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Functional Safety Assessment of a Generic Accelerator Control System With Electronic Throttle Control in Electric Vehicles

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Foreword

NHTSA’s Automotive Electronics Reliability Research Program

The mission of the National Highway Traffic Safety Administration is to save lives, prevent injuries, and reduce economic costs due to road traffic crashes. As part of this mission, NHTSA researches methods to ensure the safety and reliability of emerging safety-critical electronic control systems in motor vehicles. The electronics reliability research program focuses on the body of methodologies, processes, best practices, and standards that are applied to ensure the safe operation and resilience of vehicular systems. More specifically, this research program studies the mitigation and safe management of electronic control system failures and making operator response errors less likely.

NHTSA has established five research goals for the electronics reliability research program to ensure the safe operation of motor vehicles equipped with advanced electronic control systems. This program covers various safety-critical applications deployed on current generation vehicles, as well as those envisioned on future vehicles that may feature more advanced forms of automation and connectivity. These goals are:

1. Expand the knowledge base to establish comprehensive research plans for automotive electronics reliability and develop enabling tools for applied research in this area;
2. Strengthen and facilitate the implementation of safety-effective voluntary industry-based standards for automotive electronics reliability;
3. Foster the development of new system solutions for ensuring and improving automotive electronics reliability;
4. Research the feasibility of developing potential minimum vehicle safety requirements pertaining to the safe operation of automotive electronic control systems; and
5. Gather foundational research data and facts to inform potential future NHTSA policy and regulatory decision activities.

This Report

This report describes the research effort to assess the functional safety of accelerator control systems with electronic faults, such as errant electronic throttle control signals, following an industry process standard. This study focuses specifically on errant signals in motor vehicles with electric propulsion. This study follows the concept phase process in the ISO 26262 standard and applies a hazard and operability study, functional failure modes and effects analysis, and systems theoretic process analysis (STPA) methods. In total, this study identifies 7 vehicle-level safety goals and 202 ACS/ETC system safety requirements (an output of the ISO 26262 and STPA processes). This study uses the results of the analysis to identify potential opportunities to improve the risk assessment approach in the ISO 26262 standard.

This publication is part of a series of reports that describe NHTSA's initial work in the automotive electronics reliability program. This research specifically supports the first, second, fourth, and fifth goals of NHTSA's electronics reliability research program by gaining understanding on both the technical safety requirements for ACS/ETC systems and how the industry standard may enhance safety

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LIST OF ACRONYMS

A/D	analog-to-digital
ACC	adaptive cruise control
ACS	accelerator control system
AEB	automatic emergency braking
AIS	Abbreviated Injury Scale
AP	accelerator pedal
APP	accelerator pedal position
APPS	accelerator pedal position sensor
ASIL	automotive safety integrity level
BP	brake pedal
BPP	brake pedal position
BPP	brake pedal position sensor
BTO	brake throttle override
C	controllability
CAN	controller area network
CC	cruise control
CF	causal factor
CPU	central processing unit
DTC	Diagnostic Trouble Code
E	exposure
ECU	electronic control unit
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPS	electric powertrain subsystem
ESD	electrostatic discharge
ETC	electronic throttle control
EV	electric vehicle
FMEA	failure mode and effects analysis
FMVSS	Federal Motor Vehicle Safety Standard
FTTI	fault tolerant time interval
HAZOP	Hazard and Operability Study
HEV	hybrid electric vehicle
HV	high voltage
HVIL	high voltage interlock loop
I/O	input/output
IC	integrated circuit
ICE	internal combustion engine
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization

kph	kilometers per hour
MISRA	Motor Industry Software Reliability Association
mph	miles per hour
NPRM	Notice of Proposed Rulemaking
PCM	powertrain control module
QM	quality management
RESS	rechargeable energy storage system
SAE	Society of Automotive Engineers
S	Severity
STPA	systems theoretic process analysis
TBD	to-be-determined
TCS	traction control system
TICM	traction inverter control module
UCA	unsafe control action

EXECUTIVE SUMMARY

This report describes research by the Volpe National Transportation Systems Center (Volpe), in conjunction with the National Highway Traffic Safety Administration, to identify example safety requirements[1] related to the failures and countermeasures of the accelerator control system with electronic faults, such as errant electronic throttle control signals. ACS/ETC systems are the subset of ACS architectures where the throttle is controlled electronically, rather than through a mechanical connection to the driver-operated control. Specifically, this report focuses on the identification of example safety requirements for the ACS/ETC systems in electric vehicles.[2] The NHTSA Notice of Proposed Rulemaking for Federal Motor Vehicle Safety Standard 124 defines the throttle for EVs as the electric power delivery to the traction motor [1].

The primary purpose of this work is to study and analyze the potential hazards that could result from cases of electrical or electronic failures impacting the functions of vehicular control systems. The study follows the International Organization for Standardization 26262 [2] process to identify the integrity requirements of these functions at the concept level, independent of implementation variations. This study also considers potential causes that could lead to such functional failures and documents the technical requirements the ISO 26262 process suggests with respect to the identified automotive safety integrity level of the item under consideration. While this study does not go into implementation strategies to achieve these ASIL levels, the ISO 26262 process provides a flexible framework and explicit guidance for manufacturers to pursue different methods and approaches to do so. Manufacturers employ a variety of techniques, such as ASIL decompositions, driver warnings, fault detection mechanisms, plausibility checks, redundancies, etc., to achieve the necessary ASIL levels that effectively mitigate the underlying safety risks.

This particular research follows the Concept Phase process (Part 3) in ISO 26262 to derive a list of potential safety requirements. Specifically, this research:

1. Defines the scope and functions of a generic EV ACS/ETC, and represents the system in block diagrams.
2. Performs a vehicle-level hazard analysis using both the Hazard and Operability (HAZOP) study and the STPA method. By integrating the hazards identified in both the HAZOP study and STPA, the process establishes seven vehicle-level hazards (Table ES-1).
    a. The HAZOP study identifies 132 malfunctions from analysis of the 19 EV ACS/ETC functions (see Section 4.2.3, Table 3 for details).

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[1] All requirements presented in this section are intended to illustrate a comprehensive set of requirements that could be derived from the safety analysis results. These safety requirements are not intended to represent NHTSA's official position or requirements on an ACS/ETC system.
[2] Vehicle-level hazards and requirements identified in this study are based on the analysis of a generic EV ACS/ETC. More complex systems (e.g., with integrated advanced driver assist systems) may result in additional hazards and functional safety requirements.

   b. The STPA method identifies 95 unsafe control actions from analysis of the 13 ACS/ETC control actions (see Section 4.3.4, Table 13 for details).
3. Applies the ASIL assessment[3] approach in the ISO 26262 standard to evaluate the risks associated with each of the identified hazards. In total, 69 operational situations are developed to assess the seven vehicle-level hazards. Following the practice in the ISO 26262 process, the most severe ASIL is chosen for each vehicle-level hazard. Table ES-1 summarizes the outcome.

Table ES-1. Vehicle-Level Hazards and Corresponding ASIL

	Hazards	**ASIL**
H1	Potential uncontrolled vehicle propulsion	D
H1.a	Potential uncontrolled vehicle propulsion when the vehicle speed is zero	B[i]
H2	Potential insufficient vehicle propulsion	C[ii]
H3	Potential vehicle movement in an unintended direction	C
H4	Potential propulsion power reduction/loss or vehicle stalling	D
H5	Potential insufficient vehicle deceleration	C[ii]
H6	Potentially allowing driver's command to override active safety systems[iv]	D[iii]
H7	Potential electric shock	B

i. *For certain control system features that only operate when vehicle speed is zero, the ASIL of this hazard is B. This ASIL is based on a reduced severity from impact occurring at a low speed (i.e., impact occurs before the vehicle reaches high speeds). An example of such a feature is the hill-holder that prevents a car from rolling backward on a hill when the BP is released.*
ii. *The ASIL assessment for this hazard varied among safety analysts in the absence of objective data. This research finds that objective data are not readily available for the assessment of the three dimensions used to determine the ASIL--severity, exposure, and controllability.*
iii. *The effects of H6 are contained in H1, H2, H4, and H5. Therefore, H6 takes on the most severe ASIL value among those four hazards.*
iv. *This hazard may not apply in ACS/ETC systems designed to give the driver's command priority over all active safety systems.*

4. Performs a safety analysis using both the FMEA and the STPA method.
   a. The Functional FMEA identifies 30 failure modes and 90 causes (see Section 7.1, Table 25 for details).
   b. The STPA method identifies 1,048 causes that may lead to 95 UCAs (see Section 7.2, Table 27 for details).

5. Identifies 202 example safety requirements for the ACS/ETC system and components by combining the results of the two safety analyses (Functional FMEA and STPA) and leveraging industry practice experiences.
   a. This study derived 112 example functional safety requirements by following the Concept Phase in the ISO 26262 standard

[3] The ASIL is established by performing a risk analysis of a potential hazard that looks at the severity, exposure, and controllability of the vehicle operational situation.

b. This study derived 90 examples of additional safety requirements by following the additional safety strategy in the military standard MIL-STD-882E [3]. These 90 requirements are out of the scope of the Functional Safety Concept phase in ISO 26262 (Part 3 of the ISO 26262 standard). However, subsequent steps in the ISO 26262 process — Systems Engineering (Part 4), Hardware Development (Part 5), and Software Development (Part 6) — cascade the Functional Safety Concept requirements into additional development-specific safety requirements, and may identify these 90 additional requirements.

Table ES-2 provides a breakdown of the 112 example functional safety requirements and 90 examples of additional safety requirements.

Table ES-2. Breakdown of Safety Requirements

ACS/ETC System/Subsystem	**Number of Functional Safety Requirements**	**Number of Additional Safety Requirements**
General ACS/ETC System	11	17
Accelerator Pedal Assembly	8	3
Electric Vehicle Powertrain Control Module	49	29
Electric Powertrain Subsystem	28	14
Communication Signals	5	4
Power Supply (Low and High Voltage)	6	2
Interfacing Systems	5	21

In the course of following the ISO 26262 process, this research also makes the following observations:

- Although ISO 26262 requires a hazard to take the most severe ASIL among all operational situations, if a vehicle feature only operates in a subset of all operational situations, its ASIL could be lower. For example, although *H1-Uncontrolled Vehicle Propulsion* has an ASIL D for all operational situations considered, *H1.a-Uncontrolled Vehicle Propulsion when Vehicle Speed is Zero* has a lower ASIL (ASIL B). This lower ASIL is based on a reduced severity value from impact occurring at a low speed (i.e., the vehicle does not reach high speeds). Therefore, an electronic control system feature such as hill-holder that only operates when the vehicle speed is zero may receive ASIL B for the *Uncontrolled Vehicle Propulsion* hazard.
- The generation of operational situations could be improved by leveraging the variables and codes in the NHTSA crash databases and naturalistic driving datasets.
- Without the support of objective data, the ASIL assessment may vary among safety analysts.
    - o Statistics from the NHTSA crash databases are available to support the assessment of severity.

    - Statistics are not readily available for the assessment of exposure, but may be derived from the naturalistic driving data sets.
    - Statistics are not publicly available for the assessment of controllability.

The results of this study may be used to:

- Benchmark safety requirements for the EV ACS/ETC system.
- Illustrate how STPA may be incorporated as one of the potential hazard and safety analysis methods that can support the ISO 26262 process.
- Provide inputs to the development of performance testing.

1 INTRODUCTION

1.1 Research Objectives

In conjunction with NHTSA, Volpe is working on a project that supports the need for additional safety requirements[4] related to the failures and countermeasures of the ACS with electronic faults, such as errant ETC signals. This project focuses on the ACS/ETC, which is the subset of ACS architectures where the throttle is controlled electronically, rather than through a mechanical connection to the driver-operated control.

This project is part of NHTSA's electronics reliability research program for ensuring the safe operation of motor vehicles equipped with advanced electronic control systems. The objectives of this project are:

1. Conduct a hazard analysis for electronic-related ACS/ETC failures; and
2. Derive example safety requirements and safety constraints for different ACS/ETC propulsion system variants in accordance with the International Organization for Standardization (ISO) 26262 Concept Phase (Part 3, [2]) and other system safety standards, such as MIL-STD-882E [3].

In this project, Volpe is examining the ACS/ETC for the following propulsion system variants.

1. Gasoline ICE
2. Diesel ICE
3. Electric vehicle
4. Hybrid electric vehicle with a gasoline ICE for three common architectures:
   a. Series
   b. Parallel
   c. Series-parallel
5. Fuel cell HEV

This report covers the study of the EV ACS/ETC in light motor vehicles (i.e., passenger cars, vans, minivans, sport utility vehicles, and pickup trucks with a gross vehicle weight rating of 10,000 pounds or less). This report documents the approach and the findings of the analysis.

1.2 Report Outline

In addition to the Introduction, this report contains the following sections:

- Section Two: details the analysis approaches, including descriptions of the hazard and safety analysis methods used in this study.

[4] All requirements presented in this section are intended to illustrate a comprehensive set of requirements that could be derived from the safety analysis results. These safety requirements are not intended to represent NHTSA's official position or requirements on an ACS/ETC system.

- Section Three: provides the description of a generic ACS/ETC system in EVs. It also defines the analysis scope and assumptions used in this study.
- Section Four: details the vehicle-level hazard analysis approaches and results.
- Section Five: documents the risk assessment on the identified vehicle-level hazards.
- Section Six: summarizes the vehicle-level safety goals as the result of the hazard analysis and risk assessment.
- Section Seven: details the safety analysis that supports the functional safety concept and the safety requirements.
- Section Eight: describes the functional safety concept.
- Section Nine: lists the safety requirements.
- Section Ten: discusses observations on the application of the ISO 26262 standard.
- Section Eleven: considers potential uses of the results of this study.

Sections two, ten, and eleven of this report are essentially unchanged from a previous report published as part of this project, *Functional Safety Assessment of a Generic Accelerator Control System with Electronic Throttle Control in Gasoline-FueledVehicles*.[5] These sections are reproduced here so that this report can serve as a stand-alone document.

[5] Van Eikema Hommes, Q. D., & Becker, C. (2018, July). Functional safety assessment of a generic accelerator control system with electronic throttle control in gasoline-fueled vehicles (Report No. DOT HS 812 557). Washington, DC: National Highway Traffic Safety Administration.

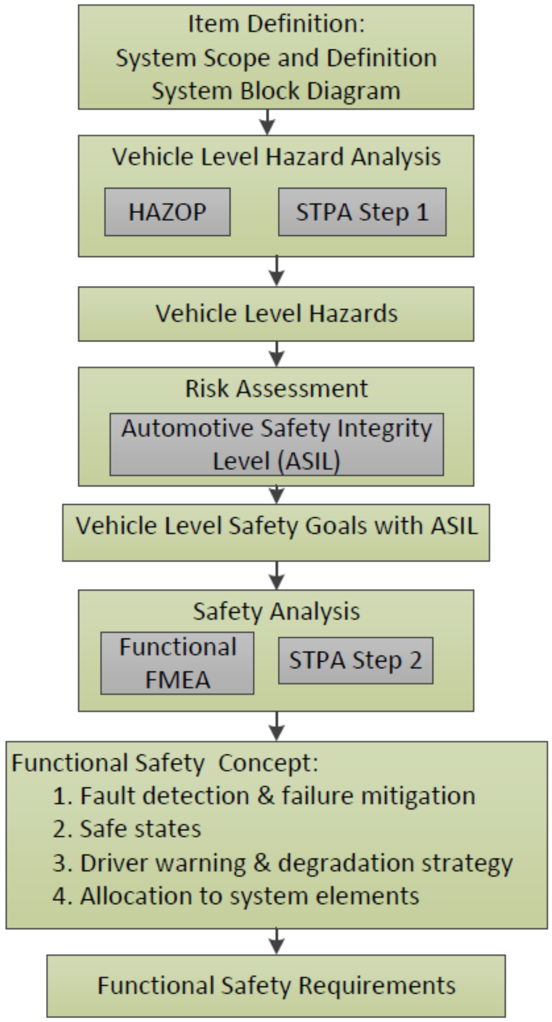
2 ANALYSIS APPROACH

The primary purpose of this work is to study and analyze the potential hazards that could result from cases of electrical or electronic failures impacting the functions of vehicular control systems. The study follows the ISO 26262 process to identify the integrity requirements of these functions at the concept level, independent of implementation variations. ISO 26262 is a functional safety standard adapted from the International Electrotechnical Commission Standard 61508, and is intended for application to electrical and electronic systems in motor vehicles (Introduction in Part 1 of ISO 26262). Part 3 of ISO 26262 describes the steps for applying the standard during the concept phase of the system engineering process.

