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Active Management Assistant System for Embry-Riddle EcoCAR 3 Hybrid Supervisory Control System

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1. Abstract

The Embry-Riddle EcoCAR 3 team is developing a prototype hybrid Chevrolet Camaro utilizing a customized vehicle powertrain controller. This controller is serving to ensure system safety, vehicle operation, and consumer drivability while also incorporating advanced driving aids to achieve both the desired performance levels one expects from a Camaro as well as vehicle efficiency. This vehicle must reach the team set vehicle technical specifications of a 4.9 second 0 to 60 time while maintaining a 53 miles per gallon gasoline equivalence rating.

In order to reach the efficiency goal, the team is developing an Active Management Assistance System utilizing computer vision tools to analyze traffic and road conditions to actively change the vehicle through its seven operational states to achieve the highest levels of energy savings. Currently, this project is in the initial testing phase where baseline functionality of the hybrid powertrain controller is being tested in a hardware-in-the-loop simulation environment to ensure operational safety as well as doing vehicle platform integration of systems. At the end of the spring 2016 term, the hybrid Camaro will be road worthy, and the vision systems will have completed basic functionality testing and be ready for system integration. At the end of the 2017 academic year, the system will be integrated into the vehicle platform and by the end of the 2018 academic year, the system will be fully integrated into the completed hybrid vehicle controller.

2. Executive Summary

This technical update provides an overview of the progress made in the controls system for the ERAU Camaro ESS. Currently, the vehicle functions in four operational modes. These modes include the standard Dual Charge Deplete EV only mode, the cruising mode of Parallel Charge sustain, the aggressive and performance tuned Sport mode and the fault mitigation Crawl mode. Regenerative braking and series charge sustain modes have yet to be implemented.

For this report, a high level architecture description detailing the controls plan and components is given in section 6. The primary control modules and functionalities are outlined in section 7. In addition, all of the control system requirements are listed in section 9.3. These are the governing principles and rules for the control system.

Technical data detailing the vehicles four primary serial CAN networks is also provided. These networks are organized based on function as well as to prevent CAN ID conflicts and for bus load optimization. The supervisory control unit for the Camaro ESS operational strategies are also detailed, this includes component function descriptions, component start up sequences, and details about the four implemented powertrain modes. The torque allocation and security for each of these modes is explained as well as how the four tier fault identification system works with the two step fault mitigation strategy to ensure the safest and most reliable vehicle.

3. Team Vehicle System Architecture

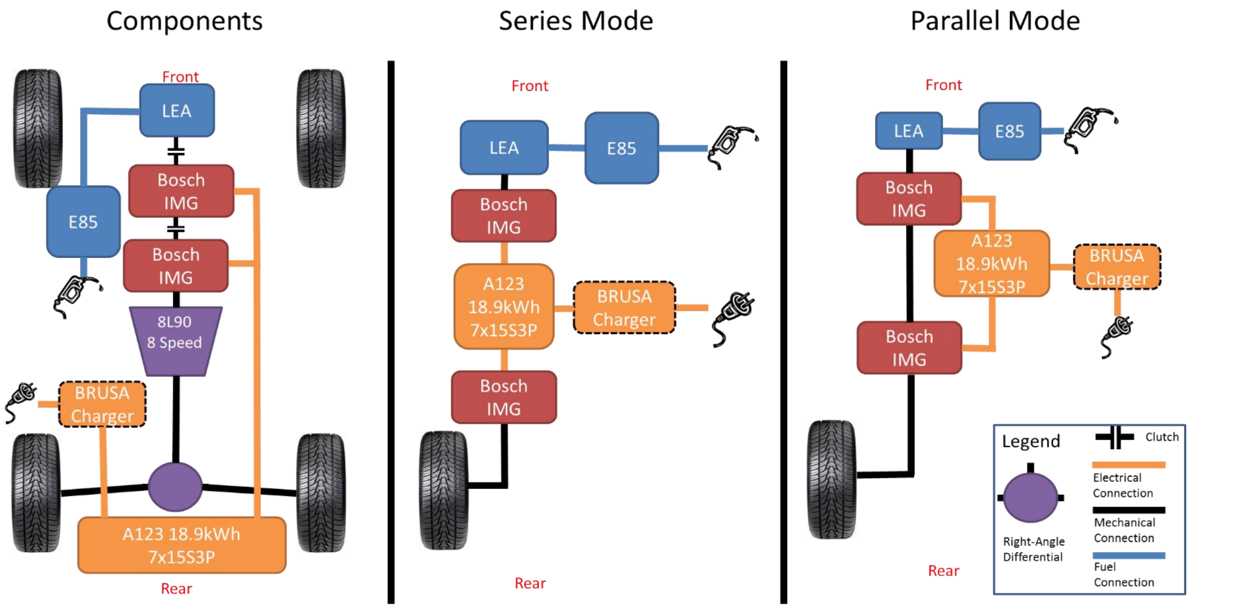

Figure 1 - 2016 ERAU Camaro ESS Vehicle Architecture

Shown here in

Figure 1, is the 2016 ERAU Camaro ESS (EcoSuperSport) P2-P2 Plug-in Hybrid Electric Vehicle (PHEV). This vehicle can operate in series or parallel hybrid configurations, with 100 % rear wheel torque. The ICE used is a donated 2.4L GM LEA ECOTec which uses E85 fuel. The engine's power is supplemented by two Bosch IMG electric motors containing internal clutches. The motors are controlled by Bosch inverters and the high torque produced is distributed to the wheels by a GM 8L90 8-speed automatic transmission. The on-board ESS is an A123 battery pack with a capacity of 18.9kWh. Using this combination of components arranged in the described architecture, the EcoEagles hope to achieve unique goals that surpass the EcoCAR 3 requirements as well as the suggested targets.

4. Primary Control Modules

Table 1 - Control Modules and Function Summary

Control Module	Functionality
MicroAutoBox	Supervisory control unit, responsible for full vehicle control and all primary control decisions. Vehicle fault management, driver interactions and system safety are all managed by this unit
Engine Control Module	Based on signals from the MABX, this control unit manages all engine critical systems including the fuel pump control module to deliver the demanded amount of power.
Bosch Inverter(s)	Manages its perspective electric machine to deliver the demanded amount of torque while insuring both directional control and power management to protect the HV systems. These units also feature integrated DC/DC converters to sustain the 12v bus.
Clutch Control Units	Control team added clutches and maintain pressures desired to ensure the ability to change vehicle modes.
Transmission Control Module	Based on vehicle powertrain signals and vehicle speed, manages gear shifting to enable efficient operation while in drive and allows for both reverse and park.
Battery Control Module	Manages the energy storage system of the vehicle and ensures proper charging and discharging of the pack. Also monitors pack status for safety and will disable the HV systems in the event of an issue to protect both itself and the vehicle.
Body Control Module	Provides secondary driver interfaces and also is used to give the current vehicle status to the driver via the on dash indicators and heads up display.

