%
Surges	409	18%
Idles	224	10%
Clears	614	27%
Data Errors	16	1%
Total Maneuvers	2266	100%

Figure 23. Overall Event Distribution

The 2266 events were distributed almost evenly between the two raters and the distribution was similar to the overall data-set, as shown in Figure 24.

Rater 1

Totals (All Severities)		
Hesitations	276	24%
Stumbles	242	21%
Surges	213	18%
Idles	121	10%
Clears	308	26%
Data Errors	6	1%
Total Maneuvers	1166	100%

Rater 2

Totals (All Severities)		
Hesitations	256	23%
Stumbles	229	21%
Surges	196	18%
Idles	103	9%
Clears	306	28%
Data Errors	10	1%
Total Maneuvers	1100	100%

Figure 24. Events Distribution among Raters

Figure 25 shows the weighted accuracy at an event level. The weights were calculated by dividing the number of times a specific event was triggered by the total number of events.

$$Weighted\ Mean\ Accuracy\ Hesitation = \frac{Number\ of\ hesitations}{Total\ Number\ of\ events} * accuracy_{hesitation}$$

For example, when a hesitation event was triggered, raters reported a hesitation event 97% of the time as seen in Figure 25. Similarly, for stumble, the accuracy was about 96%. The combined weighted mean accuracy over all events was about 95% as indicated by the dashed red line in Figure 25.

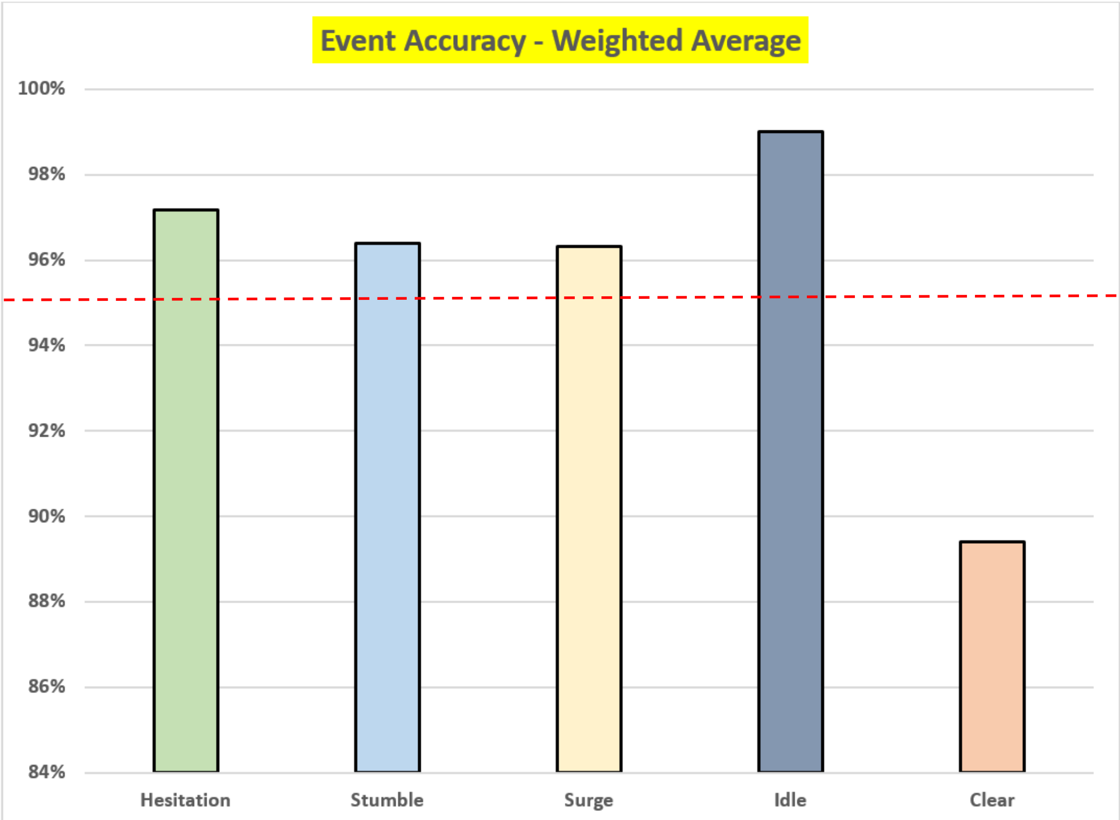


Figure 25. Accuracy at Event Level

8.2 Accuracy at Severity Level

With above 95% event-level accuracy, the team evaluated accuracy at a severity level for each triggered event. Only trace, moderate, and heavy severity events were triggered and calibrated during testing. No extreme severity events were triggered or calibrated, although raters sometimes rated events extreme.

Stumbles

The final calibration for the stumble event is shown in Figure 26. The top part shows the duration of power drop and the bottom part shows the actual drop in pedal percentage. One can appreciate the tight band within which raters distinguish between a trace severity versus a moderate severity. For example, trace severity for a light throttle maneuver has a duration of 230 milliseconds. For the same light throttle maneuver, a moderate severity has a duration of 390 milliseconds. The difference is just 160 milliseconds. A moderate to heavy severity has a more noticeable difference of about 400 milliseconds.