This study also considers potential causes that could lead to such functional failures and documents the technical requirements the ISO 26262 process suggests with respect to the ASIL of the item under consideration. While this study does not go into implementation strategies to achieve these ASIL levels, the ISO 26262 process provides a flexible framework and explicit guidance for manufacturers to pursue different methods and approaches to do so. Manufacturers employ a variety of techniques, such as ASIL decompositions, driver warnings, fault detection mechanisms, plausibility checks, redundancies, etc., to achieve the necessary ASIL levels that effectively mitigate the underlying safety risks.

Figure 1 illustrates the safety analysis and safety requirements development process in this project, which is adopted from the Concept Phase (Part 3) of ISO 26262 . The process shown in Figure 1 was developed in part based on learnings from applying Part 3 of the ISO 26262 standard in a previous study.[6]

[6] Brewer, J., Nasser, A., Hommes, Q. V. E., Najm, W., Pollard, J., & Jackson, C. (2018, July). *Safety management of automotive rechargeable energy storage systems: The application of functional safety principles to generic rechargeable energy storage systems* (Report No. DOT HS 812 556). Washington, DC: National Highway Traffic Safety Administration.



HAZOP: Hazard and Operability study
STPA: Systems Theoretic Process Analysis

- **STPA Step 1**: Identify Unsafe Control Actions
- **STPA Step 2**: Identify Causal Factors

FMEA: Failure Modes and Effects Analysis

Note: ISO 26262 does not recommend or endorse a particular method for hazard and safety analyses. Other comparable and valid hazard and safety analysis methods may be used at the discretion of the analyst/engineer.

Figure 1. Safety Analysis and Requirements Development Process

2.1 Analysis Steps

As depicted in Figure 1, this project involves the following steps:

1. Define the system:
    a. Identify the system boundary. Clearly state what components and interactions are within the system boundary, and how the system interacts with other components and systems outside of the system boundary.
    b. Understand and document how the system functions.
    c. Develop system block diagrams to illustrate the above understandings and to assist the analysts in the rest of the process.
2. Carry out hazard analysis using both the HAZOP study [4] and the STPA method [5]. The output of the hazard analysis is a list of vehicle-level hazards.
3. Apply the ISO 26262 risk assessment approach to the identified vehicle-level hazards, and assign an ASIL to each hazard as defined in ISO 26262.
4. Generate vehicle-level safety goals, which are vehicle-level safety requirements based on the identified vehicle-level hazards. The ASIL associated with each hazard is also transferred directly to the vehicle-level safety goal.
5. Perform safety analyses on the relevant system components and interactions as defined in the first step of this process. This project applies both a Functional FMEA [6] and STPA in the safety analysis.
6. Develop a functional safety concept and functional safety requirements for the EV ACS/ETC at the system and component levels by following the ISO 26262 process. The functional safety concept and safety requirements are based on results from the hazard and safety analyses, ISO 26262 guidelines, and industry practice experiences.

2.2 Hazard and Safety Analysis Methods

This project uses multiple analysis methods to generate a list of hazard and safety analysis results.[7] These methods are described in this section.[8]

2.2.1 Hazard and Operability Study

This study uses the HAZOP study as one of the methods for identifying vehicle-level hazards. Figure 2 illustrates the analytical steps of the HAZOP study.

[7] ISO 26262 does not recommend or endorse specific methods for hazard or safety analysis. Comparable and valid hazard and safety analysis methods may be used at the discretion of the analyst/engineer.

[8] This report provides more details on STPA than other methods because the application of the STPA method to automotive electronic control systems is relatively new. Unlike HAZOP and Functional FMEA, a standard approach has not been defined and published for STPA. Therefore, this report provides more description to better explain how the analysis is performed.

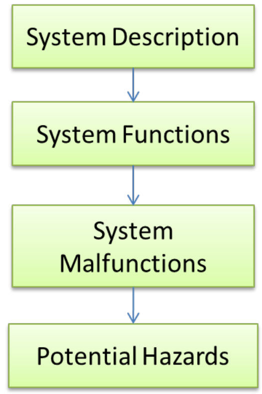


Figure 2. HAZOP Study Process

This study performs the HAZOP study steps in Figure 2 as follows:

1. Define the system of study and the scope of the analysis. Draw a block diagram to illustrate the system components, system boundary, and interfaces. This step is accomplished in the first step of the overall project (Figure 1).
2. List all of the functions that the system is designed to perform. This step is also accomplished in the first step of the overall project (Figure 1).
3. Apply a set of guidewords to each of the identified functions to describe the various ways in which the function may deviate from its design intent. IEC 61882[9] lists 11 suggested guidewords, but notes that the guidewords can be tailored to the particular system being analyzed [4]. The HAZOP study implemented in this project uses the following seven malfunction guidewords.
    - Loss of function
    - More than intended
    - Less than intended
    - Intermittent
    - Incorrect direction
    - Not requested
    - Locked function
4. Assess the effect of these functional deviations at the vehicle level. If a deviation from an intended function may result in a vehicle-level hazard, the hazard is then documented.

[9] IEC 61882:2001, *Hazard and operability studies (HAZOP studies) - Application guide*, provides a guide for HAZOP studies of systems using the specific set of guide words defined in this standard; and also gives guidance on application of the technique and on the HAZOP study procedure, including definition, preparation, examination sessions, and resulting documentation.

2.2.2 Functional Failure Mode and Effects Analysis

The FMEA is a bottom-up reliability analysis method that relies on brainstorming to identify failure modes and determine their effects on higher levels of the system. There are several types of FMEAs, such as System or Functional FMEAs, Design FMEAs, and Process FMEAs. This study uses a Functional FMEA in the safety analysis to identify failure modes at the function level that could potentially lead to the vehicle-level hazards. The failure modes identified by the Functional FMEA are used to derive the safety requirements.

Standard J1739 by the Society of Automotive Engineers (renamed SAE International in 2006) provides guidance on applying the Functional FMEA method [6]. The analysis includes the following steps.

1. List each function of the item on a FMEA worksheet.
2. Identify potential failure modes for each item and item function.
3. Describe potential effects of each specific failure mode and assign a severity to each effect.
4. Identify potential failure causes or mechanisms.
5. Assign a likelihood of occurrence to each failure cause or mechanism.
6. Identify current design controls that detect or prevent the cause, mechanism, or mode of the failure.
7. Assign a likelihood of failure detection to the design control.

This study applies the first four steps listed above for the Functional FMEA. Since this study is performed during the Concept Phase of ISO 26262, the analysis is not based on a specific design and does not assume controls or mitigation measures are present; there are not enough data to support Steps 5 through 7. The completed Functional FMEA worksheet is intended to be a living document that is continually updated throughout the development process.

2.2.3 Systems Theoretic Process Analysis

STPA is a top-down systems engineering approach to system safety [5]. In STPA, the system is modelled as a dynamic control problem, where proper controls and communications in the system ensure the desired outcome for emergent properties, such as safety. In the STPA framework, a system will not enter a hazardous state unless an unsafe control action is issued by a controller, or a control action needed to maintain safety is not issued. Figure 3 shows a process flow diagram for the STPA method.

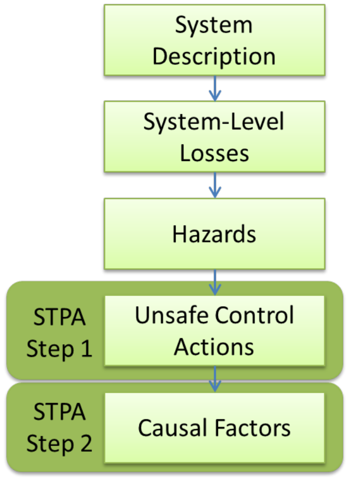


Figure 3. STPA Process

This project performs STPA following these steps:

1. Define the system of study and the scope of the analysis:
    a. Draw a hierarchical control structure of the system that captures the feedback control loops (controllers, sensors, actuators, controlled processes, and communications links). This control structure is a generic representation of the functions for a typical system.
    b. Identify the system boundary and interfaces with other vehicle systems and the external environment.

    This step is accomplished in the first step of the overall project (Figure 1).

2. Define the loss at the system level that should be mitigated. STPA defines system-level losses as undesired and unplanned events that result in the loss of human life or injury, property damage, environmental pollution, etc. [5]. For this project, the losses include the occurrence of a vehicle crash and electrocution.
3. Identify a preliminary list of vehicle-level hazards. STPA defines a hazard as a system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to a system-level loss [5]. Initially, based on engineering experience and a literature search, a preliminary hazard list is generated. This list is further refined through iterations in STPA Steps 1 and 2 — UCA and causal factor identification.
4. **STPA Step 1**: Identify potentially UCAs issued by each of the system controllers that could lead to vehicle-level hazards. Four sub-steps are involved:

    a. For each controller in scope of the system, list all the control actions it can issue.

b. For each control action, develop a set of context variables.[10] Context variables and their states describe the relevant external control inputs to the control system and the external environment that the control system operates in, which may have an impact on the safety of the control action of interest. The combinations of context variable states are enumerated to create an exhaustive list of possible states. A recent enhancement to the STPA method [7] enumerates the process model variable states in the first step of STPA. Process model variables refer to variables that the control algorithm uses to model the physical system it controls. This study does not assume the detailed algorithm design is known, and hence, modifies this STPA approach to focus on context variables instead of process model variables.

c. Apply the UCA guidewords to each control action. The original STPA literature includes four such guidewords [5]. This study uses a set of six guidewords for the identification of UCAs as illustrated in Figure 4.

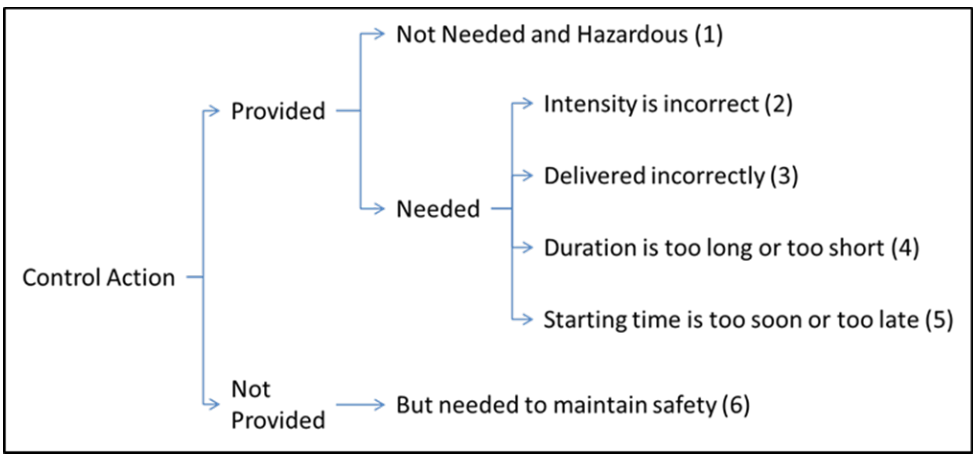


Figure 4. Guidewords for UCAs

For each control action, assess each of the six guidewords against each of the context variable combinations to determine if it could lead to one or more of the vehicle-level hazards. If new hazards are identified, add these hazards to the vehicle-level hazard list initiated in the previous step.

d. Apply logical reduction to the resulting UCA matrix using the Quine-McCluskey minimization algorithm [8] to reduce the overall number of UCA statements.

[10] The context variables describe the context in which the control commands act. For example, the control command "enter BTO mode" may operate in the context of the "driver presses both AP and BP."

STPA Step 1 produces a list of UCAs that can be used to derive safety requirements for software control logic and initiate the STPA Step 2 analysis.

5. **STPA Step 2:** Determine CFs for each UCA identified in STPA Step 1.

   Each component and interaction in the control structure representation of the system is analyzed to determine if the component or the interaction may contribute to one of the UCAs identified in STPA Step 1. STPA literature provides 17 guidewords to assist the analyst in identifying CFs [5]. This project used an expanded list of 26 guidewords for identifying CFs. Appendix A provides the list of CF guidewords and detailed causes under each guideword that are used in this project.

As discussed above, there are two main analysis steps in STPA (Figure 3). This project applies STPA Step 1 in the hazard analysis stage of the study and STPA Step 2 as part of the safety analysis (Figure 1) stage.

3 SYSTEM DEFINITION

3.1 System Analysis Scope

In ACS:

> *"all vehicle components, including both mechanical and electrical/electronic components and modules, that operate a vehicle's throttle in response to movement of the driver-operated control and that, upon removal of actuating force on the driver-operated control, return both the throttle and the driver-operated control to their idle or rest positions."* [11]

Furthermore, ACS describes the components and connections as:

> *"a series of linked components extending from the driver-operated control to the throttling or fuel-metering device on the engine or motor."* [12]

The scope of this analysis generally conforms to the ACS/ETC definition in the 2012 FMVSS 124 NPRM. In addition to the ACS/ETC as defined in the 2012 FMVS 124 NRPM, this analysis also considers incoming torque requests from other vehicle systems, such as cruise control or the traction control system. However, this analysis assumes that these other vehicle systems correctly issue torque requests to the ACS/ETC; failures in other vehicle systems that could result in incorrect torque requests are out of scope for this study.

The following list identifies specific elements considered to be in-scope for this study:

1. All components leading from the driver-operated control to the high voltage power supply connection to the traction motor, including the following.
   - Accelerator pedal
   - Accelerator pedal position sensor
   - EV powertrain control module
   - Traction inverter control module
   - Gate drive board
   - Inverter/converter (also known as the power stage)
   - Phase/current sensor
   - Motor position and speed sensor
   - Inverter temperature sensor
2. All connections between the components listed above, including:
   - Wired connections
   - Communication over the vehicle bus (e.g., controller area network)

[11] Van Eikema Hommes, Q. D., Becker, C., & Najm, W. (2018, July). *Functional safety assessment of a generic accelerator control system with electronic throttle control in diesel-fueled vehicles* (Report No. DOT HS 812 585). Washington, DC: National Highway Traffic Safety Administration.

[12] Ibid.

3. Brake throttle override function
4. Incoming torque requests from other vehicle systems
5. Interfaces with the rechargeable energy storage system, including
    - HV power supply to the inverter / converter
    - High voltage interlock loop information
    - Requests to discharge the HV bus
6. Interfaces with the vehicle cooling system
7. Interfacing sensors, including
    - Vehicle speed data
    - Brake pedal position sensor
    - Vehicle direction data (forward or reverse gear)

The following list identifies specific elements considered to be out-of-scope for this study.

- Torque generation by the traction motor and downstream torque transmission (e.g., reduction gears)
- Hazards not directly caused by malfunctioning behavior of the electronic control system, such as fire hazards
- Brake system malfunctions that may lead to acceleration- or deceleration-related hazards, including regenerative braking malfunctions
- Malfunctions in other vehicle systems leading to incorrect torque requests
- Malfunctions and related hazards in the high voltage system, including the RESS
- Notifications from the ACS/ETC to the driver, such as malfunction indicator lights
- Driver errors, such as incorrect pedal application or gear selection
- Failures due to improper maintenance over the lifetime of the vehicle (e.g., incorrect parts, incorrect assembly, and failure to conduct scheduled inspections)
- Multiple point failures in the ACS/ETC system or interfacing systems

3.2 Analysis Assumptions

In addition to the system scope described in Section 3.1, this analysis includes several assumptions regarding the operation of the EV ACS/ETC system. The following list identifies the key assumptions made in this study. Each assumption is addressed by explaining how the findings from this study may apply to cases where the assumption is no longer valid, or whether additional analysis is needed.

- The EV powertrain operates a single traction motor that is used to provide torque to the drivetrain.
    - *Additional analysis may be required for architectures with multiple traction motors (e.g., wheel hub motors) to ensure coordination and proper supply of HV power to each motor.*

- The vehicle speed is provided to the EV PCM by the brake/stability[13] control module. Some system architectures may obtain the vehicle speed from other components.
    - *Requirements related to vehicle speed would apply to whichever component is responsible for providing this information to the EV PCM.*
- In order to exit BTO mode and resume acceleration, the driver needs to not only remove the pedal conflict, but also explicitly increase the AP angle. This assumption is based on a brake override process flow diagram published by Toyota [9]. Other manufacturers may have different strategies for exiting BTO mode.
    - *Manufacturers implementing other BTO strategies may require a separate analysis to identify requirements related to the safe functioning of their BTO algorithm.*
- The driver's intent for acceleration and deceleration is only conveyed via the AP and brake pedal (BP). Furthermore, this analysis assumes the driver input is correct and does not examine why the driver may incorrectly or intentionally press the pedals.
    - *Requirements related to other types of driver-operated controls for acceleration and braking may require additional analysis. Additional analysis is also needed to understand why the driver may incorrectly or non-intuitively apply the AP or the BP.*
- Cooling for the inverter/converter is provided by a separate vehicle cooling system that is not part of the EV ACS/ETC. This analysis assumes that the EV ACS/ETC requests cooling from the cooling system based on the inverter/converter temperature. Some system designs may have other cooling strategies, such as permanent cooling (e.g., immersion).
    - *The requirements related to the cooling system identified in this study would apply to architectures where the inverter/converter has a dedicated cooling system. However, additional analysis may be required to identify requirements related to other types of cooling strategies.*
- The RESS is responsible for monitoring the HV system and disconnecting the HV system in the event of a failure. The EV ACS/ETC is responsible for discharging the HV bus when requested by the RESS.
    - *Requirements related to the incoming request to discharge the bus apply to whichever system issues this request to the EV ACS/ETC. If discharging the HV bus is not performed through the EV ACS/ETC, then these requirements would not apply.*
- The EV PCM may be responsible for opening the contactor when the vehicle is in a crash or when the HVIL is violated. In other designs, the contactor may only be controlled through the RESS.
    - *If the system design does not use the EV PCM to open the HV contactor in the event of a crash or HVIL violation, requirements related to opening the contactor would not apply.*

[13] Vehicle stability control may include antilock braking system, electronic stability control system, TCS, etc.