5. Controls Content

5.1 High-Level CAN Diagram

The ERAU Camaro ESS will utilize four primary CAN networks with the option to add two additional buses in the future. These four primary buses include the stock GM high speed bus, stock GM low speed bus, a team added ERAU high speed and a team added ERAU powertrain expansion bus. The high level bus layout shown in Figure 2 includes locations of termination resistors, ECUs and bus baud rates in kbits/s. The baud rates were chosen to match stock bus networks in terms of functionality and for ease of use.

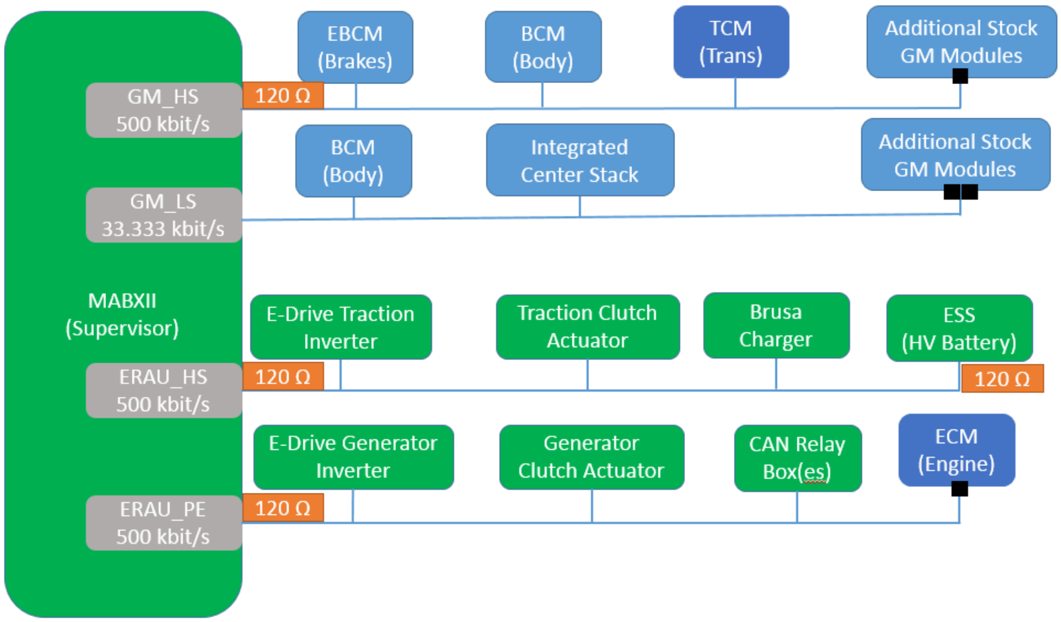

Figure 2 - High Level CAN Schematic

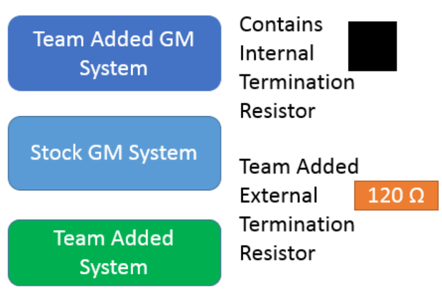

Figure 3 - High Level CAN Schematic Key

The new TCM has been placed on the stock GM_HS bus as it is directly replacing an identical OEM ECU, this is to minimize the need for using gateways to redirect messages. The ECM has not been placed on this bus due to a difference in CAN specification generations, the ECM is GM generation 5 while the remainder of the vehicle is GM generation 6. In order to allow for designed functionality of the GM_HS systems as well as the ECM on ERAU_PE, the MABX will serve as a signal gateway unit to convert and transmit the required information. The team is utilizing the GM low speed bus to integrate with the stock GM center stack as well as the instrument cluster for driver alerts. The ERAU high speed bus contains a single inverter, its paired clutch control unit, as well as the ESS and Brusa charger; this is to eliminate CAN ID conflicts caused by having identical ECUs on the same bus. In addition to preventing ID conflicts, the ERAU powertrain expansion bus was implemented to reduce bus utilization levels to below 50%.

5.2 Active Management Assistant System

For year two, the primary focus for AMAS vision processing system was to get basic functionality out of a vision based detection system to be able to identify lane marking, identify and track objects such as other vehicles and stop signs, and to plot distances to potential road hazards. This was accomplished utilizing Matlab's vision processing toolbox and a S32V Vision processing board donated by NXP. These tools allowed for real-time detection and tracking at 30 frames per second. Shown below in Figure 4 is an example of tracking a vehicle that is in what would be the EcoCAR's path of travel, this particular example is based on a motion capture simulation.

Figure 4 - Traffic Detection and Tracking

Above the identified potential risk, is the distance from the EcoCARs vision system to the rear of the object which in this case, is a van. Here in Figure 5 is a plot of the distance from the vehicle to the van as well as points where the development system lost target tracking due to various obstructions. This system is currently still under development to increase the tracking accuracy to ensure full vehicle safety and functionality. As mentioned above, this system is also designed to detect and identify street signs. This function will be used to deliver critical information to the driver such as excess speed or impending stop, this data will also be utilized to help optimize the vehicles powertrain to minimize the amount of wasted energy during stopping events but tuning for higher regenerative braking actions rather than maintaining vehicle speed as approaching a stop sign, however for safety reasons this system will never have direct control over torque application and will only serve as a suggestion to either the driver or to the control system for mode selection.