STUMBLE DURATION (MILLISECONDS)				
		Severity		
		Trace	*Moderate*	*Heavy*
Throttle	*Light*	230	390	800
	Moderate	200	310	690
	Wide Open	380	470	700

STUMBLE PEDAL DROP (PERCENT)				
		Severity		
		Trace	*Moderate*	*Heavy*
Throttle	*Light*	50	50	80
	Moderate	50	50	80
	Wide Open	70	75	85

Figure 26. Calibrations Tested for a Stumble Event

Figure 27 shows the combined accuracy of the raters for stumble events. The weighted mean accuracy across all severity levels for the stumble event was calculated to be about 47%, which was much less than anticipated.

		Executed Event		
		Stumble Trace	Stumble Mod	Stumble Hvy
Rater Response	Clear	16%	0%	0%
	Trace	**67%**	36%	5%
	Moderate	10%	**42%**	34%
	Heavy	1%	19%	**52%**
	Extreme	0%	0%	3%
	Incorrect Event Rated	6%	3%	5%
	Total	100%	100%	100%
	Total Number of Tests	**70**	**328**	**73**

Figure 27. Combined Accuracy at Severity Level for Stumbles (both Raters)

Rater 1

Rater Response	Stumble Trace	Stumble Mod	Stumble Hvy
	Executed Event		
Clear	27%	1%	0%
Trace	**61%**	65%	10%
Moderate	3%	**23%**	36%
Heavy	0%	7%	**44%**
Extreme	0%	0%	0%
Incorrect Event Rated	9%	4%	10%
Total	100%	100%	100%
Total Number of Tests	33	170	39

Rater 2

Rater Response	Stumble Trace	Stumble Mod	Stumble Hvy
	Executed Event		
Clear	5%	0%	0%
Trace	**73%**	5%	0%
Moderate	16%	**62%**	32%
Heavy	3%	32%	**62%**
Extreme	0%	0%	6%
Incorrect Event Rated	3%	1%	0%
Total	100%	100%	100%
Total Number of Tests	37	158	34

Figure 28. Stumble Accuracy Partitioned by Raters

As the team analyzed individual rater's performance, the reason became evident. Figure 28 shows the accuracy of individual raters to an executed event. For example, from the left side of Figure 28, note that rater 1 is calling 65% of moderate stumbles as trace stumbles. To improve the accuracy of rater 1 on a moderate stumble event (indicated by red arrow), the event would need to be made more aggressive. For the same calibration, the right part of Figure 28 clearly suggests that rater 2 classified 62% of the events accurately (indicated by red arrow) and categorized 32% of the moderate events as heavy. Increasing the aggressiveness of the event may improve accuracy of rater 1, but it would reduce accuracy of rater 2. Therefore, the combined overall accuracy would still suffer.

1	Clear
2	Trace
3	Moderate
4	Heavy
5	Extreme

Figure 29. Severity Key Established to Capture Sensitivity Differences in Raters

To simplify presenting the data, a severity key, as shown in Figure 29, was established to present the sensitivity differences among raters in a succinct manner. In an ideal scenario, calibrations should result in mean severity of 2, 3, and 4 across the three different columns: trace, moderate, and heavy. The accuracy of the raters over the stumble event is presented along with the weighted mean severity of each rater in Figure 30. The weighted mean severity is presented in the last row of the tables in Figure 30.

Rater 1

	Executed Event		
Rater Response	Stumble Trace	Stumble Mod	Stumble Hvy
Clear	27%	1%	0%
Trace	**61%**	65%	10%
Moderate	3%	**23%**	36%
Heavy	0%	7%	**44%**
Extreme	0%	0%	0%
Incorrect Event Rated	9%	4%	10%
Total	100%	100%	100%
Total Number of Tests	33	170	39
Mean	1.6	2.3	3.0

Rater 2

	Executed Event		
Rater Response	Stumble Trace	Stumble Mod	Stumble Hvy
Clear	5%	0%	0%
Trace	**73%**	5%	0%
Moderate	16%	**62%**	32%
Heavy	3%	32%	**62%**
Extreme	0%	0%	6%
Incorrect Event Rated	3%	1%	0%
Total	100%	100%	100%
Total Number of Tests	37	158	34
Mean	2.1	3.2	3.7

Figure 30. Weighted Mean Severity for Stumble Event for each Rater

For example, rater 1's mean severity of 1.6 for trace stumble implies that current calibration for trace severity is somewhere between a clear and trace severity for rater 1. But the same calibration results in rater 2's mean severity of about 2.1 for a trace event which is close to ideal value of 2.0. While rater 1 is at a mean severity of 2.3 for moderate stumble, rater 2 has a mean severity of 3.2 for the same calibration. The trend continued for heavy severity with rater 1 at 3.0 and rater 2 at 3.7. The conclusion from the analysis was that rater 1 is less sensitive to stumble events compared to rater 2. Calibrating the event to be more aggressive might improve system accuracy for rater 1 but accuracy for rater 2 might decrease as more heavy events might be reported as extreme. Combined accuracy would not improve.