- The motor position and speed are provided to the TICM, which communicates the traction motor health to the EV PCM. Some system architectures may have relevant motor data provided directly to the EV PCM.
  - *Requirements related to the traction motor position and speed would apply regardless of whether this information is provided to the TICM or EV PCM. Similarly, requirements related to the communication of this data can be readily adapted to other system architectures.*
- Safety strategies, such as redundant sensors, are not considered in the hazard analysis or safety analysis stages.
  - *Once specific design strategies have been adopted, additional hazard and safety analyses should be performed.*

3.3 Key Differences between the EV and ICE Architectures

The EV architecture differs significantly from the traditional ICE powertrain in several ways:

- Propulsion power generation:
  - In ICEs, propulsion power is generated through controlled combustion of hydrocarbons in the engine. The driver-operated control regulates the combustion elements entering the engine, thereby controlling the engine torque output.
  - In EVs, propulsion power is generated by converting electrical energy to torque through the traction motor. The driver-operated control regulates the current flow to the traction motor, thereby controlling the torque output.

  As a result of this difference in how propulsion is generated between the EV and ICE architectures, the components within the ACS/ETC and the key interfacing systems are significantly different between the two architectures.

- Idle speed control:
  - In most ICE architectures,[14] the engine rotational speed is maintained at an idle speed when the AP is not pressed. The ACS/ETC determines the minimum amount of air and fuel flow required to maintain the engine at idle speed. This also results in a "creep" speed that results from transmission of the engine idle torque to the drive train.
  - In EV architectures, the traction motor speed can be reduced to zero without causing the vehicle to stall. However, EVs may still experience stall-like conditions, for example if the Electric Powertrain Subsystem (EPS) shuts down unexpectedly. Any "creep" speed or idle torque output from the EV ACS/ETC is simulated in the software to create a behavior more like traditional ICEs.

[14] In ICEs equipped with the start-stop feature, the engine is designed to shut down instead of idle in certain situations.

- Engine braking:
  - In ICEs, when the AP is released, the engine acts to slow the vehicle resulting in additional deceleration even when the BP is not pressed.
  - In EVs, releasing the AP will cause the vehicle to coast resulting in a different deceleration profile from traditional ICEs. Some EV designs simulate engine braking by activating regenerative braking when the driver releases the AP, even if the BP is not pressed.

- Vehicle direction control:
  - In ICEs, the engine only rotates in one direction (e.g., clockwise). A separate transmission system is used to reverse the direction of the engine torque output when the driver selects reverse.
  - In EVs, the traction motor is capable of rotating in both directions (clockwise and counterclockwise) without the need for a separate transmission system. The direction of the traction motor torque output is determined by the current supply to the traction motor from the EV ACS/ETC. The EV ACS/ETC is responsible for controlling the direction of vehicle motion.

3.4 System Block Diagram

The EV powertrain converts electrical energy supplied by the HV system to propulsion for the vehicle. The EV ACS/ETC regulates the electric power supply to the traction motor to control the motor torque output in response to changes in the driver-operated control.

Figure 5 shows a block diagram representation of the EV ACS/ETC system considered in this study. The dashed line indicates the system boundary for the EV ACS/ETC, based on the system definition in the 2012 FMVSS 124 NPRM. Other vehicle systems, shown in gray, are treated as black boxes with respect to the EV ACS/ETC and are assumed to be functioning correctly. Interfaces between these systems and the EV ACS/ETC are shown as lines that cross the EV ACS/ETC system boundary.

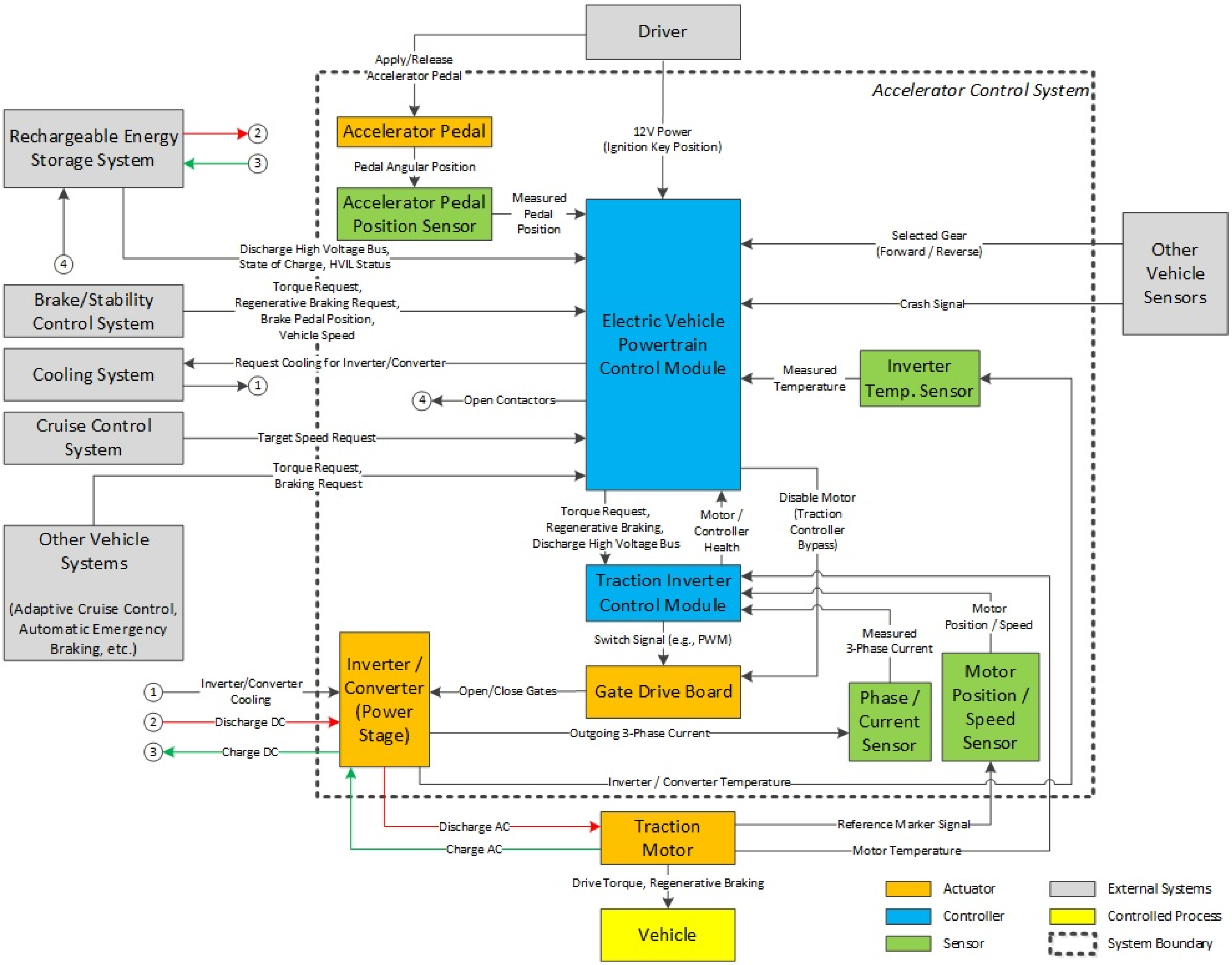


Figure 5. Block Diagram of the ACS/ETC in Electric Vehicles

3.5 System Description

The following description outlines the functions of an EV ACS/ETC system. [10] [11] [12] [13] [14] [15]

3.5.1 Driver-Operated Control and Other Torque Requests

The AP assembly allows the driver to command a desired torque from the traction motor. When the driver presses the AP, an integrated sensor – the APPS – measures the angular displacement of the AP. The APPS converts the angular displacement of the AP to a voltage signal, which is transmitted to the EV PCM. The signal may be transmitted via a direct connection between the APPS and EV PCM or over the vehicle communication bus (e.g., CAN bus).

The EV PCM converts the voltage signal from the APPS to a desired traction motor torque. The EV PCM then reconciles the torque requested by the driver with torque requests from other vehicle systems. These systems vary depending on the vehicle design and features, but typically include:

- Torque requests from the brake/stability system, and
- Torque requests from the CC system.

In addition to requesting torque via the AP, the driver also determines the desired vehicle direction (e.g., drive or reverse) using the gear selector. The transmission range sensor communicates the gear selector position to the EV PCM. The EV PCM then commands torque from the traction motor in the direction that corresponds to the driver's selection.

3.5.2 Traction Motor Current Control

After the EV PCM computes the direction and amount of torque necessary to meet the driver's request and other vehicle demands, the EV PCM sends a torque command to the TICM. The TICM computes the amount of electrical current required by the traction motor to meet the torque command from the EV PCM. The electrical current supplied to the traction motor determines both the direction and amount of torque produced by the traction motor.

The TICM causes current to flow to the traction motor by sending switching signals to the gate drive board. The gate drive board serves as a power amplifier that switches the transistors in the inverter/converter according to the TICM's command. The gate drive board may also electrically isolate the TICM from the high-voltage inverter/converter to prevent damage to the microcontroller.

Depending on the EV architecture, the traction motor may operate using either HV direct current or alternating current. The inverter/converter is designed to provide the appropriate HV power supply to the traction motor. For EVs with DC motors, the inverter/converter converts the HV DC from the RESS to the appropriate voltage level for the traction motor. For EVs with AC motors, the inverter/converter converts the HV DC from the RESS to the AC required by the traction motor. The inverter/converter also contains a converter that converts high-voltage DC to the low-voltage DC needed for the vehicle's auxiliary systems.

A phase/current sensor measures the current supply from the inverter/converter to the traction motor. The phase/current sensor measurement provides feedback to the TICM allowing closed-loop control of the switching signal provided to the gate drive board.

The traction motor provides torque to the transaxle of the driven wheels, providing propulsion for the vehicle. The traction motor position and speed is measured by an integrated sensor in the motor assembly (e.g., a resolver). The traction inverter controller uses feedback from the motor position and speed sensor to adjust the switching signal provided to the gate drive board to achieve the desired torque output from the traction motor.

3.5.3 Idle Speed Control

When the driver releases the AP, mechanical components (e.g., springs) in the AP assembly return the pedal to the idle (i.e., undepressed) position. In an EV, the traction motor torque output can be reduced to zero when the AP is released. This is in contrast to vehicles with ICEs that maintain an idle speed when the AP is released.[15] In order to simulate the "creep" speed found in ICEs, some EV PCMs are designed to provide current to the traction motor when the AP is released based on a pre-programmed idle torque level.

If the AP is released when the vehicle speed is above the idle creep speed, the EV PCM may either coast down to the idle creep speed or may activate regenerative braking to slow the vehicle at a faster rate. This latter approach is typically used to simulate the effect of engine braking found on vehicles with ICEs.

3.5.4 Brake Throttle Override Function

When the driver presses the BP, the BPPS sends a signal to the EV PCM. If both the AP and BP are pressed, the EV PCM must determine if the driver's intent is to stop the vehicle. To accomplish this, the EV PCM may consider other factors in addition to the accelerator pedal position and brake pedal position, such as vehicle speed and the duration with which both pedals are pressed. If it appears that the driver is trying to stop the vehicle, the EV PCM engages the BTO feature.

In BTO mode, the EV PCM will override the torque request from the driver via the AP and either reduce the current supply to the pre-set current level for BTO mode or reduce the current supply to zero. Since regenerative braking relies on the traction motor, it is possible that the EV PCM engages regenerative braking while in BTO mode, effectively overriding the AP torque

[15] In ICEs, the engine runs at an idle speed to provide torque to vehicle accessories and prevent engine stalling from drag torque. A portion of the idle torque gets transmitted through the transmission and produces a low "creep" speed.

request. The EV PCM will maintain the current supply to the traction motor at the BTO level until BTO mode is disengaged. According to the 2012 FMVSS 124 NPRM, the EV PCM should not exit BTO mode while a conflict between the AP and BP still exists [1].

3.5.5 Fault Detection

In addition to regulating the traction motor torque output, the EV PCM is also responsible for monitoring the EV ACS/ETC electronic system components to determine if faults are present. If the EV PCM detects a fault in the system, the EV PCM will log a diagnostic trouble code (DTC) and may force the EV ACS/ETC into a safe state, such as the "limp-home mode." The EV PCM will also issue a command to turn on the malfunction indicator light on the vehicle's instrument display panel.

Some examples of system faults include the following.

- APPS voltage signals exceeding the calibration range
- Faults in the TICM or inverter/converter
- Faults in the HV supply
- Internal software or hardware faults in the EV PCM

If the TICM has a fault, the EV PCM may be able to bypass the TICM and communicate directly with the gate drive board to disable current flow to the traction motor.

3.5.6 Related System: Braking System

In addition to providing vehicle propulsion, the traction motor is responsible for supporting the EV brake/stability system through regenerative braking. Regenerative braking occurs when the traction motor is operated as a generator, converting the kinetic energy of the vehicle into potential energy stored by the RESS. This dissipates the vehicle's kinetic energy, slowing the vehicle.

When the BP is pressed, the BPPS measures the angular displacement of the BP. This measurement is converted to an electrical signal that is sent to the EV PCM. The EV PCM then develops a braking strategy that meets the demanded level of braking while maximizing energy recovery through regenerative braking. When the available regenerative braking force is not sufficient to meet the braking demand, the EV PCM can request braking from traditional mechanical (i.e., friction) brakes. Note that in some vehicle configurations, the braking strategy may be developed by another vehicle controller, such as the brake/stability control module, and the EV PCM only receives a request to supply a certain level of regenerative braking.

The EV PCM sends a request for regenerative braking to the TICM. Similar to the traction motor control described above, the TICM determines the appropriate current flow from the traction motor to achieve the required level of regenerative braking. The electrical energy generated by the traction motor is converted to HV DC suitable for the RESS through the inverter/converter.

Although regenerative braking uses many of the same components as the EV ACS/ETC, as described in Section 3.1 of this report, regenerative braking is outside the scope of this study.

3.5.7 Related System: Rechargeable Energy Storage System

The RESS is not considered part of the EV ACS/ETC, but it is a closely related system and is essential for achieving the desired torque output from the traction motor. The RESS is responsible for controlling both the charging and discharging the high-voltage battery, including charging the battery through regenerative braking. The RESS supplies the inverter/converter with high-voltage DC and receives high-voltage DC from the inverter/converter during regenerative braking.

When a voltage or current abnormality is detected or when the RESS receives a signal from the occupant restraint system crash sensors, the RESS may send a signal to the EV PCM to discharge the HV bus. The EV PCM transmits the request to discharge the HV bus to the TICM. The TICM commands the inverter/converter, through the gate drive board, to discharge the HV bus across resistors integrated into the inverter/converter.

4 VEHICLE-LEVEL HAZARD ANALYSIS

This study performs two types of hazard analysis – HAZOP study and STPA. Section 4.1 presents the synthesized vehicle-level hazards from both analyses. Sections 4.2 and 4.3 provide additional details about the HAZOP study and STPA.

4.1 Vehicle-Level Hazards

In this study, HAZOP and STPA identify similar vehicle-level hazards. These hazards were synthesized to produce a consistent list. Table 1 shows the vehicle-level hazards and their definitions.