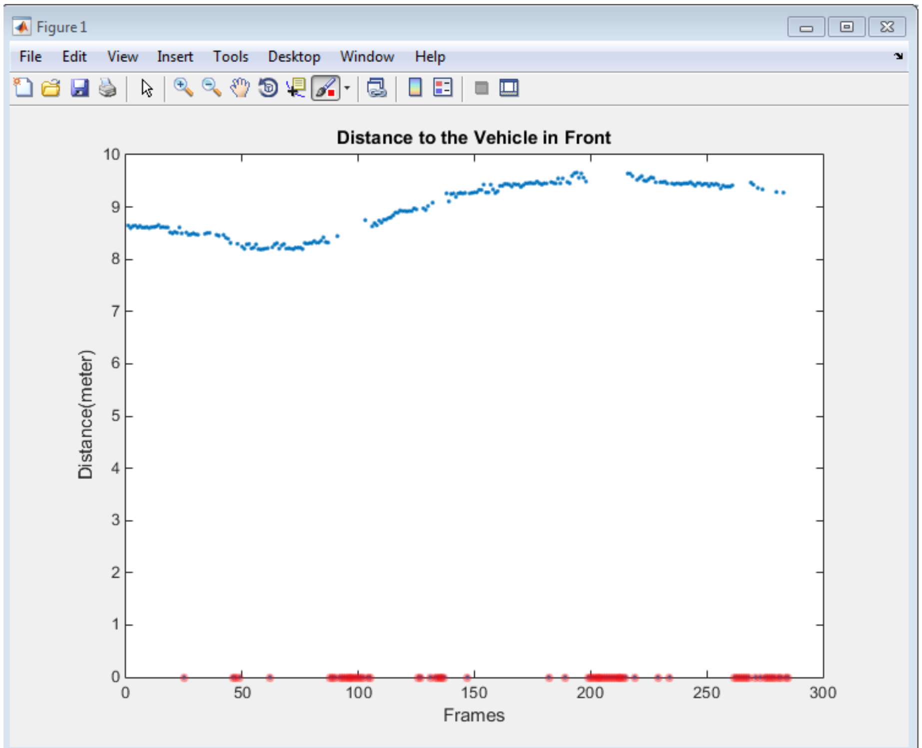

Figure 5 - Distance Tracking

5.3 Control Strategy Overview

During year 2 of the EcoCAR 3 competition, the team is targeting to have four of the primary operational modes for the vehicle implemented. Shown in Table 2 are the year 2 modes along with a brief description of each mode. For identification purposed, the IMG motor closest to the transmission has been named the traction motor and the IMG between the LEA and traction motor has been name the generator motor. These names are based on the potential and primary use cases of each motor.

Table 2 - Year Two Operational Modes

Year 2 Modes	Active Powertrain Components	Description	Use Case
Dual-Charge Deplete	Traction Motor Generator Motor	Uses both IMG electric motors combined to achieve optimal efficiency while maintaining baseline performance	Default mode, utilized while sport button is not depressed and the SOC is greater than 20 %
Parallel Charge Sustain	LEA Traction Motor Generator Motor	Uses a P2-P2 parallel power flow via all powertrain components to maintain the SOC for the ESS	Used when SOC less than or equal to 20% this mode will activate and will remain active until SOC is greater than 30%
Sport	LEA Traction Motor Generator Motor	Uses the P2-P2 design to target maximum vehicle performance	Used when SOC is greater than 20% and the sport button is depressed
Crawl	Any achievable components	This mode is only used in the event of a critical system fault if it is still safe to apply small amounts of torque to prevent stalling in an unsafe environment.	Active in the event of a critical system fault to allow vehicle to continue low speed motion if it is still safe to do so

The primary control strategy for allowing torque in the vehicle passes through a series of three logical setup blocks before the requests are processed in each individual component sub-controller. First the vehicle processes the mode selection logic, shown in Figure 6.

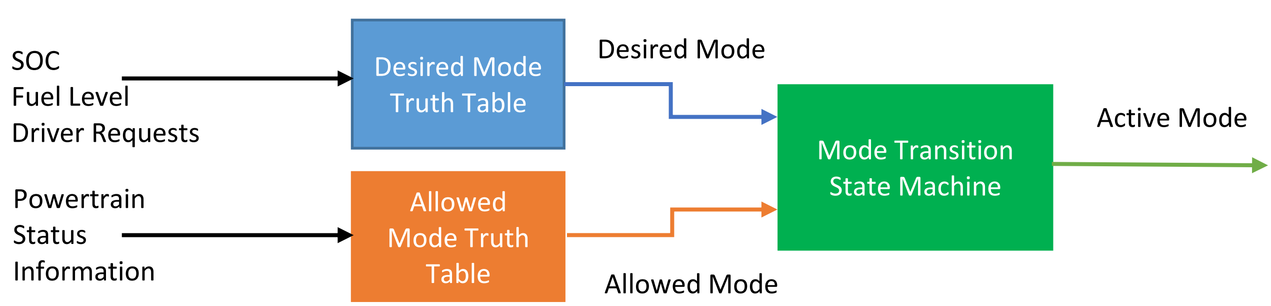

Figure 6 - Mode Selection Control Logic

This logic views the current state of all vehicle components such as clutch position and engine status to determine the allowable operational modes. Running in parallel is a logic table processing vehicle SOC, fuel percent, and sport request to determine which mode is the desired operational state. These modes are then passed through a state machine to declare the active operational mode of the vehicle. The active mode outputs can be any of the primary operational modes found in Table 2 as well as transition modes to move from between each of the defined operational modes.

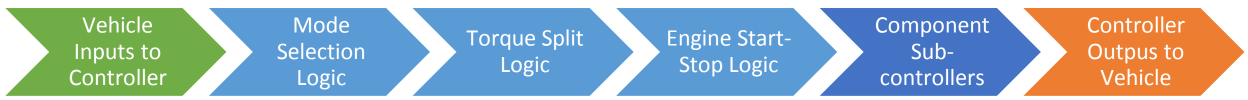

Figure 7 - Control Logic Flow Diagram

Once the active vehicle mode is set, that mode is passed to the torque split sub-controller. Using the driver input from the accelerator pedal, a total desired axle-torque is calculated via 1-D lookup table. In addition, the instantaneous vehicle accessory load is calculated as a torque value required to offset the 12v draw. The last set of data being calculated prior to distribution of torque to the powertrain components is a weighting ratio of engine torque to motor torque. This value is used in the torque split for sport mode. Utilizing these calculations and values, the equations shown in Table 3 were developed to handle the distribution of the requested torque. These equations are preliminary and currently not optimized nor final nor do they include the equations for control modes to be added during year three of the competition. The value of X in crawl mode has yet to be determined; its goal is to allow the vehicle to still have the automatic creep you find in a standard vehicle while in gear.