Hesitations

Final calibrations used for testing hesitations are shown in Figure 30. Like stumbles, the difference between trace and moderate severity events was about 150 milliseconds, while the heavy hesitations were spread apart more.

HESITATION (milliseconds)				
		Severity		
		Trace	*Moderate*	*Heavy*
Throttle	*Light*	410	570	1000
	Moderate	440	520	1000
	Wide Open	230	360	730

Figure 31. Final Calibration used for Hesitation Event Testing

Figure 32 shows the combined accuracy for hesitation events across both the raters. The weighted mean accuracy at a severity level for the hesitation event was calculated to be about 40%. The team analyzed the data further to understand the low accuracy.

		Executed Event		
		Hesit. Trace	Hesit. Mod	Hesit. Hvy
Rater Response	Clear	38%	7%	10%
	Trace	**43%**	26%	6%
	Moderate	9%	**41%**	44%
	Heavy	0%	24%	**33%**
	Extreme	0%	1%	5%
	Incorrect Event Rated	9%	2%	1%
	Total	100%	100%	100%
	Total Number of Tests	74	380	78

Figure 32. Combined Accuracy at Severity Level for Hesitations (both Raters)

Like stumble events, the data was partitioned at a rater level and weighted mean severities were computed as shown in Figure 33. The mean severities are shown in the bottom row. Unlike the stumbles, the hesitation data revealed a different trend. Both raters have mean severity of about 1.6 for trace events and 3.1 for heavy events. In this case, changing the calibration to increase severity would improve the accuracy for both raters. Therefore, in the case of hesitation, there is potential for accuracy improvement for both raters by making the calibrations more aggressive.

Rater 1

		Executed Event		
		Hesit. Trace	Hesit. Mod	Hesit. Hvy
Rater Response	Clear	45%	9%	10%
	Trace	**39%**	40%	8%
	Moderate	11%	**27%**	33%
	Heavy	0%	22%	**44%**
	Extreme	0%	1%	3%
	Incorrect Event Rated	5%	2%	3%
	Total	100%	100%	100%
	Total Number of Tests	38	199	39
	Mean	1.6	2.6	3.1

Rater 2

		Executed Event		
		Hesit. Trace	Hesit. Mod	Hesit. Hvy
Rater Response	Clear	31%	4%	10%
	Trace	**47%**	11%	5%
	Moderate	8%	**55%**	54%
	Heavy	0%	27%	**23%**
	Extreme	0%	0%	8%
	Incorrect Event Rated	14%	2%	0%
	Total	100%	100%	100%
	Total Number of Tests	36	181	39
	Mean	1.5	3.0	3.1

Figure 33. Weighted Mean Severity for Hesitation Event for each Rater

Surges

Final calibrations used for testing surges are shown in Figure 34. The amplitude dictates the attenuation from the base pedal value. A frequency of around 2 Hz worked well across all severities. The total duration dictated how long the surge event lasted.

SURGE			
	Severity		
	Trace	*Moderate*	*Heavy*
Amplitude (percent)	19	25	50
Frequency (Hertz)	2.1	2	2
Total Duration (seconds)	2.1	2.6	4

Figure 34. Final Calibration used for Surge Event Testing

Figure 35 shows the combined accuracy for surges for both raters. The weighted mean accuracy at a severity level for the overall data-set was calculated to be about 48%.

		Executed Event		
		Surge Trace	Surge Mod	Surge Hvy
Rater Response	Clear	12%	3%	4%
	Trace	**51%**	29%	4%
	Moderate	21%	**41%**	20%
	Heavy	6%	24%	**70%**
	Extreme	0%	0%	1%
	Incorrect Event Rated	10%	3%	0%
	Total	100%	100%	100%
	Total Number of Tests	**68**	**270**	**71**

Figure 35. Combined Accuracy at Severity Level for Surges (both Raters)

Like other driveability events, Rater 1 is less sensitive than Rater 2 for surges as shown by mean severities in Figure 36. For example, rater 1 is calling 39% of the heavy surges as moderate severity whereas rater 2 is calling 91% of the heavy surges accurately. The trend continues for other severity levels.

Rater 1

Rater Response	Executed Event: Surge Trace	Surge Mod	Surge Hvy
Clear	11%	4%	3%
Trace	**63%**	49%	8%
Moderate	9%	**37%**	39%
Heavy	0%	6%	**50%**
Extreme	0%	0%	0%
Incorrect Event Rated	17%	4%	0%
Total	100%	100%	100%
Total Number of Tests	35	142	36
Mean	1.6	2.4	3.4

Rater 2

Rater Response	Executed Event: Surge Trace	Surge Mod	Surge Hvy
Clear	12%	2%	6%
Trace	**39%**	7%	0%
Moderate	33%	**45%**	0%
Heavy	12%	45%	**91%**
Extreme	0%	0%	3%
Incorrect Event Rated	3%	2%	0%
Total	100%	100%	100%
Total Number of Tests	33	128	35
Mean	2.4	3.3	3.9

Figure 36. Weighted Mean Severity for Surge Event for each Rater

Idle Quality

The final idle calibration is shown in Figure 37. Cold idle testing was beyond the scope of this work and not performed. However, the capability exists in software.