Table 1. Vehicle-Level Hazards and Definitions

	Driver Action	Vehicle Response	Hazards
Acceleration-Related	Does not command acceleration or commands less than the provided acceleration	Accelerates in direction specified by driver	**H1: Potential Uncontrolled Vehicle Propulsion** - is analogous with Unintended Acceleration, defined as "any vehicle acceleration that the driver did not purposely cause to occur" [1]. **H1.a: Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed is Zero**
	Commands acceleration	Does not accelerate or accelerates at a rate that is less than the specified speed increase profile	**H2: Potential Insufficient Vehicle Propulsion** - refers to incidents where the vehicle does not accelerate to the level commanded by the driver or at the rate commanded by the driver.
		Accelerates in a direction other than specified by the driver	**H3: Potential Vehicle Movement in an Unintended Direction** – refers to vehicle acceleration in response to the driver's command. However, the vehicle accelerates in a direction other than the direction selected by the driver.
Deceleration-Related	Does not command deceleration or commands less than the provided deceleration	Decelerates	**H4: Potential Propulsion Power Reduction/Loss or vehicle stalling** - refers to incidents where there is any degree of deceleration of the vehicle that the driver did not purposely cause to occur.
	Commands deceleration	Does not decelerate or decelerates at a rate that is less than the specified speed decrease profile	**H5: Potential Insufficient Vehicle Deceleration** - refers to incidents where the vehicle does not decelerate to the level commanded by the driver or at the rate commanded by the driver when the driver reduces the angular position of the AP.
Applicable to both Acceleration and Deceleration	Command either acceleration or deceleration	Accelerates or decelerates following driver's command, and overrides active safety function	**H6: Potentially Allowing Driver's Command to Override Active Safety Systems** - refers to situations where the ACS/ETC system follows the driver's input when the system design specifies the ACS/ETC should follow an active safety system's torque request.[i]
Not Motion Related			**H7: Potential Electric Shock** – refers to situations where the HV circuit is exposed and may come into contact with individuals.
[i] This hazard may not apply in ACS/ETC systems designed to give driver's command priority over all active safety systems.			

This study considers "Potential Electric Shock" as an EV ACS/ETC vehicle-level hazard even though it is not related to vehicle motion. This hazard results directly from the function of the EV ACS/ETC system and therefore falls within the scope of the EV ACS/ETC according to ISO 26262 (Part 3 Clause 1) .

4.2 Hazard and Operability Study

4.2.1 System Description

The HAZOP study uses a block diagram as a visual representation of the EV ACS/ETC system. The HAZOP study block diagram identifies the key system elements, internal interfaces, and high-level external interfaces. Figure 6 illustrates the block diagram used in the HAZOP study.

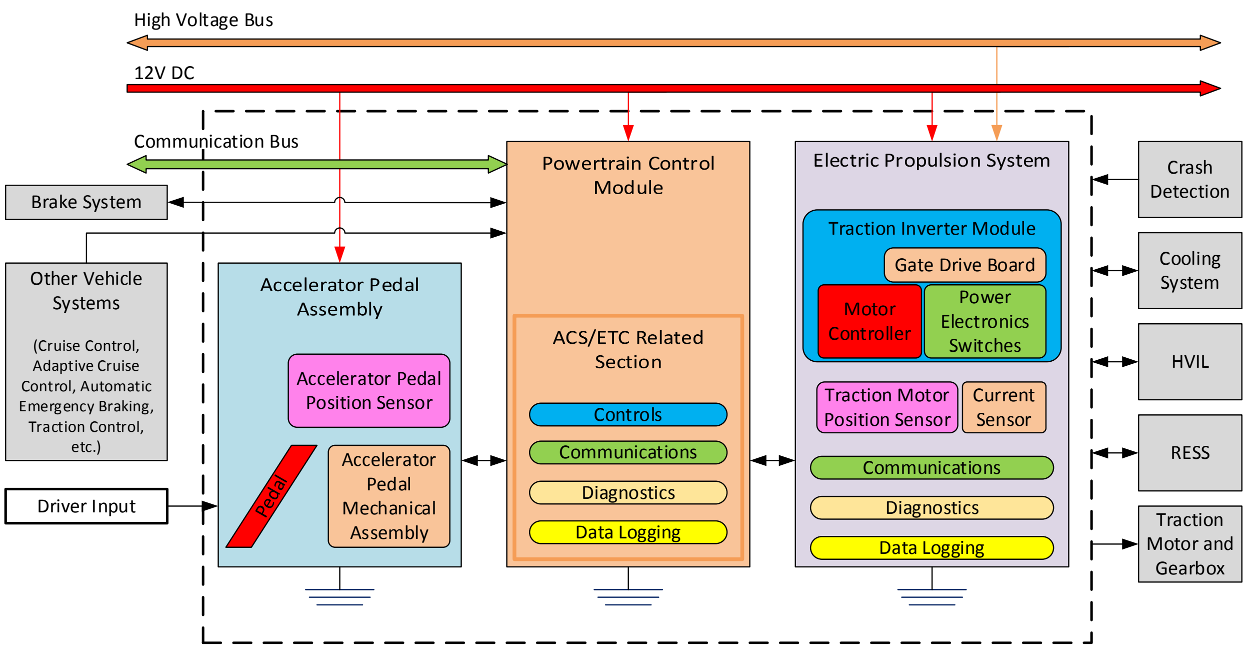


Figure 6. Block Diagram of the EV ACS/ETC System for the HAZOP Study

The dashed line in Figure 6 defines the boundary of the EV ACS/ETC system considered in the HAZOP study. The EV ACS/ETC contains three main subsystems.

- AP Assembly
- EV PCM
- EPS

The AP in the AP assembly receives the driver's input, which is communicated to the EV PCM by the APPS. The EV PCM determines the corresponding torque output from the traction motor, taking into account relevant parameters of the vehicle operating conditions, such as vehicle speed, vehicle direction, and torque requests from other vehicle systems. The EV ACS/ETC receives torque requests from systems such as:

- Adaptive cruise control,
- Automatic emergency braking, and
- TCS.

The EV PCM transmits the desired torque to the EPS. The EPS includes the TICM, motor current sensors, motor position sensors, and other hardware and software necessary to drive and control the motor torque. The EPS supplies current to the traction motor, which provides torque to the drivetrain.

In addition to torque requests, the EV ACS/ETC has other interfaces with the following vehicle systems.

- Brake system – regenerative braking, vehicle speed data, etc.
- Cooling system – inverter/converter cooling
- HVIL – high voltage circuit faults
- RESS – HV system status, discharge bus requests, etc.
- Occupant restraint system – crash detection

The EV ACS/ETC is also connected to the 12-volt direct current power supply, the HV power supply, and communication bus (e.g., CAN bus).

4.2.2 System Functions

The HAZOP study identifies 19 system functions for the EV ACS/ETC.

1. Command torque from the EPS.
2. Receives energy from the HV DC bus.
3. Delivers current to the traction motor.
4. Provide the APP to the EV PCM.
5. Return the AP to the at-rest (i.e., undepressed) position within the specified time.
6. Provide AP request rate limiting.
7. Communicate the delivered torque magnitude and direction to the EV PCM.
8. Return the torque output to the creep value within the specified time.[16]
9. Establish the creep torque value.[17]
10. Provide creep state control. [17]
11. Provide BTO control.
12. Store the APP and motor speed torque maps.

[16] If the EV ACS/ETC is not designed to simulate an idle creep speed, the analogous function would be to return the torque output to zero within the specified time.
[17] This function may not apply if the EV ACS/ETC is not designed to simulate an idle creep speed.

13. Provide bus capacitance discharge request to the EPS.
14. Discharge the bus capacitance.
15. Communicate with internal subsystems and external vehicle systems.
16. Provide diagnostics.
17. Provide fault detection and failure mitigation.
18. Store relevant data.
19. Provide traction motor current values.

Functions 17, 18, and 19 are shown here for completeness. Function 17 is part of the design to mitigate hazards resulting from other malfunctions in the system. The HAZOP study concludes that malfunctions derived from Function 18 would not result in vehicle-level hazards. Function 19 is part of the design implementation and may be considered by some analysts to be integral to the TICM.

4.2.3 System Malfunctions and Hazards

The application of the seven HAZOP study guidewords presented in Section 2.2.1 to each of the 19 EV ACS/ETC functions listed above results in a list of 132 malfunctions. Each of these malfunctions is assessed to determine if the malfunction could lead to one or more of the potential vehicle-level hazards.

Table 2 provides an example of how malfunctions were derived from one of the EV ACS/ETC functions. Table 3 shows the number of malfunctions identified for each of the 19 EV ACS/ETC functions. Appendix B provides the complete results of the HAZOP study.

Table 2. Derivation of Malfunctions and Hazards using the HAZOP Study (Example)

Function: Provide the APP to the EV PCM.

HAZOP Guidewords	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
Loss of function	Does not provide the APP to the FCEV PCM	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2, 3, 4) Potential uncontrolled vehicle propulsion 1, 2, 3, 4) Potential propulsion power reduction/loss or vehicle stalling 1, 2, 3, 4) Potential insufficient vehicle propulsion 1, 2) Potential insufficient vehicle deceleration 3, 4) Potential uncontrolled vehicle propulsion when the vehicle speed is zero 1, 2) Potential vehicle movement in the wrong direction
More than intended	Provides larger AP travel position than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2, 3, 4) Potential uncontrolled vehicle propulsion 3, 4) Potential uncontrolled vehicle propulsion when the vehicle speed is zero 1, 2, 3, 4) Potential propulsion power reduction/loss or vehicle stalling
Less than intended	Provides smaller AP travel position than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2, 3, 4) Potential insufficient vehicle propulsion 1, 2) Potential insufficient vehicle deceleration
Intermittent	Provides APP intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2, 3, 4) Potential uncontrolled vehicle propulsion 1, 2, 3, 4) Potential propulsion power reduction/loss or vehicle stalling 1, 2, 3, 4) Potential insufficient vehicle propulsion 1, 2) Potential insufficient vehicle deceleration 3, 4) Potential uncontrolled vehicle propulsion when the vehicle speed is zero 1, 2) Potential vehicle movement in the wrong direction
Incorrect direction	Provides AP travel position in the wrong direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2, 3, 4) Potential propulsion power reduction/loss or vehicle stalling 1, 2) Potential uncontrolled vehicle propulsion
Not requested	Provides AP travel position when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None. This condition is for unintended but correct information.
Locked function	Does not update AP travel position (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	1, 2) Potential uncontrolled vehicle propulsion 1, 2) Potential insufficient vehicle propulsion 1, 2) Potential insufficient vehicle deceleration 3, 4) Potential propulsion power reduction/loss or vehicle stalling

ON: Engine on; **D**: Drive; **R**: Reverse

Table 3. Number of Identified Malfunctions for Each HAZOP Function

HAZOP Function	Number of Identified Malfunctions
Command torque from the EPS	7
Receive energy from the HV DC bus	7
Delivers current to the traction motor	7
Provide the APP to the EV PCM	7
Return AP to the at-rest (i.e., undepressed) position within a specified time	9
Provide AP request rate limiting	7
Communicate the delivered torque magnitude and direction to the EV PCM	7
Return the torque output to the creep value within a specified time [i]	9
Establish creep torque value [ii]	7
Provide creep torque control [ii]	7
Provides BTO control	7
Stores the APP and motor speed torque maps	7
Provide bus capacitance discharge request	7
Discharge the bus capacitance	7
Communicate with internal subsystems and external vehicle systems	6
Provide diagnostics	6
Provide fault detection and failure mitigation [iii]	6
Store relevant data [iii]	6
Provide traction motor current values [iii]	6

[i] If the EV ACS/ETC is not designed to simulate an idle creep speed, the analogous function would be to return the torque output to zero within the specified time.
[ii] This function may not apply if the EV ACS/ETC is not designed to simulate an idle creep speed.
[iii] This function is only included for completeness.

4.3 Systems Theoretic Process Analysis: Step 1

4.3.1 Detailed Control Structure Diagram

Figure 7 illustrates the detailed control structure diagram used in the STPA method to represent a generic EV ACS/ETC system and its interfacing systems and components. The EV ACS/ETC components are delineated by the dashed line. The 12-volt power supply is only shown on this diagram as an effect of the driver's action on the ignition key. However, the impact of the 12-volt power supply on the system is considered in detail as part of STPA Step 2.

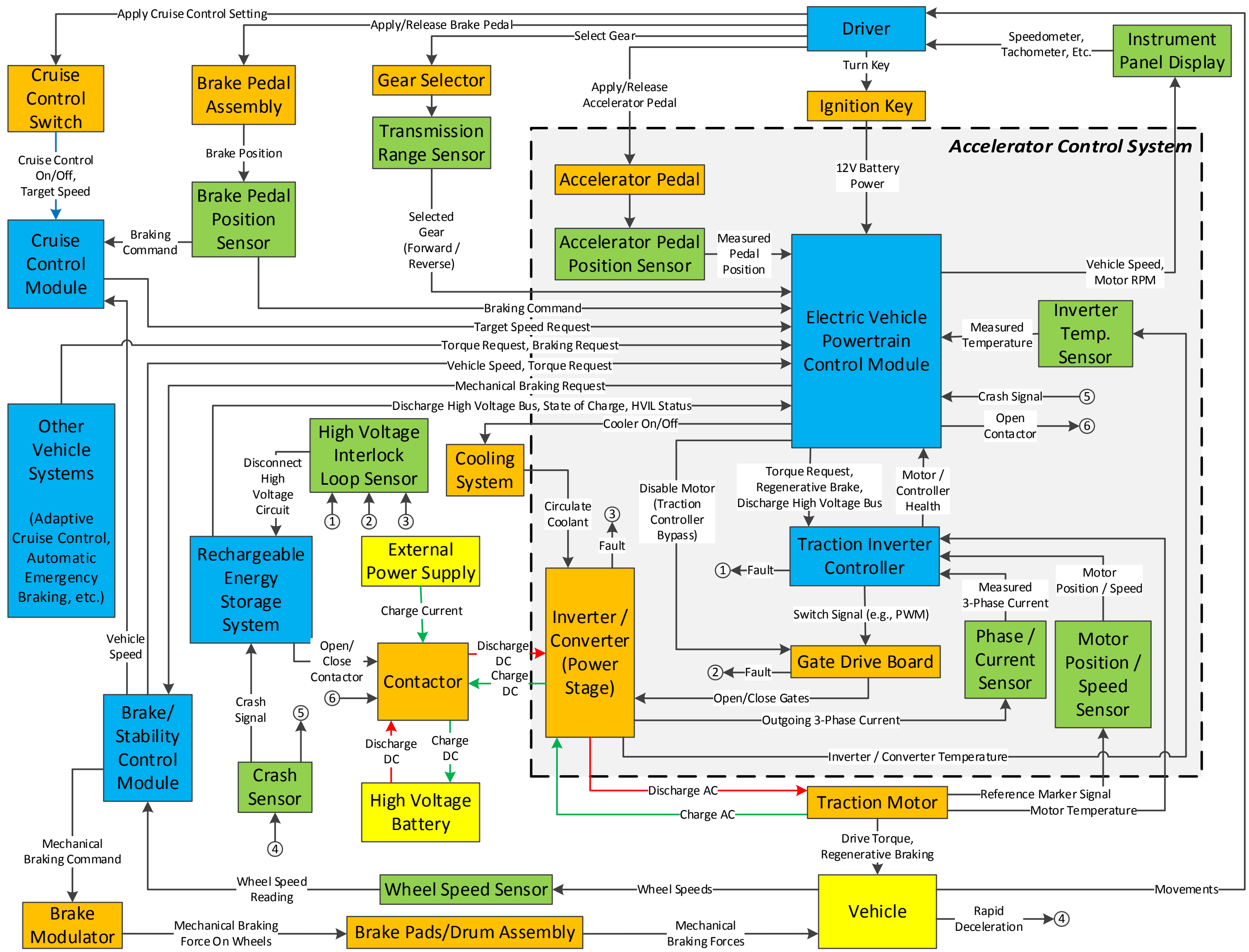


Figure 7. Detailed Control Structure Diagram for the EV ACS/ETC System

4.3.2 Vehicle-Level Loss and Initial Hazards

STPA begins by identifying specific losses that the study is trying to prevent. In the STPA method, these losses result from a combination of a hazardous state along with a worst-case set of environmental conditions [5]. The vehicle-level losses relevant to this study are a vehicle crash and electrocution.

An initial list of vehicle-level hazards is generated based on literature search and engineering experiences. As the analyst identifies UCA as part of STPA Step 1, the initial hazard list may be refined. Section 4.3.3 and Section 4.3.4 provide the details of this process. Then, the hazards generated from both the HAZOP study and STPA are synthesized to produce the hazard list shown in Table 1.

4.3.3 Control Actions and Context Variables

STPA Step 1 studies ways in which control actions in the system may become unsafe, leading to vehicle-level hazards. This study identifies 11 control actions issued by the EV PCM and two control actions issued by the TICM related to the EV ACS/ETC function. The 11 EV PCM control actions include the following:

1. Two control actions are related to mode switching. These control actions are internal to the EV PCM and result in a change in the EV PCM operating state.
   i. **Enter BTO mode** – the EV PCM issues this control action to enter an operating state that causes the driver's request for braking to override the AP command.
   ii. **Enter normal mode** – the EV PCM issues this control action to resume normal ACS/ETC operation (i.e., exit BTO mode).

   The context variable states used to analyze the mode switching control actions are listed in Table 4. The vehicle speed states in Table 4 are based on the maximum speed above which BTO must engage, as described in the 2012 NPRM for FMVSS 124. Manufacturers may elect to have lower vehicle speed threshold values.