Table 3 - Preliminary Torque Split Control Equations

Active Vehicle Mode	Engine Equation	Generator Motor Equation	Traction Motor Equation
Off	Eng_Trq = 0	Gen_Trq = 0	Trac_Trq = 0
Dual Charge Deplete	Eng_Trq = 0	Gen_Trq = 0.5 * Trq_Req	Trac_Trq = 0.5 * Trq_Req
Parallel Charge Sustain	Eng_Trq = Trq_Req + (1.2 * AccLoad)	Gen_Trq = -0.6 * AccLoad	Trac_Trq = -0.6 * AccLoad
Sport	Eng_Trq = Trq_Req*Eng_EM_Weighting	Gen_Trq = Trq_Req * ((1-Eng_EM_Weighting)/2)	Trac_Trq = Trq_Req * ((1-Eng_EM_Weighting)/2)
Crawl	Eng_Trq = X	Gen_Trq = X	Trac_Trq = X

After the mode selection and torque split logic has been executed, the torque values along with active mode and desired mode are passed through to the engine start-stop subsystem. This system utilizes a state flow diagram which will rebalance torque during an engine start-up or shutdown sequence to allow for continued vehicle operation. If an engine start or stop is not being requested by the mode selection controller, this subsystem acts as a pass-through and does not change any signal values.

5.4 Torque Command and Feedback Signals

After the mode selection logic determines which components are going to be active and the torque split controller has determined torque demand to each powertrain component, individual subsystem controllers are utilized to hand the demands and properly relay the information to the hardware. Table 4 shows all subsystem controllers and their primary methods for controlling each of their respective ECUs. All control methods are non-optimized and are for initial vehicle testing and are subject to change throughout the development process.

Table 4 - Subsystem Control Strategies

Subsystem Controller	Targeted Hardware	Method of Control	Description
Engine	ECM	PID controlling artificial pedal displacement	Uses multiple lookup tables and gain schedules to allow for safe use in all CS modes as well as sport mode
Generator and Traction Clutch Controllers	Generator CCU Traction CCU	Logic table coupled with PID for piston actuation	Uses the logic table to determine operational direction and the PID to perform smooth clutch engagements. Each clutch controller is identical minus clutch assignment
Generator Motor Controller	Generator IMG Inverter	Speed control PID or Torque control PID	Uses two different PIDs to control power demanded from the motor based on operational mode and mode transitions

Traction Motor Controller	Traction IMG Inverter	Torque controlling PID	Uses a PID controller to send torque requests to traction IMG
Transmission Controller	TCM	Logic shift tables and state machines	Uses state machines and lookup tables to follow shifting maps based on torque demand and vehicle speed
Battery Controller	BMS	State machine	Uses a state machine to control the operational state of the ESS.
HVAC Controller	HVAC	Lookup table	Uses demanded cooling power to send PWM signal to HVAC
Lighting Controller	Independent lighting systems	State machines and logic gates	Uses a state machine to activate vehicle tail lights for illumination during regenerative braking events. Also controls competition required indicators

The signals used to control each of the torque producing components in the vehicle are not listed to respect a GM Non-disclosure agreement. In addition to the primary control signals, also shown in this table are the critical feedback signals from each ECU which is utilized in the PIDs discussed in Table 4. In regards to the inverter command messages, many signals are used to define the limits of this ECU as well as set the inverter side gains. Only the primary torque, mode, and speed command signals are listed.

5.5 Vehicle Operational Mode Functionality

Table 5 - Vehicle Mode Functionality summary

Mode	Functionally Achieved	Future Improvements
Dual Charge Deplete	Functional and Validated on Platform	Pedal Tuning and power split based on efficiency and thermal factors.
Single Charge Deplete	Tested and Validated on Platform	Currently not an allowable mode during standard driving, will be implemented as more fault detection and mitigation occurs
Engine Only	Pedal control implemented	Needs fault systems, electronic rev limiter, thermal analysis and derating, and controller tuning
Parallel Charge Sustain	Electric systems validated, for engine see Engine Only	See Engine Only in addition to clutch engagement tuning
Sport Mode	See PCS	See PCS
Crawl Mode	Needs to be tested in vehicle	Needs improved fidelity to better handle fault mitigation
Series Mode	N/A	System yet to be developed past basic levels of component control

5.6 Fault Detection and Mitigation

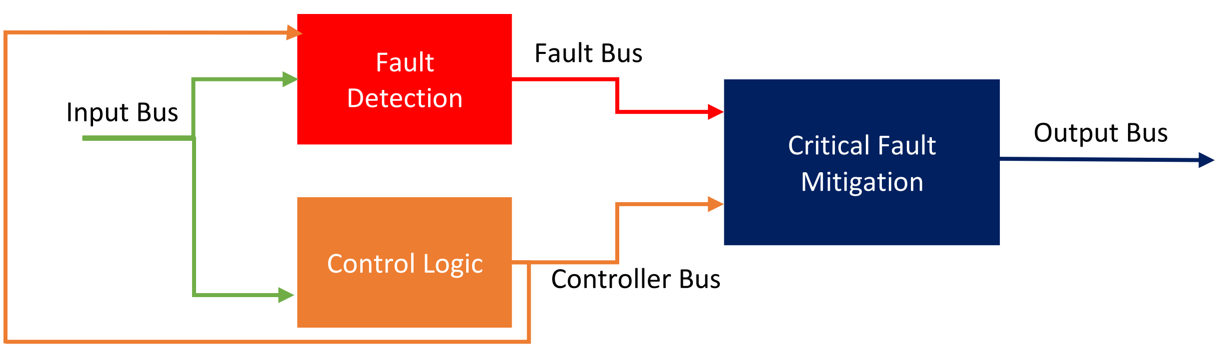

Figure 8 - Fault Detection and Mitigation Logic

To ensure torque security and system safety, all fault detection and critical mitigation happens outside the subsystem control logic in addition to the internal controller reaction. Shown in Figure 8 is the topology of the subsystem control in relation to fault detection and fault mitigation. Inside the ERAU fault detection system is a set of four operational tiers of faults which are detailed Table 6. In order to detect faults, the SCU uses CAN data, current controller data, and all powertrain feedback signals to trigger logic gates raising an independent fault flag. Once the individual fault flag is raised, a tier flag will be raised based on the fault's severity. After the flag is detected and classified, the SCU utilizes a double mitigation strategy to maximize the controller's ability to safely handle a fault while maintaining the maximum level of operability of the vehicle.