IDLE			
	Severity		
	Trace	*Moderate*	*Heavy*
Spark Timing (degrees before firing TDC)	-8	-15	-25
Random noise limits	± 5	± 10	± 15

Figure 37. Final Calibration used for Idle Quality Testing

Figure 38 shows the combined accuracy of raters for idle quality testing. The weighted mean accuracy at a severity level for the overall data-set was calculated to be about 55%.

Rater Response		Executed Event		
		Idle Trace	Idle Mod	Idle Hvy
	Clear	33%	8%	3%
	Trace	**52%**	44%	6%
	Moderate	12%	**42%**	22%
	Heavy	1%	6%	**69%**
	Extreme	0%	0%	0%
	Incorrect Event Rated	1%	0%	0%
	Total	100%	100%	100%
	Total Number of Tests	**84**	**62**	**78**

Figure 38. Combined Accuracy at Severity Level for Idle Quality (both Raters)

Like other driveability events, rater 1 is less sensitive than rater 2 for idles as shown by mean severities in Figure 39. For example, rater 1 calls 66% of moderate idles as trace whereas rater 2 is accurate 67% of the time for moderate idles. The overall mean severities also indicate the same with rater 1 at mean severity levels of 1.7, 2.0 and 3.5 whereas rater 2 is at 1.9, 2.9 and 3.7.

Rater 1

Rater Response		Executed Event		
		Idle Trace	Idle Mod	Idle Hvy
	Clear	40%	16%	4%
	Trace	**51%**	66%	7%
	Moderate	7%	**19%**	26%
	Heavy	2%	0%	**63%**
	Extreme	0%	0%	0%
	Incorrect Event Rated	0%	0%	0%
	Total	100%	100%	100%
	Total Number of Tests	**43**	**32**	**46**
	Mean	**1.7**	**2.0**	**3.5**

Rater 2

Rater Response		Executed Event		
		Idle Trace	Idle Mod	Idle Hvy
	Clear	27%	0%	0%
	Trace	**54%**	20%	6%
	Moderate	17%	**67%**	16%
	Heavy	0%	13%	**78%**
	Extreme	0%	0%	0%
	Incorrect Event Rated	2%	0%	0%
	Total	100%	100%	100%
	Total Number of Tests	**41**	**30**	**32**
	Mean	**1.9**	**2.9**	**3.7**

Figure 39. Weighted Mean Severity for Idle Quality for each Rater

Clears

The combined accuracy when no events were triggered was about 89%. In the errors, the raters reported a trace severity event majority of the time with rater 1 at 6% and rater 2 at 11% as shown in Figure 40.

Rater 1

Rater Response	None/Clear
Clear	**94%**
Trace	6%
Moderate	0%
Heavy	0%
Extreme	0%
Incorrect Event Rated	

Total	100%
Total Number of Tests	**308**

Rater 2

Rater Response	None/Clear
Clear	**85%**
Trace	11%
Moderate	3%
Heavy	0%
Extreme	0%
Incorrect Event Rated	

Total	100%
Total Number of Tests	**306**

Figure 40. Accuracy on Clear Events

8.3 Rater Consistency Check

It was important to understand if the raters were consistent from day to day for the same set of calibrations. A simple statistical study was done to calculate the mean severity of the raters across the whole test matrix. The study revealed while the mean severities of the raters were different, the raters were consistent with their ratings. Figure 41 shows the mean and variance of raters across each event. While their means are different, the variance in their responses are low.

To further confirm consistency of raters, isolated severity (or fixed severity) testing was performed to verify rater consistency. All events triggered on day 5 of testing were of moderate severity. The raters were not aware of this test methodology. Analyzing the data from fixed severity testing revealed trends similar in fashion to global trends showing that rater 1 is less sensitive than rater 2 for all events. Details are provided in Appendix 3.

Rater 1

Event	Mean	Variance
Hes Trace	1.6	0.44
Hes Mod	2.6	0.90
Hes Hvy	3.1	0.99
Stm Trace	1.6	0.26
Stm Mod	2.3	0.39
Stm Hvy	3.0	0.52
Srg Trace	1.6	0.29
Srg Mod	2.4	0.43
Srg Hvy	3.4	0.56

Rater 2

Event	Mean	Variance
Hes Trace	1.5	0.38
Hes Mod	3	0.56
Hes Hvy	3.1	0.98
Stm Trace	2.1	0.30
Stm Mod	3.2	0.30
Stm Hvy	3.7	0.31
Srg Trace	2.4	0.73
Srg Mod	3.3	0.46
Srg Hvy	3.9	0.52

Figure 41. Variances in Severity for each Event for Raters

8.4 Pedal Analysis

The pedal signal was studied across maneuvers to verify if the pedal movement correlated to a specific severity. A sample of pedal actuation for the same moderate severity hesitation event during a 0-15 light throttle maneuver is shown in Figure 42. One can notice that the pedal goes up to 27% in one case (rated hesitation heavy) whereas in another test, the pedal peaks at about 17% (rated hesitation trace). In both cases, the triggered severity was the same as well as the maneuver performed.