Table 4. STPA Context Variables for the Mode Switching Control Actions

Context Variable	Context Variable States
Accelerator Pedal	Pedal is pressed
	Pedal is released
Brake Pedal	Pedal is pressed
	Pedal is released
Vehicle Speed	≥ 10 miles per hour (MPH)
	< 10 MPH

2. Two control actions are related to controlling the magnitude of the torque output from the traction motor. These control actions are issued to the TICM, which controls the current flow to the traction motor to achieve the desired amount of torque.

i. **Increase the traction motor torque** – the EV PCM issues this control action to increase the torque output from the traction motor.
ii. **Decrease the traction motor torque** – the EV PCM issues this control action to decrease the torque output from the traction motor.

These control actions assume that the traction motor torque output is in the correct direction. The context variable states used to analyze the control actions related to the traction motor torque output are listed in Table 5.

Table 5. STPA Context Variables for the Control Actions Related to Torque Magnitude

Context Variable	Context Variable States
Accelerator Pedal Position	Driver is not pressing the pedal
	Driver reduces the pedal angular position
	Driver maintains the pedal angular position
	Driver increases the pedal angular position
EV PCM Operating Mode	BTO mode
	Normal mode
	BTO transitioning to normal mode
	Normal mode transitioning to BTO mode
Torque Requests from Other Vehicle Systems	None
	Reduce torque
	Increase torque
	Both reduce and increase torque

3. Two control actions are used to controlling the direction of the torque supplied by the traction motor. As described in Section 3.3, the EV traction motor is capable of directly supplying torque in both the forward and reverse directions. These control actions are issued to the TICM, which controls the current flow to the traction motor to provide the correct direction of rotation.
   i. **Provide torque in the forward direction** – the EV PCM issues this control action to provide torque from the traction motor that propels the vehicle in the forward direction.
   ii. **Provide torque in the reverse direction** – the EV PCM issues this control action to provide torque from the traction motor that propels the vehicle in the reverse direction.

These control actions assume that the magnitude of the traction motor torque output is correct based on the inputs from the driver and other vehicle systems. The context variable states used to analyze the control actions related to the direction of the torque output from the traction motor are listed in Table 6.

Table 6. STPA Context Variables for the Control Actions Related to the Direction of Torque Output

Context Variable	Context Variable States
Gear Selector Position	Driver has selected park
	Driver has selected reverse
	Driver has selected neutral
	Driver has selected drive/low

4. Two control actions are related to requesting cooling for the inverter/converter from the vehicle's cooling system, based on the inverter/converter temperature. The EV PCM issues these control actions to maintain the inverter/converter within an allowable temperature range. [18]
   i. **Turn cooling on** – the EV PCM issues this control action to request cooling for the inverter/converter from the vehicle's cooling system. For example, this request may cause the vehicle cooling system to activate a cooling pump.
   ii. **Turn cooling off** – the EV PCM issues this control action to stop the cooling supplied to the inverter/converter.

   The specific threshold temperature value for requesting cooling depends on the design of the cooling system as well as the inverter/converter. Therefore, this analysis simply refers to a threshold value and it is up to manufacturers to specify this value for their specific design. Table 7 lists the context variable states used to analyze the request for inverter/converter cooling control action.

Table 7. STPA Context Variables for the Inverter/Converter Cooling Control Actions

Context Variable	Context Variable States
Inverter Temperature	Above Threshold Value
	At Threshold Value
	Below Threshold Value

5. One control action is related to discharging the HV bus in response to a request from the RESS. The logic for determining when to discharge the HV bus resides in the RESS control module; the EV PCM simply executes this request. The command is issued by the EV PCM to the TICM, which controls the current flow in the inverter/converter to discharge the HV bus.
   i. **Discharge the HV bus** – the EV PCM issues this control action to discharge stored energy on the HV bus.

[18] As described in Section 3.2, this report assumes that the cooling system is actively controlled (i.e., can be turned on and off).

Table 8. STPA Context Variables for the Control Action to Discharge the HV Bus

Context Variable	Context Variable States
RESS Request to Discharge HV Bus	Yes
	No

6. One control action is related to opening the contactor for the HV power supply. Depending on the vehicle design, this control action may be issued by the EV PCM or may be part of the RESS.
   i. **Open the contactor** – the EV PCM issues this control action to disconnect the RESS from the ACS/ETC in the event of a vehicle crash or when the HVIL is violated.

Table 9. STPA Context Variables for the Control Action to Open the Contactor

Context Variable	Context Variable States
Vehicle Crash Detected	Yes
	No
HVIL Status	Fault
	No Fault

7. One control action is related to requesting DC power from the RESS. This enables the RESS to arbitrate the high voltage power demands from the ACS/ETC with high voltage power requests from other vehicle systems.
   i. **Request DC Power** – the EV PCM issues this control action to inform the RESS of the power required to meet the driver's torque request.

Table 10. STPA Context Variables for the Control Action to Request DC Power

Context Variable	Context Variable States
Request DC Power	Torque Requested
	Torque Not Requested

There are two control actions issued by the TICM:

1. Two control actions are related to controlling the current supply to the traction motor. The TICM issues these control actions to the gate drive board, which operates the transistors in the inverter/converter to regulate the HV power supply to flow to the traction motor.
   i. **Increase current supply to the traction motor** – the TICM issues this control action to increase the current supply to the traction motor, resulting in an increase in torque output.
   ii. **Decrease current supply to the traction motor** – the TICM issues this control action to decrease the current supply to the traction motor, resulting in a decrease in torque output.

Table 11. STPA Context Variables for Control Actions Regulating Current Supply

Context Variable	Context Variable States
EV PCM Torque Request	Increase torque
	Decrease torque

4.3.4 Unsafe Control Actions

The six UCA guidewords (Figure 4) are applied to each combination of context variable states for the 13 control actions listed in the previous section. Some control actions only have a single context variable. In these cases, the UCA guidewords are applied directly to the control action for each of the individual context variable states (i.e., there are no combinations of context variable states).

The analysts then assess whether the control action would result in a vehicle-level hazard, given the particular combination of context variable states. Table 12 shows how this is done for one of the control actions – "Enter BTO Mode." Appendix C contains all of the UCA assessment tables for the 13 control actions studied.

Table 12. UCA Assessment Table (Example)

Control Action: Enter BTO Mode

Context Variables			**Guidewords for Assessing Whether the Control Action May be Unsafe**								
Accelerator Pedal	**Brake Pedal**	**Vehicle Speed**	**Not provided in this context**	**Provided in this context**	**Provided, but duration is too long**	**Provided, but duration is too short**	**Provided, but the intensity is incorrect (too much)**	**Provided, but the intensity is incorrect (too little)**	**Provided, but executed incorrectly**	**Provided, but the starting time is too soon**	**Provided, but the starting time is too late**
Not Pressed	Not Pressed	<10 MPH		H4	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Not Pressed	Not Pressed	≥10 MPH		H4	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Not Pressed	Pressed	<10 MPH			N/A	N/A	N/A	N/A			
Not Pressed	Pressed	≥10 MPH			N/A	N/A	N/A	N/A			
Pressed	Not Pressed	<10 MPH		H4	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Not Pressed	≥10 MPH		H4	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Pressed	<10 MPH		H4	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Pressed	≥10 MPH	H1		N/A	N/A	N/A	N/A	H1	H4	H1

Vehicle-Level Hazards:

H1: Potential uncontrolled vehicle propulsion
H4: Potential propulsion power reduction/loss or vehicle stalling

Each cell in Table 12 represents a UCA. For example, the last row and fourth column of the table may generate the following UCA:

- *The EV PCM does not issue the Enter BTO Mode command when:*
    - *the AP is pressed,*
    - *the BP is pressed, and*
    - *the vehicle speed is 10 mph or greater.*

  This may result in Uncontrolled Vehicle Propulsion.

However, writing each cell of the table into a UCA statement will create a very long list of UCAs and many of these UCAs would have overlapping logical states. Therefore, this study further applies the Quine-McCluskey minimization algorithm [8] to consolidate and reduce the number of UCA statements.

Overall, STPA Step 1 identifies a total of 95 UCAs for the generic EV ACS/ETC system studied. The breakdown of these UCAs by control action is provided in Table 13.

Table 13. Number of Identified UCAs for Each STPA Control Action

STPA Control Action	Number of Identified UCAs
Enter BTO Mode	6
Enter Normal Mode	4
Increase the Traction Motor Torque	12
Decrease the Traction Motor Torque	24
Provide Torque in the Forward Direction	4
Provide Torque in the Reverse Direction	4
Turn Cooling On	5
Turn Cooling Off	2
Discharge the HV Bus	5
Open Contactor	7
Request DC Power	6
Increase Current Supply to the Traction Motor	8
Decrease Current Supply to the Traction Motor	8

Appendix D presents a complete list of the UCAs identified in STPA Step 1. Table 14 and Table 15 show examples of UCAs for the EV PCM and their associated vehicle-level hazards. Table 16 shows an example of a UCA for the TICM and its associated vehicle-level hazard.

Table 14. STPA UCA Statement for Traction Motor Torque Magnitude Control (Example)

Hazard	Potential uncontrolled vehicle propulsion
UCA (Example)	The EV PCM issues the Increase Torque command when the driver reduces or maintains the angular position of the AP, or is not pressing the AP.

Table 15. STPA UCA Statement for the Direction of Torque Output Control (Example)

Hazard	Potential vehicle movement in an unintended direction Potential uncontrolled vehicle propulsion
UCA (Example)	The EV PCM provides torque in the reverse direction when the driver selects park, neutral, or drive/low.

Table 16. STPA UCA Statement for Traction Motor Current Control (Example)

Hazard	Potential propulsion power reduction or loss or vehicle stalling
UCA (Example)	The TICM decreases the current to the traction motor when the EV PCM requests a decrease in torque, but the current is decreased by too much.

5 RISK ASSESSMENT

This study follows the risk assessment approach in ISO 26262. The assessment derives the ASIL for each of the seven identified vehicle-level hazards.

5.1 Automotive Safety Integrity Level Assessment Steps

The ASIL assessment contains the following steps.

1. Identify vehicle operational situations
2. For each identified vehicle-level hazard, apply the ISO 26262 risk assessment framework:
    a. Assess the probability of exposure (E) to the operational situation.
    b. Identify the potential crash scenario.
    c. Assess the severity (S) of the harm to the people involved if the crash occurred.
    d. Assess the controllability of the situation and the vehicle in the potential crash scenario.
    e. Look up the ASIL per ISO 26262 based on the exposure, severity, and controllability.
3. Assign the worst-case ASIL to the hazard.

5.1.1 Vehicle Operational Situations

Operational Situations are scenarios that can occur during a vehicle's life (Part 1 Clause 1.83 in ISO 26262). This study generates 69 vehicle operational situations that are provided in Appendix E. Below are two examples:

- Driving at high speeds (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.

- Driving in the city with heavy traffic and pedestrians present, stop-and-go driving above 16 kph, low visibility, and slippery road conditions.

Sixty-six of these 69 scenarios are described by 10 variables and their states as shown in Table 17. These variables and their states are identified following current industry practices.

Table 17. Variables and States for Description of Vehicle Operational Situations

Vehicle Speed	Very high speed (V>130 kph)	**Rail Road Track**	Near a rail road track
	High speed (100 kph<V≤130 kph)		Over a rail road track
	Medium speed (40 kph<V≤100 kph)		Not near or over a rail road track
	Inside city (16 kph<V≤40 kph)	**Road Condition**	Slippery
	Inside city very low speed (V≤16 kph)		Good
	Parking lot or drive way (V=0)	**Driving Maneuver**	Stop and go (applicable only at low speed)
	In a traffic stop (V=0)		Overtaking another vehicle
Traffic	Heavy		Evasive maneuver deviating from desired path
	Light		Going straight without special driving maneuver or not moving
Visibility	Low/bad	**Brake Pedal**	Applied
	Good		Not applied
Pedestrian Presence	Negligible	**PRNDL**	Park
	Present		Reverse
	Heavy		Neutral
Country Road	Yes		Drive
	No		Drive with hill hold on

The hazard "Potential Electric Shock" does not result from the same operating scenarios as the vehicle motion related hazards. Therefore, the variables in Table 17 were not used to determine the ASIL for "Potential Electric Shock." Instead, three additional operating scenarios were developed to describe this hazard:

1. A person is handling the HV wires when the vehicle is on, but not driving. The vehicle may be on the road, in the garage, or in storage.
2. The vehicle is in a crash event with the HV bus exposed. The vehicle occupants or first responders are in or around the vehicle.
3. The vehicle is moving and enters a safe state that requires the discharge of the bus capacitance.

5.1.2 Automotive Safety Integrity Level Assessment

ISO 26262 assesses the ASIL of identified hazards according to the severity, exposure, and controllability (Part 3 in ISO 26262).

Exposure is defined as the state of being in an operational situation that can be hazardous if coincident with the failure mode under analysis (Part 1 Clause 1.37 in ISO 26262). Table 18 is directly copied from ISO 26262 Part 3 Table 2.

Table 18. Exposure (E) Assessment

	Class				
	E0	**E1**	**E2**	**E3**	**E4**
Description	Incredible	Very low probability	Low probability	Medium probability	High probability

Severity is defined as the estimate of the extent of harm to one or more individuals that can occur in a potentially hazardous situation (Part 1 Clause 1.120 in ISO 26262). Table 19 is directly quoted from ISO 26262 Part 3 Table 1.

Table 19. Severity (S) Assessment

	Class			
	S0	**S1**	**S2**	**S3**
Description	No injuries	Light and moderate injuries	Severe and life-threatening injuries (survival probable)	Life-threatening injuries (survival uncertain), fatal injuries

Table 20 is an acceptable approach to assess severity shown in ISO 26262 (Part 3 Clause 7.4.3.2 and Annex B Table B.1).

Table 20. Acceptable Approach to Assess Severity (S)

	Class of Severity			
	S0	**S1**	**S2**	**S3**
Reference for single injuries (from AIS scale)	• AIS 0 and Less than 10% probability of AIS 1-6 • Damage that cannot be classified safety-related	More than 10% probability AIS 1- 6 (and not S2 or S3)	More than 10% probability of AIS 3-6 (and not S3)	More than 10% probability of AIS 5-6

AIS: Abbreviated Injury Scale

ISO 26262 defines controllability as the "ability to avoid a specified harm or damage through the timely reactions of the persons[19] involved, possibly with support from external measures" (Part 1 Clause 1.19 in ISO 26262). Table 21 is ISO 26262's approach to assessing controllability (Table 3 in Part 3 in ISO 26262 [2]). Table 22 shows how ASIL is assessed based on exposure, severity, and controllability (Table 4 in Part 3 of ISO 26262).

[19] People involved can include the driver, passengers, or persons in the vicinity of the vehicle's exterior.

Table 21. Controllability (C) Assessment

	Class			
	C0	**C1**	**C2**	**C3**
Description	Controllable in general	Simply controllable	Normally controllable	Difficult to control or uncontrollable

Table 22. ASIL Assessment

Severity Class	Probability Class	Controllability Class		
		C1	**C2**	**C3**
S1	**E1**	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	**E1**	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	**E1**	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

QM: Quality Management

Below are two examples of how this study assesses the ASIL for each hazard under identified operational situations.

Example 1:

- **Hazard:** Potential uncontrolled vehicle propulsion
- **Operational situation:** Driving at high speeds (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.
- **ASIL assessment:**
  - Exposure = **E4** (This operational situation occurs often, > 10 percent of the vehicle average operating time.)
  - Crash scenario: The vehicle runs into another vehicle in a rear-end crash or an object by departing the road.

        - Severity = **S3** (Front/rear collision or frontal impact with an object with passenger compartment deformation. More than 10 percent probability of AIS 5-6.)
        - Controllability = **C3** (This is the situation with rear-wheel drive vehicles. While at high speeds, the driver's reaction is braking. This situation is difficult to control. For front-wheel drive vehicles, Controllability = C2. The rear-wheel drive vehicles represent the more severe ASIL assessment.)
    - ASIL = **D**

Example 2:

- **Hazard**: Potential propulsion power reduction/loss or vehicle stalling
- **Operational situation**: Driving at very high speeds (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.
- **ASIL assessment:**
    - Exposure = **E2** (Operational situation occurs about 1 percent of the operating time of the vehicle.)
    - Crash scenario: Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.
    - Severity = **S3** (Front/rear collision with passenger compartment deformation. More than 10 percent probability of AIS 5-6.)
    - Controllability = **C3** (While at high speeds, the driver's reaction is to steer the vehicle out of traffic and apply additional braking if necessary. This situation is hard to control.)
- ASIL = **B**

Appendix F contains the full ASIL assessment table.

5.2 Automotive Safety Integrity Level Assignment for Each Hazard

The ASIL assessment for each operational situation forms the basis for the ASIL assignment to each of the seven vehicle-level hazards. ISO 26262 requires the most severe ASIL be chosen for each hazard. Table 23 shows the resulting ASIL values for each hazard.