An example of a fault is in the event the engine is producing a torque, read from an engine torque feedback signal, which differs from the demanded torque by more than the allowable threshold. The controller would identify an engine fault and raise a Tier 2 fault. At this point, the controller would respond by shifting to a mode, selected by the mode selection system, which does not utilize the engine. At the same time the critical mitigation subsystem would be disabling the engine including zeroing torque demanded from the engine, isolating the engine via opening the generator clutch, and powering off the ECM.

Table 6 - Fault Tier Description

Fault Tier	Description
Tier 1	Safety and Operational Critical Faults
Tier 2	Mode Restricting Faults
Tier 3	Power Limiting / Thermal Faults
Tier 4	Noncritical Faults

5.7 Driver Requested Torque Integrity

All system torque demands are checked against the corresponding demands to ensure that they are within a defined margin of error for each given power level. This sliding margin is a linear relationship between +/-5nm at idle throttle and +/- 30nm at peak torque. This system is in place for both driver demanded torques on tractive systems, as well as controller demanded torques on generating systems when decoupled from the roadway.

5.8 Excess Torque Remediation Example

To analyze the vehicles response to a powertrain component producing torque over the demanded value outside the margin of error tolerance, Table 7 details each remediation action. They are progressive, in the event of the first remediation failing, the next action is taken, if still unresolved the third is applied.

Table 7 - Over Torque Remediation

Component	Remediation 1	Remediation 2	Remediation 3
Engine	Request engine idle by setting artificial pedal position to zero	Open generator clutch to prevent torque being transmitted to wheels	Disable engine via ECM and turn off fuel pump
Generator Motor	Set generator inverter to safe state	Open both clutches to isolate the electric machine	Disable High Voltage Systems
Traction Motor	Set traction inverter to safe state	Disable high voltage systems	N/A

6. Test Case

Table 8 - Accelerator Pedal Fault Test Case

Test Case Overview	Accelerator pedal position sensor out of range fault insertion test
Version:	2
Last Updated (MM/DD/YYYY)	11/23/2015
Author(s):	Matthew Nelson
Test Case Description:	During drive cycle execution, a random number generator will trigger one of the APP sensor values to transmit values out of acceptable range.
Test Case Procedure	
Test Initialization:	1. Drive cycle loaded to driver model 2. Vehicle startup sequence off key request 3. PRNDL moves from Park to Drive 4. Begin drive cycle
Test Body:	At a point determined via a random number generator at script initialization of the drive cycle, a one of the accelerator pedal position sensors will be shifted to operate outside the designed operational range. This is to test the controllers fault detection and torque security systems. The test will terminate when the driver model stops the vehicle in response to the fault detection or 15 seconds after fault insertion without a controller response.

Test Completion:	After test is completed, the controller and plant model will be reset to the system off state for re-initialization into any additional tests. At the completion of all tests, AutomationDesk will generate a PDF report of the test documenting the time at which the fault was inserted and the controllers response. A pass/fail flag will also be set in this PDF based on the controller's ability to detect and respond accordingly to the inserted fault or the test operator will de-note all test results in the test log.
Test Case Summary	
Expected Results:	The expected result is the controller triggering the Tier 1 fault, APP out of range fault flag and disable all APP input. The controller shall change current operational mode to crawl.
Performed On (MM/DD/YYYY):	
Performed By:	
Controller Version Number :	
Test Result (PASS/FAIL) :	
Log File/Test Report File Name:	
Log File/Test Report File Location:	

The test case in Table 8 follows a team template which walks team members through setting up the test case and its expected results. A completed test case will also lead team members to the location and file name of the complete test generated with AutomationDesk for HIL testing. Each requirement will be linked to an individual test, if a requirement cannot be linked to a specific test a new test will be created for that requirement.

7. Development Plan

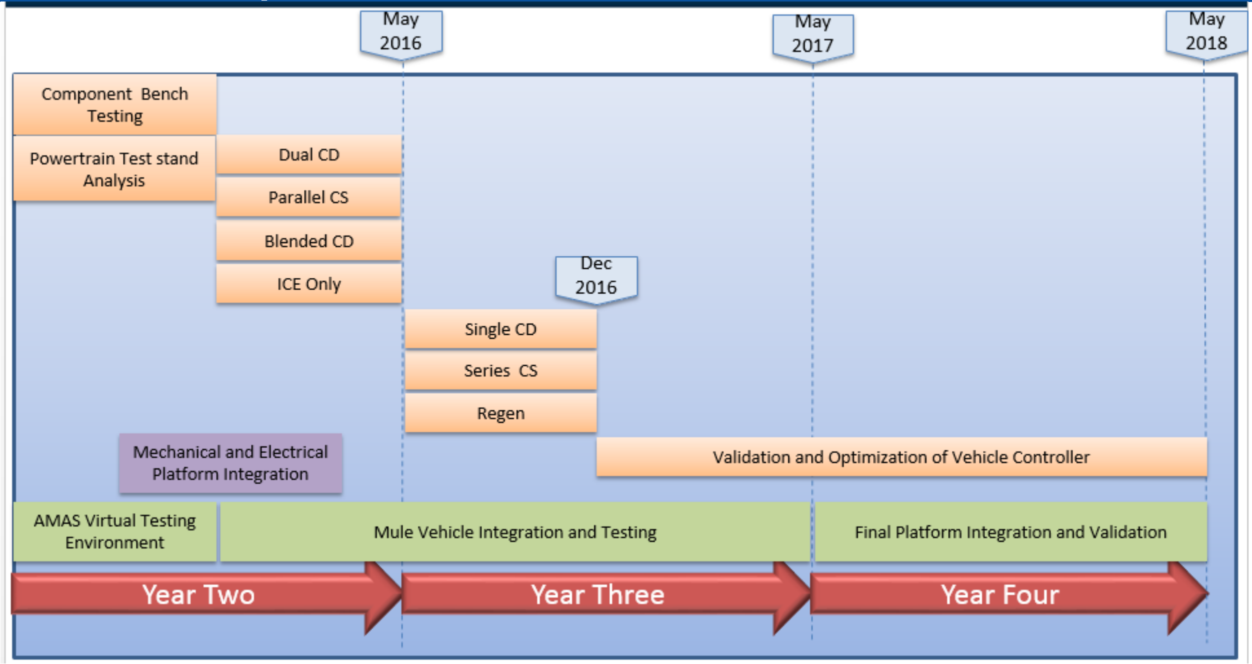

Figure 9 - Controls Overall Development Plan

Above in Figure 9, is the overall development schedule for the vehicle control system in terms of semester goals. Currently, component bench testing has been established and a model template exists. During the second half of year two, the subsystem controllers will created and tested. This includes each powertrain component controlling PID and state machines.