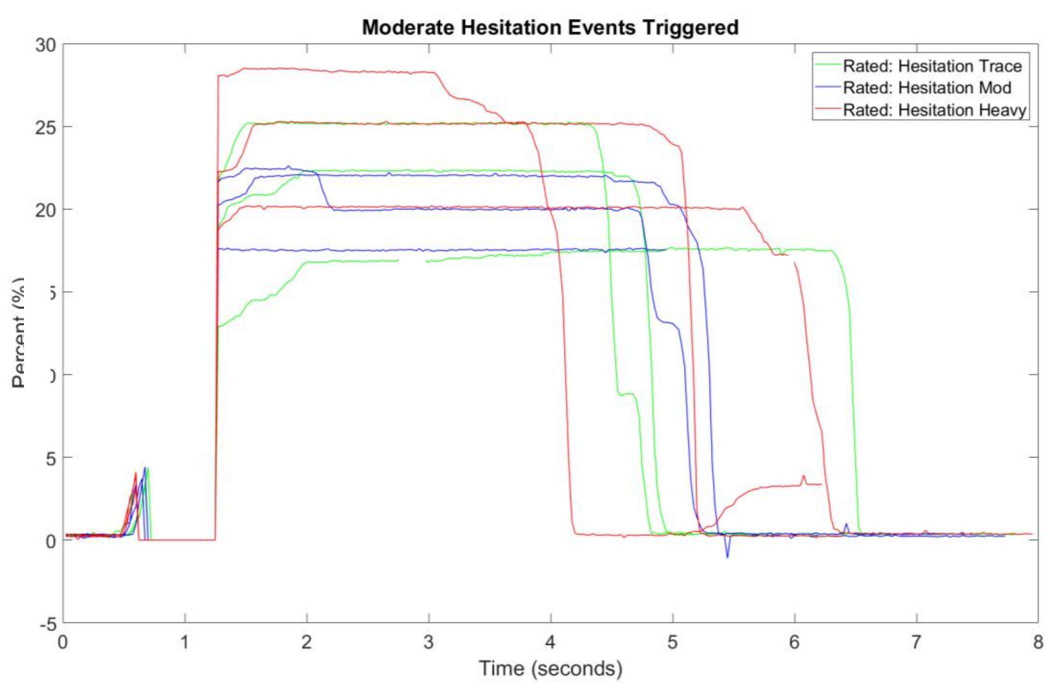


Figure 42. Raw Pedal Trace for Hesitation Events at Various Reported Severities

L1-norm (defined below) is a common statistical term that is used to quantify variation of signals. L1-norm value for pedal signal for the fixed severity testing performed on day 5 is shown in Figure 42. There were no groups of trace, moderate or heavy severity events that could be identified in the plot. No concrete bands or classification could be identified. The L1-norm values of all severities were intertwined as shown in Figure 43. In summary, no concrete trends could be identified by analyzing the way the pedal was actuated compared to a reported severity.