Table 23. Vehicle-Level Hazards and Corresponding ASIL

	Hazard	ASIL
H1	Potential uncontrolled vehicle propulsion	D
H1.a	Potential uncontrolled vehicle propulsion when the vehicle speed is zero	B[i]
H2	Potential insufficient vehicle propulsion	C[ii]
H3	Potential vehicle movement in an unintended direction	C
H4	Potential propulsion power reduction/loss or vehicle stalling	D
H5	Potential insufficient vehicle deceleration	C[ii]
H6	Potentially allowing driver's command to override active safety systems[iv]	D[iii]
H7	Potential electric shock	B

i. *For certain control system features that only operate when vehicle speed is zero, the ASIL of this hazard is B. This ASIL is based on a reduced severity from impact occurring at a low speed (i.e., impact occurs before the vehicle reaches high speeds). An example of such a feature is the hill-holder that prevents a car from rolling backward on a hill when the BP is released.*
ii. *The ASIL assessment for this hazard varied among safety analysts in the absence of objective data. This study finds that objective data is not readily available for the assessment of the three dimensions used to determine the ASIL--severity, exposure, and controllability.*
iii. *The effects of H6 are contained in H1, H2, H4, and H5. Therefore, H6 takes on the most severe ASIL value among those four hazards.*
iv. *This hazard may not apply in ACS/ETC systems designed to give driver's command priority over all active safety systems.*

6 VEHICLE-LEVEL SAFETY GOALS

Based on the hazard analysis and risk assessment, the safety goals (i.e., vehicle-level safety requirements) are established as listed in Table 24. Each safety goal (SG) corresponds to the potential hazards in Table 23.

Table 24. Safety Goals with ASIL

ID	Safety Goals	ASIL
SG 1	Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than To-Be-Determined (TBD) m/s^2 for a period greater than TBD seconds is to be mitigated in accordance with the identified ASIL.	D
SG 1a	Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 with zero speed at start is to be mitigated in accordance with the identified ASIL.	B
SG 2	Potential insufficient vehicle propulsion[i] is to be mitigated in accordance with the identified ASIL.	C[ii]
SG 3	Potential vehicle movement in the wrong direction is to be mitigated in accordance with the identified ASIL.	C
SG 4	Potential propulsion power loss/reduction resulting in vehicle deceleration greater than TBD m/s^2 is to be mitigated in accordance with the identified ASIL.	D
SG 5	Potential insufficient vehicle deceleration[i] is to be mitigated in accordance with the identified ASIL.	C[ii]
SG 6	The ACS/ETC control algorithm is to choose the torque command that has the highest priority for safety in accordance with the identified ASIL.	D
SG 7	Potential electric shock is to be mitigated in accordance with the identified ASIL.	B

i. *Insufficient vehicle propulsion/deceleration is defined as the vehicle deviating from the correctly functioning speed increase/decrease profile under any operating conditions by more than TBD sigma. These hazards specifically relate to speed increases or decreases that result from the driver increasing or decreasing the angular position of the AP.*

ii. *The ASIL assessment for the hazard associated with this safety goal varied among safety analysts in the absence of objective data. This study finds that objective data are not readily available for the assessment of the three dimensions used to determine the ASIL--severity, exposure, and controllability.*

7 SAFETY ANALYSIS

This study performs two types of safety analysis — Functional FMEA and STPA.

7.1 Functional Failure Mode and Effects Analysis

This study carried out Functional FMEA for hazards H1, H1a, H2, H3, H4, H5, and H7 (Table 1). Because the consequences of H6 are captured in hazard H1, H2, H4, and H5, a separate Functional FMEA was not performed for H6. Overall, the Functional FMEA covers 4 ACS/ETC subsystems and 6 interfacing systems. The Functional FMEA identifies 30 failure modes and 90 potential causes of failures. Table 25 shows the number of identified causes for each of the failure modes.

Table 25. Number of Identified Faults by Failure Mode

System / Subsystem	Failure Mode	Number of Identified Faults
AP Assembly	APP value interpreted higher than actual	19
	APP value interpreted lower than actual	19
	AP is not returned to idle position correctly	1[i]
	APP communicates with EV PCM incorrectly	19
EV PCM	Commands a larger amount of torque than requested by the driver	20
	Commands a smaller amount of torque than requested by the driver	20
	Commands torque in the wrong direction	20
	Misinterprets the APPS input	20
	APP-Torque map corrupted	18
	APP rate limiting fault (over-limiting/under-limiting)	20
	Incorrectly establishes idle torque [ii]	20
	BTO control fault	5
	Miscommunicates with internal subsystems	4
	Miscommunicates with external systems	3
	Fails to command a discharge of the HV bus capacitance	19
	Diagnostics fault	1[iii]
EPS	Delivers more torque than requested by the EV PCM	28
	Delivers less torque than requested by the EV PCM	30
	Delivers torque in the opposite direction of the EV PCM command	28
	Fails to maintain idle torque [ii]	30
	Does not discharge the HV bus capacitance	21
Motor speed sensor	Provides incorrect motor speed to EV PCM	1
Vehicle speed sensor	Provides incorrect vehicle speed to EV PCM	1
Vehicle direction sensor	Provides incorrect vehicle direction to EV PCM	1
BPPS	Provides incorrect input to EV PCM	1
Other interfacing vehicle systems	Provides request for incorrect (more) propulsion torque	1
	Provides request for incorrect (less) propulsion torque	1
RESS controller	Communicates incorrect state of charge to EV PCM	1
	Incorrectly communicates HV bus capacitance discharge request to EV PCM	1
Vehicle communication system (e.g., CAN bus)	Communication messages corrupted during transfer within the ACS/ETC, or between the ACS/ETC and interfacing vehicle systems	1
Note: Some faults may potentially result in multiple failure modes. [i] These faults are mechanical in nature and are outside the scope of ISO 26262. [ii] This failure mode only applies to designs where the EV PCM simulates an idle creep speed. [iii] This failure mode is only considered as part of a multiple point failure analysis.		

The Functional FMEA also identified the possibility of faults within interfacing vehicle systems. However, as described in Section 3.2, other vehicle systems are assumed to be operating correctly. Therefore, these faults are not included in Table 25.

Table 26 shows a few examples of the Functional FMEA. Appendix G provides the complete Functional FMEA results.

Table 26. Sample Functional FMEA for Potential Uncontrolled Vehicle Propulsion (H1) (Not Complete)

System/Subsystem	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code (DTC)
EV PCM	Commands a larger amount of torque than requested by the driver	EV PCM fault:	Three-level monitoring		EV PCM Fault
		Hardware fault (sensors, integrated circuits, circuit components, circuit boards…)		Hardware diagnostics	EV PCM Fault
		Internal connection fault (short or open)		Hardware diagnostics	EV PCM Fault
		Break in EV PCM input/output connections	Critical messages/data transfer qualification	Stuck Open/Short	I/O Fault
		Short in EV PCM I/O connections to ground or voltage	Critical messages/data transfer qualification	Stuck Open/Short	I/O Fault
		Short in EV PCM I/O connections to another connection	Critical messages/data transfer qualification	Stuck Open/Short	I/O Fault
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three-Level Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three-Level Monitoring		System Fault

7.2 Systems Theoretic Process Analysis: Step 2

STPA Step 1 identifies UCAs and vehicle-level hazards. The goal of STPA Step 2 is to identify CFs that may lead to the UCAs, which then may result in one or more of the 7 vehicle-level hazards. Each of the 26 CF guidewords and the detailed causes (Appendix A) are applied to the components and connections depicted in the STPA control structure diagram (Figure 7). Specifically, the STPA Step 2 analysis includes the following components and connections.

- ACS/ETC components – defined as any component within the ACS/ETC scope boundary
- ACS/ETC connections – defined as any interaction entirely within the ACS/ETC scope boundary (e.g., a connection between two components)
- Interfacing connection – defined as an interaction between an ACS/ETC system component and a component outside the ACS/ETC system scope boundary
- Interfacing components – defined as a component where an interfacing interaction originates

The choices of these components and connections enable the analysis to focus on the defined scope of this study while still considering critical interfaces between the ACS/ETC system and other vehicle systems. For example, the vehicle speed signal from the brake/stability system is considered by analyzing the brake/stability control module and the connection between the brake/stability control module and the EV PCM. However, other failures in the brake system, such as faults in the wheel speed sensor, are not considered as part of this study.

Each identified CF relates to one or more of the UCAs identified in STPA Step 1, providing a traceable pathway from CFs up to vehicle-level hazards (Figure 8).

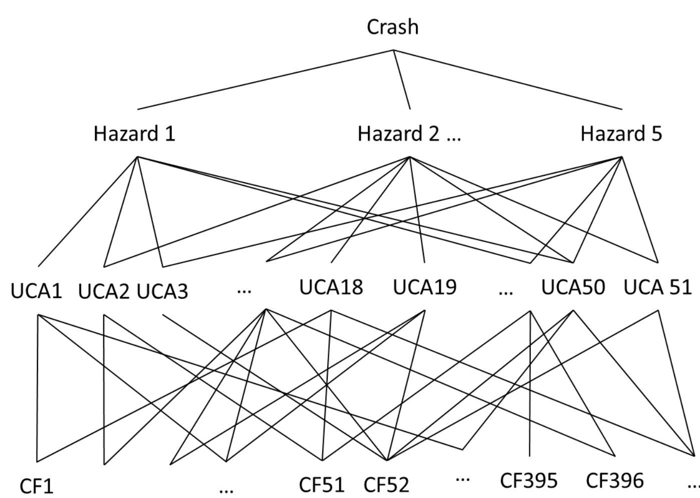


Figure 8. Traceability in STPA Results

The STPA Step 2 analysis identifies a total of 1,048 unique CFs. Below is a breakdown of CFs by the type of UCAs they affect. As shown in Figure 8, each CFs can potentially lead to more than one type of UCA. Therefore the breakdown below exceeds the number of unique CFs.

- 200 CFs may lead to UCAs related to mode switching
- 224 CFs may lead to UCAs related to commanding the traction motor torque output
- 444 CFs may lead to UCAs related to converting the torque request to a current
- 84 CFs may lead to UCAs related to providing torque in the requested direction
- 165 CFs may lead to UCAs related to controlling the inverter/converter temperature
- 203 CFs may lead to UCAs related to discharging the HV bus
- 55 CFs may lead to UCAs related to opening the HV contactor
- 55 CFs may lead to UCAs related to requesting DC power

Table 27 shows a breakdown of the identified CFs by the 26 CF guidewords applied in this study.

Table 27. Number of Identified Causal Factors by Causal Factor Category

Causal Factor Category	**Number of Identified Causal Factors**
Actuation delivered incorrectly or inadequately: Actuation delayed	2
Actuation delivered incorrectly or inadequately: Hardware faulty	4
Actuation delivered incorrectly or inadequately: Incorrect connection	3
Actuator inadequate operation, change over time	27
Conflicting control action	2
Controlled component failure, change over time	3
Controller hardware faulty, change over time	30
Controller to actuator signal ineffective, missing, or delayed: Communication bus error	24
Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	37
Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	12
External control input or information wrong or missing	12
External disturbances	317
Hazardous interaction with other components in the rest of the vehicle	301
Input to controlled process missing or wrong	2
Output of controlled process contributes to system hazard	3
Power supply faulty (high, low, disturbance)	33
Process model or calibration incomplete or incorrect	19
Sensor inadequate operation, change over time	31
Sensor measurement delay	5
Sensor measurement inaccurate	5
Sensor measurement incorrect or missing	7
Sensor to controller signal inadequate, missing, or delayed: Communication bus error	38
Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	58
Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	20
Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	53

Appendix H provides the complete list of CFs. Table 28 shows two examples of CFs for a UCA related to commanding a torque increase.

Table 28. Examples of Causal Factors for a Torque Increase UCA

Hazard	Potential uncontrolled vehicle propulsion	
UCA (Example)	The EV PCM issues the Increase Torque command when: • the EV PCM is in BTO mode or is transitioning from normal mode to BTO mode.	
Potential Causal Factors (Examples)	**Component**	**Potential Causal Factor**
	EV PCM	Electromagnetic interference or electrostatic discharge from other vehicle components could affect the EV PCM.
	EV PCM	The EV PCM may respond to requests from other vehicle systems to increase the torque output while the EV PCM is in BTO mode or is transitioning from normal mode to BTO mode.

- The first CF describes an interaction between vehicle components, where EMI or ESD generated by another vehicle component (e.g., the traction motor) affects the function of the EV PCM.
- The second CF describes a flaw in the software logic design where the EV PCM responds to a request to increase the traction motor torque from another vehicle system while the EV PCM is in BTO mode or is transitioning into BTO mode.

Table 29 shows three examples of CFs for a UCA related to decreasing the current supply to the traction motor.

Table 29. Examples of Causal Factors for a UCA for Decreasing the Current Supply

Hazard	Potential propulsion power reduction/loss or vehicle stalling	
UCA (Example)	The TICM decreases the current to the traction motor when: • the EV PCM requests a decrease in torque, but the current is decreased by too much.	
Potential Causal Factors (Examples)	**Component**	**Potential Causal Factor**
	Motor Position / Speed Sensor to TICM	Moisture, corrosion, or contamination could affect the connection terminals of the motor position/speed sensor or the TICM, resulting in an incorrect motor position/speed reported to the TICM.
	TICM	The TICM may incorrectly think there is a problem with the traction motor (e.g., over-temperature).
	Motor Position/Speed Sensor	The reporting frequency of the motor position/speed sensor may be too low.

- The first CF describes moisture or other contamination affecting the connection between the motor position speed sensor and TICM. If the TICM has the incorrect motor position or speed information, this could affect how the TICM computes the current required by the traction motor.

- The second CF describes an error in the TICM process model where the TICM software logic incorrectly thinks that there is a fault in the traction motor. The TICM may attempt to shut down the motor or limit the motor torque output, resulting in decreasing the current supply by too much.
- The third CF describes a delay in the transmission of critical sensor data to the TICM. If the TICM does not receive the motor position or speed data in a timely manner and continues to operate using the old data, the TICM may continue to decrease the current supplied to the motor.

8 FUNCTIONAL SAFETY CONCEPT

The objective of the functional safety concept is to derive a set of functional safety requirements from the safety goals, and to allocate them to the preliminary architectural elements of the system, or to external measures (Part 3 Clause 8.1 in ISO 26262). Figure 9 illustrates how the functional safety concept takes into consideration the results from the safety analysis; applies safety strategies, industry practices, and engineering experiences; and derives a set of safety requirements following the established process in ISO 26262.

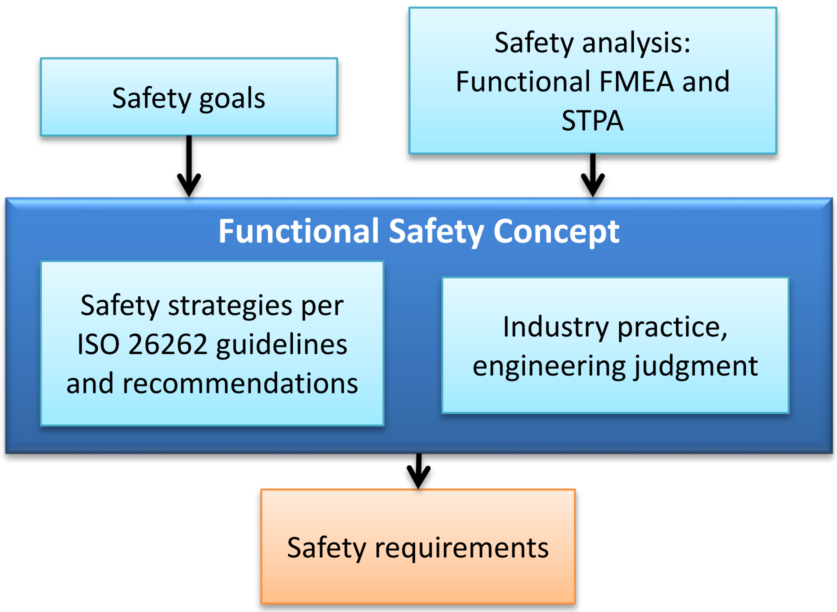


Figure 9. Functional Safety Concept Process

8.1 Safety Strategies

As stated in ISO 26262 Part 3 Clause 8.2, "*the functional safety concept addresses:*

- *Fault detection and failure mitigation;*
- *Transitioning to a safe state;*
- *Fault tolerance mechanisms, where a fault does not lead directly to the violation of the safety goal(s) and that maintains the item in a safe state (with or without degradation)*
- *Fault detection and driver warning to reduce the risk exposure time to an acceptable interval (e.g., engine malfunction indicator lamp, anti-lock brake fault warning lamp);*
- *Arbitration logic to select the most appropriate control request from multiple requests generated simultaneously by different functions.*"

Typical safety strategy elements may include the following:

1. Ensure that the system elements are functioning correctly.
2. Ensure that the critical sensors' inputs to the main controller are valid and correct (redundant measurements paths).
3. Validate[20] the health of the main controller (using an auxiliary processor).
4. Ensure the validity and correctness[21] of critical parameters (mitigate latent faults through periodic checks).
5. Ensure the validity and correctness of the critical communication signals internal and external to the ACS/ETC (quality factors[22]).
6. Ensure the correct torque, in terms of magnitude and direction, is delivered to the drivetrain with the correct timing.
7. Ensure the health and sanity of the BTO control algorithm.
8. Ensure that low-voltage power is available until the safe state is reached under all safety hazards conditions.
9. Mitigate the safety hazards when an unsafe condition is detected.
10. Ensure that the safe state is reached on time when a hazard is detected.
11. Ensure driver warnings are delivered when an unsafe condition is detected.
12. Ensure the correctness and timeliness of the arbitration strategy.