8. References

Car Reviews - New Cars for 2015 and 2016 at Car and Driver. (n.d.). Retrieved November 12, 2015, from http://www.caranddriver.com/

Fuel Economy. (n.d.). Retrieved November 12, 2015, from http://www.fueleconomy.gov/

9. Appendix

9.1 Vehicle Technical Specifications

Table 9 - EcoEagles VTS

Specification	Targets	Req's	ERAU
Acceleration, IVM–60 mph (s)	5.9	7.9	4.9
Acceleration, 50–70 mph (Passing) (s)	7.3	9.9	3.7
Braking, 60–0 mph (ft.)	128	135	120
Acceleration Events Torque Split (Front/Rear) (%)	RWD	49%/51%	RWD
Lateral Acceleration, 300 ft. Skid Pad (g)	0.85	0.8	0.95
Double Lane Change (mph)	55	52	56
Highway Gradeability, @ 20 min, 60 mph (%)	6%	6	6%
Cargo Capacity (ft^3)	N/A	2.4	9.9
Passenger Capacity	4	2	4
Curb Mass Added to Stock Vehicle (kg)	N/A	<314 kg	
Starting Time (s)	2	15	5
Total Vehicle Range* (mi)	N/A	150	180
CD Mode Range* (mi)	N/A	N/A	36
CD Mode Total Energy Consumption* (Wh/km)	N/A	N/A	244
CS Mode Fuel Consumption* (Wh/km)	N/A	N/A	568
UF-Weighted Fuel Energy Consumption* (Wh/km)	N/A	N/A	237
UF-Weighted AC Electric Energy Consumption* (Wh/km)	N/A	N/A	157
UF-Weighted Total Energy Consumption* (Wh/km) (mpgge)	700 30	840 25	395 53
UF-Weighted WTW Petroleum Energy Use* (Wh PE/km)	420	750	70
UF-Weighted WTW Greenhouse Gas Emissions* (g GHG/km)	225	250	134
UF-Weighted WTW Criteria Emissions* (g/km)	-	-	-

9.2 Additional AMAS Vision Processing Images

Figure 10 - Stop Sign Detection

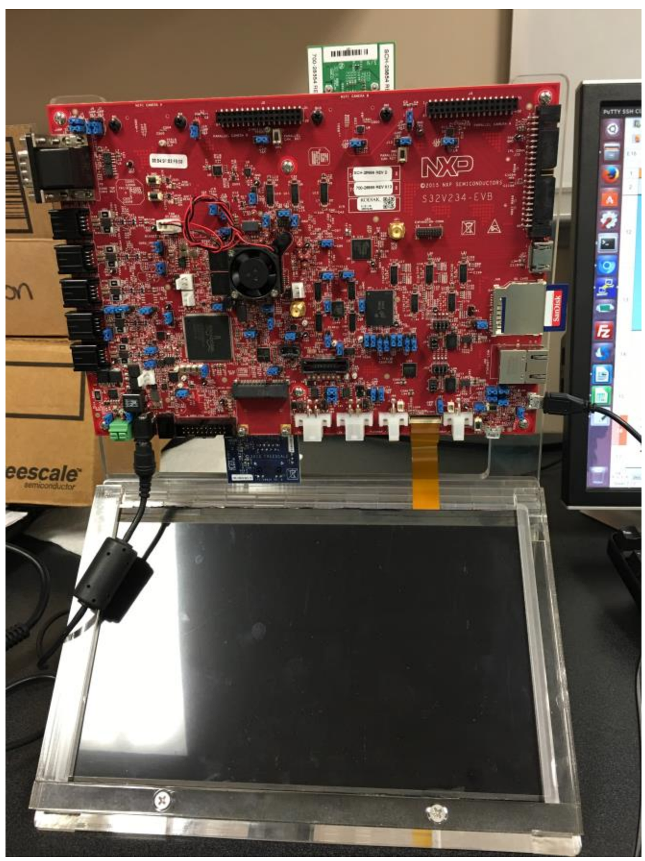

Figure 11 - NXP S32V Vision Processing System

9.3 Subset of Control System Requirements

Table 10 - Control System Requirements

Classification	System	Requirement & Validation Procedure Number	Requirements
Torque Security	PRNDL	1.1.1	Shifter shall move sequentially through gears P-R-N-D-L without skipping gears
		1.1.2	PRNDL lever shall cause the vehicle to enter P, R, N, D states on cabin indicators.
		1.1.3	No Torque shall be allowed while in P or N
		1.1.4	D and R shall allow torque
		1.1.5	Invalid PRNDL location shall be a Tier 1 fault case.
		1.1.6	Vehicle must be capable of shifting a rate defined by Trans.maxshiftrate
	Ignition	1.2.1	High voltage system shall be enabled when key is cycled ON-CRANK-ON.
		1.2.2	High voltage system shall be disabled when key is cycled ON-ACC.
		1.2.3	High voltage system shall not be active when key is OFF
		1.2.4	Powertrain shall not active when key is OFF.
Torque Application	Accelerator Pedal	2.1.1	Accelerator pedal shall correspond to a torque demand from 0 to **THRESHOLD** in drive.
		2.1.2	Accelerator pedal shall correspond to a torque demand from 0 to 125 Nm in reverse.
		2.1.3	Maximum torque under no-fault condition shall be no higher than **THRESHOLD** in the forward direction.
		2.1.4	Mismatching value between sensors shall be a Tier 1 fault case.
		2.1.5	Sensor values out of range shall be a Tier 1 fault case.
		2.1.6	Accelerator pedal runaway condition shall be a Tier 1 fault case.