$$L1\ norm = \frac{\sum_{i=1}^{N} |x_i|}{N}$$

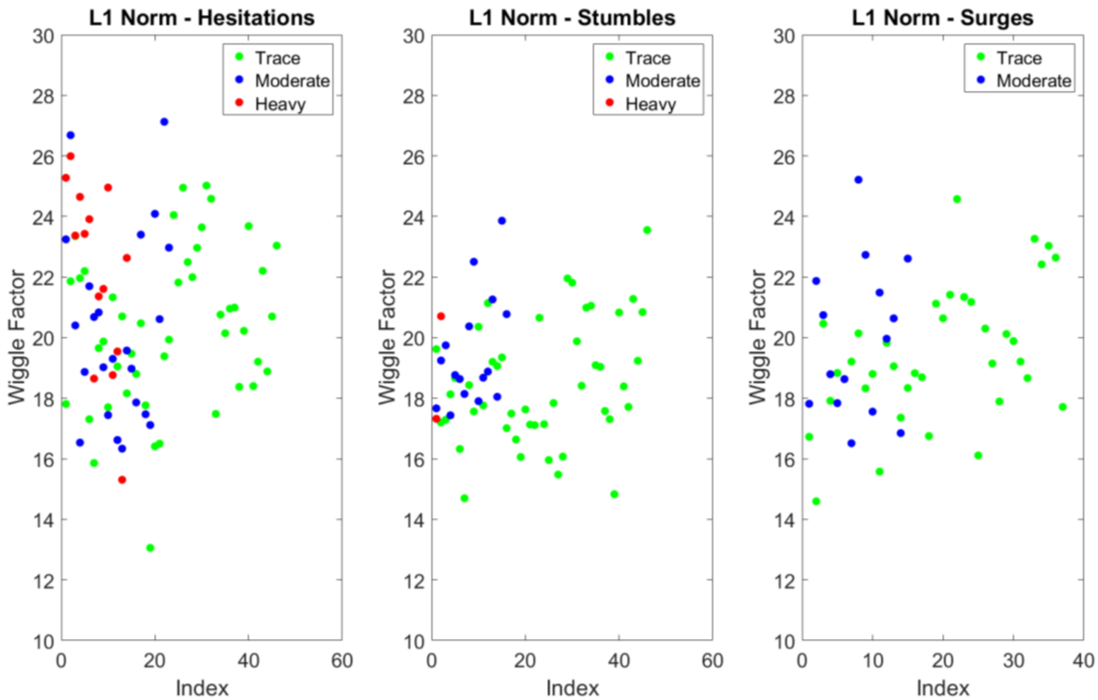


Figure 43. L1-Norm Value of Pedal Input at Various Reported Severities

9.0 CONCLUSIONS

All the project objectives were met successfully. A vehicle to cause driveability events on-demand was built and validated with industry renowned, trained CRC raters.

Fueling override was not a requirement to cause driveability events. All driveability events could be triggered via pedal and ignition timing override. Track quality was an important factor for driveability testing. Raters were happy with the set-up built as part of this effort. The data obtained from testing was rich and adequate to draw broad conclusions. The accuracy at event level was good at about 95%. Accuracy at a severity level was not good and mostly below 50%. Further analysis revealed rater 1 was less sensitive than rater 2 for all the events. It is possible to increase accuracy for a single rater by modifying the calibration. A global calibration that satisfies both raters is not feasible. While mean sensitivity of raters is different, they are consistent in their ratings. No concrete trends were identified via pedal analysis correlating pedal movement to a reported severity.

10.0 CLOSURE

SwRI would like to thank the CRC and its members for funding this effort. SwRI is confident the built trick car will serve as an extremely useful tool for training future raters and other driveability programs envisioned by the CRC. With various driveability events quantified as part of this program, it is possible to build a “golden standard” that will reflect consumer acceptance.

APPENDIX 1

VEHICLE SPECIFICATION

Catalog: FUSION CC7 2013-
VIN: 3FA6P0HDXER240876
Model Year: 2014
Build date: 12/10/2013

Major Attributes

Engine: 1.5 L GTDI I4
Transmission: 6 speed auto trans 6f mid-range drive: lhd 2wd (front wheel drive)
Version: series 10
Air conditioning: dual zone auto temp control a/c exterior paint: tuxedo black metallic
Interior environment: charcoal black interior interior fabric: salerno/salerno / charcoal black axle ratio: 3.07 ratio
Territory: United States

Minor Features

2 way rear headrestraint- lvl ii
2nd row 60/40 (3 p) folding seat
4 door sedan
4 load compartment tie down loops
4 wheel anti-lock braking system
4450 lb. Gvw
7000 rpm tachometer a/c refrigerant-r134a active grilleshutter
Automatic dimming rear view mirror automatic gearshift
Blt/d&p frt/1&2 row/d/p kne
Body colored exterior door handle capless fuel filler without lock cold start -29 deg c
Console - with closed bin convenience group no.16 cup holders (2) - row 1
Dg9c-5560-fnb left rear coil
Dg9c-5560-fnb right/rear coil driver heated seat-variable temp
Drv power seat adjust with memory dual pwr/heat/mem/e chr/pud lmp mr emission compliance - usa
Engine cover - under hood exterior paint - solid feature content group 3
Filter cowl intake - pollen/odor floor mat kit - 12 oz lanier
For unleaded fuel ford division derivative frequency - 315mhz
Front bumper body colored plastic front door scuff plate - mic
Fusion
Generic country group 1 green tinted
Group market #7
Header mounted courtesy/maplights heater controls alt a
Hermosillo plant build human machine interface 4 leather steering wheel less - btsi manual override less air purifier sensor
Less automated parking system less auxiliary heater
Less blind spot information system
Less cell phone interface system
Less collision mitigation system less console ashtray
Less daytime running lamps less dome/mirror lamp less dress up rso
Less driver technology pack less electrical outlet
Less electronic speed limitation less exhaust pipe extension less exterior appearance pack

Catalog: FUSION CC7 2013-
VIN: 3FA6P0HDXER240876
Model Year: 2014
Build date: 12/10/2013

Less family entertainment system less fire extinguisher fixings less fleet
Less floor mats-fia less foot pedal covers
Less front bumper sensor device less front mudflaps
Less front parking aid less front towing hook less fuel water separator
Less head lamp beam operation less headlamp levelling
Less headlamp washer/wiper less heated steering wheel less heated washer jet
Less heated windscreen less immersion heater
Less inter cladding surfaces less interior courtesy lamp
Less interior light group
Less interior pack less interior partition
Less keyless entry system less lane keeping aid
Less lighting packages less load area cover less load rest
Less load retention net
Less low speed safety system less luggage compartment net kit less moonroof pack
Less multi - contour seats less noise insulation package
Less parking brake warning lamp less pass seat back control switch less passenger air bag deactivation less power point plug
Less preprogrammed speed limit less rear heated seat
Less rear mudflaps less rear seat ash tray less rear seat belts
Less rear seat radio controls less rear towing hooks
Less rear window blinds
Less rear window wiper/washer less remote starter
Less remote starter - fia less roof line conversion
Less roof rack
Less seat pack
Less side window film less ski bag provision
Less spd control distance sensing less special seat covers
Less specialty packages
Less speed audible warning device less speed sign recognition
Less spoiler
Less tape stripes - fia
Less tire repair service kit less trailer coupling
Less trailer sway control (tsc) less u/body corrosion protect less vp application label
Less warning display
Less water wading equipment less wheel covers
Less wireless charging
Load compartment light - led lower grille - low gls w/blk smile luggage compartment mat lumbar seat - 2 way driver
Lumbar seat supt pass. Fixed mfd tft touch screen
Mid audio + cd + sdarsmini overhead cnsl w/sunglass bin muffler w/ single chrome tip
My key
Non-locking lug nuts
Normal fuel fill owner hand book pack p235/45 r18