8.2 Example Safe States

A safe state may be the intended operating mode, a degraded operating mode, or a switched off mode (Part 1 Clause 1.102 of ISO 26262). The developer of the functional safety concept attempts to maximize the availability of the item while ensuring the safety of the vehicle operation. Therefore, careful consideration is given to selecting the safe states in relation to the potential failure modes.

The safe states for the EV ACS/ETC are either full operation (full torque availability), degraded operation (0 < Torque < Full), or switched off mode (zero torque). The degraded operation may include different levels depending on the potential failure mode.

For example, in cases where the APPS signal is good, but cannot be confirmed, the safe state may allow full torque but at a ramp rate slower than normal to give the driver more time to react in case of unintended vehicle behavior. On the other hand, if the APPS signal is unreliable but the vehicle can still be controlled by the brakes and the EPS, the EV PCM may allow a torque level higher than creep torque.

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[20] "Validate" means to ensure that the value of a parameter or the state of an element falls within a valid set of values or states.

[21] "Correctness" means that the value of a parameter is the correct one from the valid set.

[22] Quality factors refer to techniques for error detection in data transfer and communication including checksums, parity bits, cyclic redundancy checks, error correcting codes, etc.

Safe states may include, but not limited to, the following states commonly used in the automotive industry:

- Safe State 1: Disable input from other vehicle systems, such as ACC and AEB.
- Safe State 2: Limit the maximum allowable propulsion torque to the propulsion torque level that was computed at the instant immediately prior to when the fault occurred.
- Safe State 3: Slow torque ramp rate in response to AP input (e.g., single APPS fault)
- Safe State 4: Torque produced without AP input; speed limited to TBD (> creep) mph (e.g., two APPS faults; EV PCM fault with EPS still able to control throttle)
- Safe State 5: Torque produced at zero AP input value of the torque map (e.g., two APPS faults plus BPPS fault)
- Safe State 6: Zero torque output (e.g., vehicle disabled; system is unable to mitigate the hazards or ensure Safe States 1-5).
- Safe State 7: Disconnection of the HV bus from the RESS.

The safe states listed above describe propulsion reduction (Safe States 2, and 4-6) or deviations from the specified speed decrease or increase profiles (Safe State 3). While these vehicle responses may be similar to vehicle behaviors resulting from the identified hazards H2, H4, H5, and H6, there are key differences:

- The propulsion reduction or modified speed decrease/increase profiles are controlled when entering a safe state, while the hazards describe uncontrolled changes in propulsion (e.g., changes may not be smooth or consistent).
- When entering a safe state, the driver is informed that the vehicle is in a degraded operating state and can take appropriate action. The driver may not be notified of the degraded operating state when hazard H2, H4, H5, or H6 manifests.

8.3 Example Driver Warning Strategies

The following is an example of driver warning strategies commonly seen in the automotive industry:

- Amber Light: Potential violation of a safety goal is detected, but the probability of violating the safety goal is moderate (e.g., single APPS fault, BTO algorithm fault regardless of the need to execute the BTO algorithm)
- Red Light: Potential violation of a safety goal is detected and probability of violating the safety goal is high (e.g., AP torque map corruption, AP or BP communication/data transfer fault), or a violation of a safety goal is detected
- Chime: Audible notification of the driver is implemented whenever the conditions for the red-light driver warning are identified. The chime may continue until the fault is removed.

- Messages: Messages are displayed to the driver when the red-light driver warning is issued. Manufacturers may also elect to display messages in other situations, such as when the amber-light driver warning is issued. The messages include instructions to the driver, such as exiting or staying away from the vehicle.
- Haptic warning: Haptic warnings may be an additional driver warning strategy. Dashboard lights and audible chimes are commonly used in conjunction with haptic warning. It may be beneficial to assess the drivers' reactions to haptic warning at the same time the system attempting to reach a safe state and degraded operation mode.

9 APPLICATUION OF THE FUNCTIONAL SAFETY CONCEPT

This study uses the example safety goals identified for the generic EV ACS/ETC system introduced in this research and exercises the functional safety concept process depicted on Figure 9. Through this process, this study identifies a total of 202 illustrative safety related engineering requirements for the concept ACS/ETC system and its components.[23]

These include 112 ACS/ETC system and component functional safety requirements identified by following the Concept Phase (Part 3) in the ISO 26262 standard. Sections 9.1 and 9.2 present these findings.

Furthermore, this study identifies an additional 90 safety requirements related to the generic ACS/ETC system and components based on the use of STPA and the additional safety strategies suggested in MIL-STD-882E [3]. These 90 requirements are out of the scope of the Functional Safety Concept in ISO 26262 (Part 3 of the standard). However, the subsequent parts in ISO 26262 — Systems Engineering (Part 4), Hardware Development (Part 5), and Software Development (Part 6) — cascade the Functional Safety Concept requirements into additional development-specific safety requirements, and may capture these additional safety requirements. Section 9.3 presents these additional 90 requirements.

9.1 Example Vehicle-Level Safety Requirements (Safety Goals)

Vehicle-level safety requirements for the generic EV ACS/ETC system correspond to the example safety goals presented in Table 24. The safety goals are summarized below, along with the recommended safety strategies.

SG 1: Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 is to be mitigated in accordance with ASIL D classification.

SG 1a: Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 with zero vehicle speed at start is to be mitigated in accordance with ASIL B classification.

SG 2: Potential insufficient vehicle propulsion is to be mitigated in accordance with ASIL C classification.

- Insufficient vehicle propulsion is defined as the vehicle deviating from the correctly functioning speed increase profile under any operating conditions (e.g., when the driver increases the angular position of the AP) by more than TBD sigma.

[23] All requirements presented in this section are intended to illustrate a comprehensive set of requirements that could be derived from the safety analysis results. These safety requirements are not intended to represent NHTSA's official position or requirements on an ACS/ETC system.

SG 3: Potential vehicle movement in the wrong direction is to be mitigated in accordance with ASIL C classification.

SG 4: Potential propulsion power loss/reduction resulting in vehicle deceleration exceeding the driver's intent by TBD m/s² ***is to be mitigated in accordance with ASIL D classification.***

SG 5: Potential insufficient vehicle deceleration is to be mitigated in accordance with ASIL C classification.

- Insufficient vehicle deceleration is defined as the vehicle deviating from the correctly functioning speed decrease profile under any operating conditions (e.g., when the driver reduces the angular position of the AP) by more than TBD sigma.

SG 6: The ACS/ETC control algorithm is to choose the torque command that has the highest priority for safety in accordance with ASIL D classification.

SG 7: Potential electric shock is to be mitigated in accordance with ASIL B classification.

The following outlines the framework used to derive the safety requirements for each of the example safety goals listed above:

- The ACS/ETC is to prevent or detect faults and failures that could lead to vehicle-level hazards that the safety goals intend to mitigate.
- The ACS/ETC is to prevent all failures that lead to the initiation of a propulsion torque increase or decrease when a change in propulsion torque is not requested by the driver or other vehicle systems.
- The ACS/ETC is to detect all faults in requests to modify the propulsion torque issued by other vehicle systems.
- The ACS/ETC is to acknowledge all faults communicated by other vehicle systems that may prevent the vehicle from achieving the intended increase or decrease in speed, including faults communicated by systems such as the brake/stability control system, AEB, and ACC.
- If a failure that could lead to the vehicle-level hazards occurs, the ACS/ETC is to transition into a safe state within the fault tolerant time interval.
  - The FTTI is to be set based on established industry data.
  - In the absence of data, the safe state is to be reached as fast as the technology used can diagnose the fault and trigger the system actions.
  - The safe state is to correspond to the failure.
- If a failure that could lead to the vehicle-level hazards occurs, a warning is to be sent to the driver and any actions required by the driver are to be communicated to him or her.

9.2 EV ACS/ETC System and Components Functional Safety Requirements

Following the Concept Phase (Part 3) in the ISO 26262 standard, this study identifies 112 example functional safety requirements for the generic EV ACS/ETC system and its components. The distribution of these requirements is as follows.

1. General EV ACS/ETC System – 11 requirements
2. AP Assembly – 8 requirements
3. EV PCM – 49 requirements
4. EPS – 28 requirements
5. Communication Signals – 5 requirements
6. Power Supply (low and high voltage) – 6 requirements
7. Interfacing Systems – 5 requirements

Table 30 shows examples of safety requirements associated with the EV PCM and how they are developed, and how the vehicle-level safety goal (SG 1) is allocated to one of the components in the system — the EV PCM. The safety analysis identifies many EV PCM failure modes and CFs that could potentially lead to the violation of SG 1. Here, two EV PCM controller hardware failures are chosen as examples to illustrate the development process of safety requirements.

Table 30. Examples of EV PCM Safety Requirements

Safety Goal	SG 1: Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 to be mitigated in accordance to the identified ASIL level.
ASIL	D
Component	EV PCM
Safety Analysis (Examples)	• Hardware fault (sensors, ICs, etc.) • Internal connection fault (short or open)
Safety Strategy	**Potential Safety Requirements (Examples)**
Detection	All single-point EV PCM hardware faults that lead to potential violations of a safety goal are to be detected within the fault detection time and mitigated within the FTTI (ASIL B/C/D).
Fault Tolerance	
Safe State	In case of a failure, the system is to transition to the corresponding safe state. Hardware faults include those occurring in the ICs, circuit components, printed circuit boards, I/O pins, signal connectors, and power connectors.
Warning	The EV PCM is to log and save the following data every time a transition to safe state is executed due to a potential violation of a safety goal (ASIL QM): • The diagnostics information of the faults, including the time at which the fault was detected and the nature of the fault • The time interval from the detection of the fault to reaching the safe state

	• The time the system degradation strategy started, including the start and end of each phase if applicable and the values of the system metrics for each phase (i.e., torque output level) • The time the driver warning strategy started, including the start and end of each phase if applicable and the values of the system metrics for each phase • The data are to be retained until accessed by authorized personnel

In case of a controller hardware fault, the first mitigation strategy is for the system to be able to detect the abnormality and transition the system to a safe state. This requirement corresponds to the safety strategy that involves detection, fault tolerance, and transitioning to a safe state in Table 30. Additionally, if the vehicle is to transition to a safe state with reduced or very limited propulsion power (e.g., limp-home mode) the driver would need to be notified so that he or she can maneuver the vehicle to a safe location and get the needed repair service to the vehicle. Therefore, a potential additional requirement associated with a driver warning could be the one described in Table 30.

The rest of this section lists the 112 ACS/ETC functional safety requirements derived through this process. A functional safety requirement may have more than one ASIL associated with it, because the same requirement may cover more than one safety goal and these safety goals may have different ASILs. The requirement may be implemented using different ASIL classification if independence among the implementation solutions can be demonstrated (Part 9 Clause 5.2 of ISO 26262).

9.2.1 General EV ACS/ETC System-Level Functional Safety Requirements

There are eleven general system-level functional safety requirements derived for the generic EV ACS/ETC system examined in this study. These requirements correspond to all established safety goals.

1. The ACS/ETC is to perform power-on tests, periodic tests, or continuous monitoring tests to ensure the correctness of safety-critical parameters and the integrity of critical system elements (**ASIL B/C/D**).
    a. Critical parameters include those that are used to calculate the magnitude and direction of the propulsion torque, the HV bus voltage, the low voltage, the vehicle speed, the motor speed, the vehicle direction (forward or reverse), and the safety of the HV power bus from unauthorized intrusion.
    b. Other critical parameters may include calculation and comparison results that confirm the proper operation of the system.
    c. The pedal position-speed torque maps are to be checked.
    d. The proper operation of the following critical system elements is to be checked before any propulsion torque command is issued by the ACS/ETC.
        - APPS

- The motor position sensor
- The communications channels between the APPS and the EV PCM, between the EV PCM and TICM, between the motor position sensor and the TICM, and between the brake/stability control system and the EV PCM.
- A confirmation of the sanity and health of the EV PCM and TICM is to be confirmed via an acceptable strategy before any propulsion torque command is issued by the ACS/ETC.
    - o Sanity checks may include quizzer, or seed-and-key strategies[24]
    - o State-of-health checks may include the following.
        - Random-access memory/read-only memory/electrically erasable programmable read only memory tests
        - Analog-to-digital converter test
        - Shutdown test

e. The frequency of the periodic tests is to be selected based on the FTTI, and the fault reaction time interval.

f. In case of failure in the periodic self-tests, the ACS/ETC is to transition to a safe state within TBD ms.

2. The hardware architectural single-point fault and latent fault metrics targets per ISO 26262 are to be demonstrated for each safety goal (**ASIL B/C/D**).
3. If redundant elements are used, they are to be verified against common cause failures (**ASIL C/D**).
    - Failures in the electric power supply of one element are not to affect the power supply of the other element.
    - A failure in the communication path of one element is not to affect the communication path of the other element.
4. If redundant elements are used and one element fails, the ACS/ETC is to transition into Safe State 3 within the FTTI of TBD seconds and an amber-light driver warning is to be communicated to the driver (**ASIL B/C/D**).
5. If redundant elements are used and both elements fail, or if only one element is used and it fails, then the ACS/ETC is to transition into Safe State 4 within the FTTI of TBD seconds, and a red-light driver warning is to be communicated to the driver (**ASIL B/C/D**).
6. Diagnostics of all safety-critical component functions are to be conducted. In case of detected faults, the system is to take mitigation action to prevent failures that lead to a

[24] "Quizzer" is also known as seed-and-key. It is a technique that is used to confirm the sanity (health) of a microcontroller. This is usually used as a redundancy technique to comply with ASIL C or D of ISO 26262. The technique uses sets of inputs that mimic a specific operating scenario. One controller (A), at predefined time intervals, presents a set of inputs to the controller (B) whose health is being checked. The set of inputs have a predefined response that is expected from controller B. If controller B responds within the specified time period correctly, then its health is confirmed. If controller B responds incorrectly, then a mitigation strategy is executed by controller A.

potential violation of a safety goal and appropriate DTCs are to be set (**ASIL QM/A/B**). The diagnostics approach is to cover the following.

- Hardware: APPS, EV PCM, EPS, and communication hardware
- Software Functions: APP calculations, torque command determination, torque control, and BTO

7. The ACS/ETC is to include diagnostics covering the following failure modes (**ASIL QM/A/B**).
    - APPS:
        - IC faults
        - Open/short I/Os
        - Stuck on the same reading
        - Out of range
        - Offset
        - State of health
    - Current Sensor (if only two sensors are used)
        - IC faults
        - Open/short I/Os
        - Stuck on the same reading
        - Out of range (not required if three sensors are used)
        - Offset (not required if three sensors are used)
        - State of health (not required if three sensors are used)
    - Harnesses and Connectors
        - Open/short circuits
8. The ACS/ETC is to log and retain data that can be used to reconstruct the vehicle operating scenario prior to any faults that lead to a violation of a safety goal; the recording time period is TBD seconds before and TBD seconds after the safety goal violation event. The data may include sensors data, HMI data, communication signals, and values of some critical parameters used in the propulsion torque calculations; the flowing data is to be considered (**ASIL QM**).
    - Ignition switch status
    - Gear selector position
    - Vehicle speed
    - Vehicle direction
    - APPS value
    - ACC system settings
    - AEB system state
        - Object distance from vehicle
    - Driver assist safety systems status
    - Brake/stability control system status
        - ABS

    - TCS
    - ESC
- Traction motor rotational speed
- Traction motor current sensors readings
- System low voltage value
- Driver actions regarding vehicle systems capable of initiating and or commending changes to propulsion torque, including driver override decisions of vehicle systems capable of initiating and or commending changes to propulsion torque
- Arbitration logic decisions by the PCM
- PCM torque request to the TICM
- TICM torque received request
- TICM motor current command
- PCM received torque request from ACC
- PCM torque request received from AEB
- HV bus state of charge
- Steering torque sensor value
- Vehicle yaw rate

9. DTCs are to be set every time a safety goal may be violated (**ASIL QM**).
10. Diagnostics covering the safety related functionality of the ACS/ETC system components and connections (including the EV PCM, EPS, APPS, harnesses, and connectors) are to be instituted with a level of coverage corresponding to the ASIL of the safety goal that is affected. Adhere to ISO 26262 diagnostics coverage guidelines for low, medium, and high in order to comply with the hardware architectural metrics targets (**ASIL QM/A/B**).
11. Diagnostics mechanisms are to adhere to ASIL B classification for ASIL D related elements and ASIL A classification for ASIL C related elements (**ASIL QM/A/B**).