		2.1.7	Accelerator pedal noise shall not cause tractive torque to be commanded at 0% displacement.
	Torque Limits	2.2.1	Maximum torque under no-fault condition shall be no higher than 125Nm in the reverse direction.
		2.2.2	Magnitude of maximum rate of torque application under no-fault condition shall be no higher than 150Nm/s.
		2.2.3	BCM shall close contactors when vehicle is enabled.
Battery Systems	ESS	3.1.1	(BCM cell Vmin <2.7v) condition shall be considered a Tier 2 fault condition. (Vmin stands for minimum voltage)
		3.1.2	(BCM cell Vmax > 3.6v) condition shall be considered a Tier 2 fault condition.
		3.1.3	(BCM cell Tmin < -20C) condition shall be considered a Tier 2 fault condition. (Tmin stands for minimum temperature)
		3.1.4	(BCM cell Tmax > 35C) condition shall be considered a Tier 2 fault condition.
		3.1.5	(BCM VBAT < threshold) condition shall be considered a Tier 2 fault condition.(VBAT - Battery Voltage of ESS)
		3.1.6	(BCM VBAT > threshold) condition shall be considered a Tier 2 fault condition.
		3.1.7	(BCM EPO) condition shall be considered a Tier 2 fault condition.(EPO - Emergency Power Off for ESS)
		3.1.8	(BCM t_coolant > threshold) condition shall be considered a Tier 3 fault condition.(t_coolant - Temperature of the coolant in the ESS)
		3.1.9	(BCM dis_buf < threshold) condition shall be considered a Tier 3 fault condition.(dis_buf - Discharge buffer for the ESS)
		3.1.10	(BCM chg_buf < threshold) condition shall be considered a Tier 3 fault condition.(chg_buf - Charging buffer for the ESS)
Traction Motor	Bosch IMG Inverter 1	4.1.1	Inverter command message shall contain the same torque command that exists downstream of the torque limits in the traction motor control subsystem.

		4.1.2	Inverter command message shall reflect the PRNDL position
		4.1.3	Inverter temperature above 100C shall be considered a Tier 3 fault condition
		4.1.4	Loss of performance capability of tractive system shall cause output to drop
	IMG 1	4.2.1	Motor temperature above 100C shall be considered a Tier 3 fault condition
Generator System	Bosch IMG Inverter 2	5.1.1	Inverter command message shall contain the same torque command that exists downstream of the torque limits in the traction motor control subsystem.
		5.1.2	Inverter command message shall reflect the PRNDL position
		5.1.3	Inverter temperature above 100C shall be considered a Tier 3 fault condition
		5.1.4	Loss of performance capability of tractive system shall cause output to drop
		5.1.5	Inverter command message shall always reflect CCW operation.
		5.1.6	Inverter temperature above 100C shall be considered a Tier 3 fault condition
	IMG 2	5.2.1	Motor temperature above 100C shall be considered a Tier 3 fault condition
Series Control System	Generator System	6.1.1	If not already running, the Engine/Generator system shall start when the CS button is pressed.
		6.1.2	If not already running, the Engine/Generator system shall start when the Engine on button is pressed.
		6.1.3	Engine on button shall cause engine to match road loads
		6.1.4	If not already running, the Engine/Generator system shall start when battery SOC falls below 20% and vehicle speed is less than 30 mph
		6.1.5	While running, the Engine/Generator system shall output the power necessary to reduce battery current to 0.
		6.1.6	Loss in performance capability of Series system shall cause its output to drop
		6.1.7	Loss in performance capability of ESS shall cause Series system to start

		6.1.8	While running, the Engine/Generator system shall not experience a torque rise or fall rate greater than 200Nm/s.
	Clutch 2	6.1.9	Clutch 2 shall be Engaged
	Clutch 1	6.1.10	Clutch 1 shall be Open
	ECM	6.2.1	Engine coolant temperature greater than 100C shall be considered a Tier 3 fault condition
Parallel Control System	SCU	7.1.1	If SOC <= 20% and vehicle speed is greater than 35mph shall start Parallel mode
	Clutches	7.1.2	Parallel control system shall engage both Clutch 1 and 2
	SCU	7.1.3	Parallel control system shall split power demand between Inverter 1, Inverter 2, and ECM
		7.1.4	If sport mode is pressed, parallel mode shall be engaged
		7.1.5	Parallel control system shall return to CD mode if SOC climbs above 30%
		7.1.5	Parallel control system shall return to CD mode if SOC climbs above 30%
Low Voltage	APM	8.1.1	APM shall start within 6 seconds of contactor closure
		8.1.2	APM shall output 14.5V
Fault Handling	Tier 1	9.1.1	Tier 1 fault condition shall prevent torque application
	Tier 3	9.1.2	Tier 3 fault condition shall reduce power output of systems based on thermal derating
	Tier 2	9.1.3	Tier 2 fault conditions disable operational modes based on fault cases
	Tier 4	9.1.4	Tier 4 fault condition shall disable the faulting non critical system
Communication Faults		10.1.1	Loss of communication with the Inverter 1 shall be considered a Tier 2 fault.
		10.1.2	Loss of communication with the Inverter 2 shall be considered a Tier 2 fault.
		10.1.3	Loss of communication with the ECM shall be considered a Tier 2 fault.
		10.1.4	Loss of communication with the BRUSA shall be considered a Tier 4 fault.
		10.1.5	Loss of communication with the APM shall be considered a Tier 2 fault.

		10.1.6	Loss of communication with the ACCM shall be considered a Tier 4 fault.
		10.1.7	Loss of communication with the BCM shall be considered a Tier 2 fault.
		10.1.8	Loss of communication with the Clutch 1 shall be considered a Tier 2 fault.
		10.1.9	Loss of communication with the Clutch 2 shall be considered a Tier 2 fault.
Cooling	Traction Cooling	11.1.1	RMS pump shall turn on when max RMS component temperature reaches 65C and turn off at 45C
	ESS	11.2	ESS pump
		11.2.1	ESS pump shall turn on when bcm_tmax is 35C and turn off at 30C
System Level Powertrain Control	Charge Deplete	12.1.1	Charge deplete mode shall operate the system using twin electric motors for tractive performance
		12.1.2	Charge deplete mode shall open a clutch to disconnect the engine from the drivetrain.
		12.1.3	Charge deplete mode shall operate the system only using electric energy
	Series	12.2.1	Series mode shall close a clutch between the ICE and the first electric machine
		12.2.2	Series mode shall open the clutch between the pair of electric machines.
		12.2.3	Series mode shall enable a single electric motor drive while utilizing the engine to sustain the battery state of charge while at low speeds and low power demands.
	Parallel CS	12.3.1	Parallel load balancing mode shall close all clutches connecting all powertrain components to the driveshaft.
		12.3.2	Parallel load balancing mode shall use the electric motors to load the engine more to keep it inside its most efficient ranges or to assist in tractive performance by assisting the engine for short periods of time.
		12.3.3	Parallel load balancing mode shall operate with the electric motors in a neutral state and only use engine power.
	Sport Mode	12.4.1	SPORT mode shall close all clutches to the driveshaft.
		12.4.2	SPORT mode shall connect all tractive power components to the driveshaft.