Catalog: FUSION CC7 2013-
VIN: 3FA6P0HDXER240876
Model Year: 2014
Build date: 12/10/2013

Power door lock with elec release power front windows one touch up/do power rear window one shot up/down power tilt/slide sun roof
Rear bumper body coloured plastic rear center armrest with cupholder rear floor carpet mats
Rear view camera-fixed
Remote controlled tailgate release rocker panel molding - body color salerno / salerno leather
Select shift tech (sst) w/thm swtc spare tyre-t125/80r16
Standard electric starter motor standard green glass windshield style 2 alloy 18" wheel
Sync ii
Tail lamps - level 1
Tire pressure sensors - 315 mhz traction control with advance trac with 16" mini steel spare wheel
With 2nd row reading lamps
With 49 state/non green state req with 6 speakers
With 91 octane level gasoline with automatic headlamp on/off

APPENDIX 2

RATER FEEDBACK

April 23, 2018

CRC – SwRI "Trick Car"

Mr. Sankar B. Rengarajan,

I would like to take this opportunity to say it has been my pleasure to be a consultant on the CRC- SwRI Trick Car project.

The successes achieved were the following:

1. Idle quality variability
2. Hesitation variability, from a complete stop, or in a rolling maneuver, and the entire range of Light, Moderate, or WOT applications
3. Stumble variability, throughout the spectrum of rolling maneuvers
4. Surge variability, in the light, and moderate throttle maneuvers
5. Trace, Moderate, Heavy, and Extreme can be demonstrated in all the above examples

Mr. James Fritz mentioned a possibility of a dash mounted throttle position indicator. The car was calibrated using a combination of Harold Archibald's and my own throttle positions during the specific maneuvers. Upon further reflection, it is my opinion that a position indicator, combined with the accepted, agreed upon variations in percentages for the maneuver being practiced, would give the Student Rater an excellent feel for what is required.

With that said, nothing can overcome the difficulties in programming 100% consistency for different individual (human) drivers, but in my opinion this car will be invaluable as a training tool in future Rater workshops.

Best Regards,
Rater 2

April 27, 2018

Mr. Sankar B. Rengarajan

Southwest Research Institute adapted a (2018 Ford/Focus) vehicle and designed computer software to generate driveability malfunctions and severity levels as defined by the CRC Cold-Start and Warm-up Driveability Procedure. The goal of the vehicle and software is to train novice and inexperienced driveability raters, calibrate experienced driveability raters, and potentially determine customer sensitivity to driveability issues.

Two experienced CRC driveability raters with documented histories of ratings provided input and evaluated the system over a period of two weeks. The raters provided multiple data points for malfunctions and severity levels which were used to develop a single package for training and calibration.

Another though, preprogrammed computer software to create random malfunctions and severity levels without a computer operator in the vehicle with the student rater. But still have a recorded chart of events during the test. This would prevent cuing the driver / rater that someone in the backseat creating malfunctions.

Rater 1

APPENDIX 3

FIXED SEVERITY TESTING

To confirm the consistency of raters, it was decided to perform fixed severity testing. For day 5 of testing with raters, <u>only moderate severity events</u> were triggered and a group of light throttle, moderate throttle and wide open throttle maneuvers were performed.

Sensitivity trends continued for the light throttle maneuvers as shown in Figure 44. Rater 1 was less sensitive than rater 2 for all events. For example, rater 1 called 71% of the moderate stumbles as trace whereas rater 2 was accurate 66% of the time for moderate stumbles as seen in Figure 44.

Rater 1

Rater Response	Executed Event: Hesit. Mod	Stumble Mod	Surge Mod
Clear	5%	0%	0%
Trace	54%	71%	66%
Moderate	**27%**	**23%**	**27%**
Heavy	14%	3%	0%
Extreme	0%	0%	0%
Incorrect Event Rated	0%	3%	7%
Total	100%	100%	100%
Total Number of Tests	**81**	**62**	**56**

Rater 2

Rater Response	Executed Event: Hesit. Mod	Stumble Mod	Surge Mod
Clear	5%	0%	0%
Trace	5%	2%	8%
Moderate	**58%**	**66%**	**56%**
Heavy	33%	29%	34%
Extreme	0%	0%	0%
Incorrect Event Rated	0%	3%	2%
Total	100%	100%	100%
Total Number of Tests	**66**	**62**	**62**

Figure 44. Moderate Severity Light Throttle Maneuver Results

Sensitivity trends continued for moderate throttle maneuvers with rater 1 less sensitive than rater 2 for all events as seen in Figure 45.