		12.4.3	SPORT mode shall be activated by the driver and focuses on directing maximum tractive performance to the road.
Driver Controls and Communication Systems		13.1	Vehicle controls
	Vehicle Controls	13.1.1	Vehicle shall have conventional automotive controls, including a keyless powertrain activation switch.
		13.1.2	Enabling Vehicle Powertrain
		13.1.2.1	Vehicle shall enabling and disabling the vehicle powertrain.
		13.1.2.2	Vehicle shall be started from the driver's seat by the driver.
		13.1.3	Vehicle immobilization while in part
		13.1.3.1	The vehicle shall capable of being restrained from rolling on any grade up to 20% when in park.
		13.1.3.2	The act of placing the shifter in Park shall immobilize the vehicle by engaging either a parking pawl or the parking brake.
		13.1.3.3	The vehicle shall employ a brake-pedal Park lock where the brake pedal is depressed to shift the vehicle out of Park.
		13.1.3.4	The vehicle shall not shift in or out of Park unless the vehicle is in the "accessory" or "run" mode.
		13.1.4	Neutral safety switch
		13.1.4.1	The vehicle's wheels shall not, under any circumstances, produce motive power or torque when the vehicle's gear selector is in Neutral or Park.
		13.4	Erroneous Propulsion Signal Failure
		13.4.1	The vehicle design shall prevent high-power components.
		13.4.2	The control hardware for the propulsion system or generator system shall have a fail-safe that prevents operation when a power component receives an erroneous signal from a control device that has failed.
		14.2	Antilock Braking System
		14.2.1	The antilock braking system (ABS) shall be functional at all speeds and in all vehicle modes.

Emergency Disconnect Switches		15.1	Vehicles shall have an EDS to shut down the HV and fuel systems.
		15.2	The EDS shall stop all delivery of power to the vehicle powertrain and to isolate HV to the smallest area possible.
		15.3	EDS shall have E-Stop button on the dashboard area, located within the sight and reach of a belted-in driver.
		15.4	EDS shall have E-Stop button on the right rear bumper of the vehicle.
		15.5	EDS shall have E-Stop button inertia switch that activates at >8g lateral acceleration.
		15.6	Activating the EDS shall open HV contactors on the most positive and most negative terminals of the battery.
		15.7	Activating the EDS shall prevent any buck/boost converter from supplying power to the HV bus.
		15.8	Activating the EDS shall interrupt all fuel delivery to the engine by either disabling fuel pumps or closing fuel valves.
		15.9	Activating the EDS shall shut off immediately and not continue to run on fuel remaining in the fuel lines
		15.1	Activating the EDS shall disable any HV charging devices.
		15.11	Activating the EDS shall not rely on the proper functioning of any computer system in the vehicle.
		15.12	Components that respond to the EDS circuit shall transition to a safe state with EDS activation or loss of power.
		15.13	Competition-Required Switches
		15.13.1	These switches shall only be activated when instructed by an organizer.
Vehicle Interior		16.1	Charge-Sustaining Switch
		16.1.1	Charge-Sustaining Switch shall toggle the vehicle between the current vehicle mode and CS mode.
		16.1.2	The vehicle shall then enter into CS mode.
		16.2	Regenerative Braking Disable Switch
		16.2.1	Vehicle with a regenerative braking system shall have a switch to disable regenerative braking.
		16.3	Engine-On Switch

		16.3.1	Engine-On Switch, when activated, shall prompt the engine to be fueled, start, and continue to run.
		16.3.2	The engine shall run until the switch is deactivated.
		16.3.3	Engine-On Switch, when activated, the engine shall be on and consuming fuel when the vehicle is stationary and providing power for vehicle propulsion when the vehicle is moving.
Competition Indication Lights	Ground Fault Light	17.1.1	The output of the vehicle ground fault monitor shall illuminate this indicator light.
		17.1.2	The GFI light shall be functional whenever the ESS contactors are closed.
	Ready Light	17.2.1	Vehicle ready indicator light shall be an indicator visible to the driver that is illuminated when the powertrain is enabled and will respond to control inputs.
	Charge Light	17.3.1	High voltage charging indicator light shall indicate the HV charging state of the vehicle when the charger cord is connected.
		17.3.2	High voltage charging indicator light shall be off when the charger plug is disconnected.
		17.3.3	High voltage charging indicator light shall blink in 0.5-second intervals when the vehicle is charging.
		17.3.4	High voltage charging indicator light shall on when the vehicle is done charging and still plugged in.

9.4 List of Abbreviations

AccLoad – 12v Accessory Load
ADAS – Advanced Driver Assistance System
APP – Accelerator Pedal Position
BCM – Body Control Module
BMS – Battery Management System
BPP – Brake Pedal Position
CAN – Controller Area Network
CCU – Clutch Control Unit
CMRR – Consumer Market Research Report
CSM – Current Sense Module
DDE – Distribution and Disconnect Enclosure
ECM – Engine Control Module
ECU – Electronic Control Unit
EDM – Electronic Disconnect Module
ENG – Engine
EPO – Emergency Power Off
ERAU – Embry-Riddle Aeronautical University
ESS – Energy Storage System
EWP – Electric Water Pump
HV – High Voltage
HV A/C – High Voltage A/C Unit
ICE – Internal Combustion Engine
INV – High-Voltage Inverter
IVM – Initial Vehicle Movement
LRC – Live Rolling Count
LV – Low Voltage
MABX – dSPACE MicroAutoBox II
MPGGE- Miles per Gallon of Gasoline Equivalence
PCM – Phase Change Material
PEM - Power Electric Module
PHEV – Plug-in Hybrid Electric Vehicle
PWM – Pulse Width Modulation
SCU – Supervisory Control Unit
SOC – State of Charge
TCM – Transmission Control Module
Trq_Req – Driver Requested Torque
VTS – Vehicle Technical Specifications