Rater 1

Rater Response	Executed Event: Hesit. Mod	Stumble Mod	Surge Mod
Clear	5%	0%	0%
Trace	5%	2%	8%
Moderate	**58%**	**66%**	**56%**
Heavy	33%	29%	34%
Extreme	0%	0%	0%
Incorrect Event Rated	0%	3%	2%
Total	100%	100%	100%
Total Number of Tests	**66**	**62**	**62**

Rater 2

Rater Response	Executed Event: Hesit. Mod	Stumble Mod	Surge Mod
Clear	0%	0%	0%
Trace	0%	0%	0%
Moderate	**63%**	**56%**	**26%**
Heavy	35%	44%	74%
Extreme	0%	0%	0%
Incorrect Event Rated	2%	0%	0%
Total	100%	100%	100%
Total Number of Tests	**54**	**45**	**39**

Figure 45. Moderate Severity Moderate Throttle Maneuver Results

Sensitivity trends for wide open throttle maneuvers were in-line with global trends seen before. As seen in Figure 46, hesitation events for both raters had potential for improvement with calibration less aggressive than desired. Rater 1 was less sensitive than rater 2 for stumbles. Recall raters mentioned no surge events for wide open throttle maneuvers.

Rater 1

Rater Response	Executed Event: Hesit. Mod	Executed Event: Stumble Mod
Clear	14%	5%
Trace	43%	84%
Moderate	**33%**	**11%**
Heavy	10%	0%
Extreme	0%	0%
Incorrect Event	0%	0%
Total %	100%	100%
Total Num.	**21**	**19**

Rater 2

Rater Response	Executed Event: Hesit. Mod	Executed Event: Stumble Mod
Clear	4%	0%
Trace	48%	11%
Moderate	**30%**	**58%**
Heavy	17%	32%
Extreme	0%	0%
Incorrect Event	0%	0%
Total %	100%	100%
Total Num.	**23**	**19**

Figure 46. Moderate Severity Wide Open Throttle Maneuver Results

APPENDIX 4

VEHICLE TITLE

TEXAS CERTIFICATE OF TITLE

TxDMV

TEXAS DEPARTMENT OF MOTOR VEHICLES

137488398

VEHICLE IDENTIFICATION NUMBER	YEAR MODEL	MAKE OF VEHICLE	BODY STYLE
3FA6P0HDXER240876	2014	FORD	4D

TITLE/DOCUMENT NUMBER	DATE TITLE ISSUED
00730043074093656	12/15/2017

MODEL	MFG. CAPACITY IN TONS	WEIGHT	LICENSE NUMBER
FUS		3500	KBP9130

PREVIOUS OWNER

ALLWAYS AUTO GROUP LTD PLEASANTON TX

ODOMETER READING

35901

OWNER

SOUTHWEST RESEARCH INSTITUTE
6220 CULEBRA RD
SAN ANTONIO, TX 78238

REMARK(S)

ACTUAL MILEAGE

X ______________________________

SIGNATURE OF OWNER OR AGENT MUST BE IN INK

UNLESS OTHERWISE AUTHORIZED BY LAW, IT IS A VIOLATION OF STATE LAW TO SIGN THE NAME OF ANOTHER PERSON ON A CERTIFICATE OF TITLE OR OTHERWISE GIVE FALSE INFORMATION ON A CERTIFICATE OF TITLE.

DATE OF LIEN — 1ST LIENHOLDER

NONE

1ST LIEN RELEASED ________ DATE

BY ________ AUTHORIZED AGENT

DATE OF LIEN — 2ND LIENHOLDER

2ND LIEN RELEASED ________ DATE

BY ________ AUTHORIZED AGENT

DATE OF LIEN — 3RD LIENHOLDER

3RD LIEN RELEASED ________ DATE

BY ________ AUTHORIZED AGENT

IT IS HEREBY CERTIFIED THAT THE PERSON HEREIN NAMED IS THE OWNER OF THE VEHICLE DESCRIBED ABOVE WHICH IS SUBJECT TO THE ABOVE LIENS.

RIGHTS OF SURVIVORSHIP AGREEMENT

WE, THE MARRIED PERSONS WHOSE SIGNATURES APPEAR HEREIN, HEREBY AGREE THAT THE OWNERSHIP OF THE VEHICLE DESCRIBED ON THIS CERTIFICATE OF TITLE SHALL FROM THIS DAY FORWARD BE HELD JOINTLY, AND IN THE EVENT OF DEATH OF ANY OF THE PERSONS NAMED IN THE AGREEMENT, THE OWNERSHIP OF THE VEHICLE SHALL VEST IN THE SURVIVOR(S).

SIGNATURE ________ DATE

SIGNATURE ________ DATE

SIGNATURE ________ DATE

FORM 30-C REV. 05/2016

DO NOT ACCEPT TITLE SHOWING ERASURE, ALTERATION, OR MUTILATION.