9.2.2 Accelerator Pedal Assembly Functional Safety Requirements

There are eight AP assembly functional safety requirements derived for the generic EV ACS/ETC system studied in this project. The AP assembly functional safety requirements correspond to all safety goals, unless otherwise specified.

1. The APP corresponding to the propulsion torque requested by the driver is to be mapped correctly and consistently, and the results are to be qualified for validity and correctness under all vehicle operating conditions, over the usable life of the vehicle (**ASIL B/C/D**).
2. The health and sanity of the APPS is to be monitored and confirmed under all operating vehicle conditions (**ASIL C/D**). **Safety Goals: 1 through 6**.
3. The APP value is to be measured and the value is to be valid and correct (**ASIL B/C/D**).
4. The APP to electrical conversion method is to be validated (**ASIL B/C/D**).
5. Critical communication and data transfer between the APPS and the EV PCM, including the APP and diagnostics of the APPS, are to be qualified for validity and correctness

(plausibility and rationality). In case of a fault, the correct failure mode effect mitigation strategy is to be applied (**ASIL B/C/D**).

6. In case of a fault that violates a safety goal, the APPS is to communicate the fault to the EV PCM (**ASIL B/C/D**). Faults may include, but are not limited to:
   - Internal hardware failure,
   - Degradation over time,
   - Overheating due to increased resistance in a subcomponent or internal short, and
   - Reporting frequency too low.
7. The APPS is to have diagnostics for safety-relevant failures that could be caused by EMI/electromagnetic compatibility (EMC), ESD, contamination, and other environmental conditions (**ASIL A/B**).
8. All single point APPS hardware faults that could lead to potential violation of a safety goal are to be detected and mitigated within the FTTI. In case of the detection of a failure, the system is to transition to the corresponding safe state (**ASIL B/C/D**).
   - Hardware faults include those occurring in the IC, circuit components, printed circuit board, I/O pins, signal connectors, and power connectors.

9.2.3 EV Powertrain Control Module Functional Safety Requirements

There are 49 EV PCM functional safety requirements that are derived in this project. Many of these requirements correspond to all established safety goals. However, some of the functional safety requirements only correspond to a subset of the established safety goals. These requirements have the specific safety goals listed in the end.

1. The health and sanity of the EV PCM controller are to be ensured (**ASIL C/D**). **Safety Goals: 1 through 6**
   - Power-on self-tests are to be implemented to check the health of the controller. These tests may include:
     - Central processing unit and register tests to check the internal working of the CPU. All CPU registers associated with the torque control functions are to be checked during this test.
     - Interrupt and exception tests to check the interrupt and exception processing of the controller.
     - EEPROM checksum tests to check the EEPROM health.
     - Device tests to check the peripheral devices connected the microcontroller.
2. The EV PCM's I/O pins are to be monitored for shorts to high voltages or ground (**ASIL B/C/D**).

3. The EV PCM is to have diagnostics for potential safety relevant failures caused by EMI/EMC, ESD, contamination, organic growth, single event effects,[25] and other environmental conditions (**ASIL B/C/D**).
4. All single point EV PCM hardware faults that lead to potential violations of a safety goal are to be detected and mitigated within the FTTI (**ASIL B/C/D**).
    - In case of a failure, the system is to transition to the corresponding safe state.
    - Hardware faults include those occurring in the ICs, circuit components, printed circuit boards, I/O pins, signal connectors, and power connectors.
5. The motor torque output is to be controlled and updated in the correct direction within the correct time duration. The time duration required to update the motor torque output must not result in an uncontrolled propulsion condition (failure mode in software execution, execution time, motor inertia) (**ASIL D**). **Safety Goal: 1**
6. The EV PCM is to arbitrate between multiple requests for propulsion torque modifications from interfacing vehicle systems and the driver (**ASIL B/C/D**). **Safety Goals: 1 through 6**
7. The arbitration strategy is to clearly define the action of the ACS/ETC system when there are conflicting propulsion torque requests from interfacing systems, the driver, and/or internal ACS/ETC functions (e.g., BTO) (**ASIL B/C/D**). **Safety Goals: 1 through 6**
8. The EV PCM arbitration logic strategy and algorithm are to be checked for health and sanity periodically based on the FTTI (**ASIL B/C/D**). **Safety Goals: 1 through 6**
    - In case of a failure in this arbitration strategy, the ACS/ETC system is to transition into Safe Sate 1 within a FTTI of TBD seconds and an amber-light driver warning is to be issued.
9. The output of the EV PCM arbitration logic is to be qualified for validity and correctness (**ASIL B/C/D**). **Safety Goals: 1 through 6**
10. The EV PCM is to calculate the propulsion torque based on inputs from the AP, vehicle speed sensor, vehicle direction sensor, and the inputs from the other vehicle systems that command propulsion or braking torque, such as the ACC and AEB (**ASIL B/C/D**). **Safety Goals: 1 through 6**
11. Critical communications and data transfer between the EV PCM and other vehicle systems that can request or command changes to the propulsion torque are to be qualified for validity and correctness (plausibility and rationality) (**ASIL B/C/D**). **Safety Goals: 1 through 6**
    - In case of the detection of a fault, the correct failure mode effect mitigation strategy is to be applied.

[25] Single event effects are anomalies in microelectronics caused by single energetic particles, such as protons or cosmic rays. Several different types of single event effects may occur, such as transient pulses in logic, bit flips, latch-up, or burnout of power transistors. [22]

- Critical communications and data transfer include communication signals that request propulsion torque modifications and diagnostics (failure) information of these systems.
- This also includes detecting erroneous torque commands issued by malicious intruders or aftermarket components.

12. The EV PCM is to correctly adjust the propulsion torque in response to propulsion torque modification requests by other vehicle systems, including AEB (**ASIL B/C/D**). **Safety Goals: 1 through 6**
13. Critical communications and data transfer between the EV PCM and other vehicle systems/components are to be qualified for validity and correctness (plausibility and rationality) including the BPPS (**ASIL D**), vehicle speed sensor (**ASIL D**), motor speed sensor (**ASIL D**), RESS (**ASIL D**), vehicle direction sensor (**ASIL C**), and all other inputs that are used by the torque control function. **Safety Goals: 1 through 6**
    - If the vehicle speed and motor speed are used redundantly, then the ASIL classification may be applied based on a selected ASIL decomposition strategy.
    - If torque maps or look up tables are used, their content is to be checked for validity and correctness at the correct frequency.
14. The EV PCM is to qualify the APP input(s) for validity and correctness (plausibility and rationality) (**ASIL D**). **Safety Goals: 1 through 6**
15. The APP to propulsion torque rate of change mapping is to be monitored for correctness (**ASIL C**). **Safety Goals: 2 and 5**
16. All other critical parameters used by the torque control function are to be checked periodically based on the FTTI requirements (**ASIL B/C/D**). **Safety Goals: 1 through 6**
17. The EV PCM is to correctly adjust the propulsion torque when it receives a communication of a braking action by the braking system (**ASIL B/C/D**). **Safety Goals: 1 through 6**
18. The EV PCM is to access the metrics that clearly define the limits of vehicle stability from the appropriate vehicle system (**ASIL D**). **Safety Goals: 1 and 4**
19. The EV PCM is to qualify the stability metrics input(s) for validity and correctness (plausibility and rationality).
20. The propulsion torque computed by the control algorithm is to be validated against the vehicle stability metrics before any propulsion torque command is issued (**ASIL D**). **Safety Goals: 1 and 4**
    - In case the calculated torque exceeds the vehicle stability limits, the ACS/ETC system is to transition into Safe State 2 within a FTTI of TBD seconds and an Amber level driver warning is to be issued.
    - Appropriate warnings to the driver from affected interfacing systems are to be issued.
21. All electrical hardware and software elements associated with the delivery of the torque control function are to comply with ASIL D classification for Safety Goals 1, 4, and 6,

ASIL C classification for Safety Goals 2, 3, and 5, and ASIL B classification for Safety Goals 1a and 7 unless otherwise specified. If independence of the elements (Part 9 Clause 5.2 of ISO 26262) cannot be demonstrated, then the higher ASIL classification is to be adopted.

22. The EV PCM torque command and control communication channel(s) with the EPS are to be validated at start up (**ASIL B/C/D**).
    - Torque commands are not to be issued until the validation of this communication channel(s) is successful.
    - In case of failure of validation, the ACS/ETC is to transition into Safe State 6 within a FTTI of TBD seconds.
    - A red-light driver warning is to be communicated to the driver.
23. The torque command is to be controlled and updated in the correct direction and within the correct time duration (**ASIL B/C/D**). **Safety Goals: 1, 2, 3, 4, 5, and 6**
24. The ACS/ETC system controller's torque control algorithm is to include a speed increase/decrease rate profile. The torque calculation algorithm is to specify the parameters that form the basis for the ramp rate profile (e.g., vehicle speed). (**ASIL C**). **Safety Goals: 2 and 4**
25. The EV PCM algorithm or method for calculating the torque command is to be validated (**ASIL B/C/D**). **Safety Goals: 1 through 6**
26. The torque command corresponding to the propulsion torque requested by the driver is to be calculated correctly and the results are to be qualified for validity and correctness under all vehicle operating conditions (**ASIL B/C/D**). **Safety Goals: 1 through 6**
27. The time duration required to update the torque command is not to result in violation of a safety goal. The time duration is to be reflected in the relevant software function's execution time and the transient response of the motor (**ASIL B/C/D**). **Safety Goals: 1 through 6**
28. The EV PCM torque control algorithm is to be checked periodically based on the correct TFFI to prevent violation of any safety goal (**ASIL C/D**). **Safety Goals 1 through 6**
    - The appropriate fault tolerant strategies are to be applied for the torque control function, such as redundancy, voting logic, or other techniques.
    - A control flow monitoring strategy is to be applied for the torque control function.
29. In case of a fault in the torque control function that results in the EV PCM becoming unable to control the torque command, the ACS/ETC is to transition into Safe Sate 4 within TBD ms time and the red-light driver warning is to be issued. Some industry practices establish this TBD time at 200 ms (**ASIL B/C/D**). **Safety Goals: 1 through 6**
    - In architectures with a simulated idle "creep" speed, failures that prevent the EV PCM from controlling the idle "creep" torque command may have a longer FTTI than the FTTI for operating speeds above the idle "creep" speed.
    - DTCs are to be set.

30. The EV PCM is to communicate the correct torque command to the EPS under all vehicle operating scenarios within TBD time (**ASIL B/C/D**).
31. Communications of the torque command between the EV PCM and EPS are to be qualified for validity and correctness (plausibility and rationality). In case of a fault, the correct failure mode effect mitigation strategy is to be applied (**ASIL B/C/D**).
32. The EV PCM is to be able to shut down the EPS (**ASIL C/D**). **Safety Goals: 1, 2, 3, 4, 5, 6 and 7**
33. The EV PCM is to provide BTO control (**ASIL C**). **Safety Goals: 1 through 6**
34. All electrical hardware and software elements associated with the delivery of the BTO function are to comply with **ASIL C** unless otherwise stated. **Safety Goals: 2 and 6**.
35. The EV PCM BTO control is to command a pre-determined torque output when both the AP and BP are pressed and when the vehicle speed is above the pre-determined threshold value, regardless of the amount of torque requested via the APPS (**ASIL C**). **Safety Goals: 1 through 6**
36. The EV PCM BTO control strategy is to include provisions, if necessary, for a modified control strategy if it is determined that simultaneous AP and BP applications are intended and confirmed by the driver. The modified strategy is to include a maximum allowable torque and a torque rate that will not lead to a potential violation of a safety goal (**ASIL C**). **Safety Goals: 1 through 6**
37. Critical communication and data transfer between the BPPS and the EV PCM are to be qualified for validity and correctness (plausibility and rationality). In case of a fault, the correct failure mode effect mitigation strategy is to be applied (**ASIL D**). **Safety Goals: 1 through 6**
38. The BTO control algorithm is to execute within TBD seconds (**ASIL C**). **Safety Goals: 1 through 6**
39. The EV PCM BTO control algorithm is to be checked periodically based on the correct FTTI to prevent potential violation of the safety goals (**ASIL C**). **Safety Goals: 1 through 6**
    - The appropriate fault tolerant strategies are to be applied for the BTO function, such as redundancy, voting logic, or other techniques.
    - A control flow monitoring strategy is to be applied for the BTO function.
    - In case of a fault in the BTO control algorithm that may lead to a potential failure and a potential violation of a safety goal, the system is to transition into Safe State 6 within TBD ms (200 ms is considered in the industry for similar safety goals), and the red-light driver warning is to be issued.
    - DTCs are to be set.
40. In case of a failure in the APPS and the BPPS, the ACS/ETC is to transition into Safe State 5, and a red-light driver warning is to be issued (**ASIL B/C/D**). **Safety Goals: 1 to 5**

41. All requests or commands for change in the propulsion torque by other vehicle systems are to be ignored when BTO is activated (**ASIL C**). **Safety Goals: 1 to 5**
42. In the event of EV PCM malfunction resulting in the loss of the BTO control function, the ACS/ETC is to be able to reduce the torque level to the pre-determined BTO level (**ASIL A/B/C**). **Safety Goals: 2 and 6**. Possible implementation strategies include:
    - Enter a Safe State
    - Implement a BTO control function that is subordinate to the EV PCM BTO control function, for example in the EPS.

    The ASIL classification for this requirement depends on whether it is a part of ASIL decomposition or if it is a safety mechanism to the EV PCM BTO function.

43. The EV PCM is to have a mechanism to prevent unauthorized access to the propulsion torque control calculations and command path (**ASIL B/C/D**).
44. All single point faults that result in a failure to prevent unauthorized access to the EV PCM are to be detected and mitigated (**ASIL B/C/D**).
    - In case of unauthorized access to the EV PCM, the ACS/ETC system is to transition to Safe State 5 within TBD ms, and a red-light driver warning is to be issued.
    - A DTC is to be set.
45. The EV PCM is to open the contactors following a vehicle crash. If a HVIL fault is detected and the vehicle speed is below TBD mph, the EV PCM is to open the HV contactors. If the vehicle speed is above TBD mph when the HVIL fault is detected, the EV PCM is to send an amber warning to the driver (**ASIL B**). **Safety Goal: 7**
46. The EV PCM is to qualify the vehicle crash signal for validity and correctness (**ASIL B**). **Safety Goal: 7**
47. The EV PCM is to qualify the HVIL signal for validity and correctness (**ASIL B**). **Safety Goal: 7**
48. Diagnostics covering the failures for the following parts of the EV PCM are to be implemented (**ASIL QM/A/B**).
    - Execution logic (wrong coding, wrong or no execution, execution out of order, execution too fast or too slow, and stack overflow or underflow)
    - On-chip communication and bus arbitration
    - The main controller's:
        - CPU
        - processor memory
        - arithmetic logic unit
        - registers
        - A/D converter
        - signal conditioning and converting (e.g., signal filters)
        - software program execution

    - connections I/O faults (short/open/drift/oscillation)
    - power supply
    - temperature
  - If an auxiliary processor is used, then cover its:
    - CPU
    - processor memory (if auxiliary processor is used)
    - arithmetic logic unit
    - registers
    - A/D converter
    - signal conditioning and converting (e.g., signal filters)
    - software program execution
    - I/O faults (short/open/drift/oscillation)
    - power supply
    - temperature
  - The wiring harnesses and connectors for open and short circuits
  - Critical messages including CAN messages

49. The EV PCM is to log and save the following data every time a transition to safe state is executed due to a potential violation of a safety goal (**ASIL QM**).
    - The diagnostics information of the fault(s) including the time at which the fault was detected and the nature of the fault
    - The time interval from the detection of the fault to reaching the safe state
    - The time the system degradation strategy started, including the start and end of each phase if applicable and the values of the system metrics for each phase (i.e., torque output level)
    - The time the driver warning strategy started, including the start and end of each phase if applicable and the values of the system metrics for each phase
    - The data is to be retained until accessed by authorized personnel.

9.2.4 Electric Powertrain Subsystem Functional Safety Requirements

As depicted in Figure 6, the EPS contains the power electronics used to drive the traction motor. This includes the TICM, gate drive board, inverter/converter, and relevant sensors. There are 28 EPS functional safety requirements derived in this project. These safety requirements correspond to all safety goals, except where otherwise noted.

1. The health and sanity of the EPS motor torque current calculation algorithm is to be checked periodically based on the correct FTTI to prevent violations of the safety goals (via an auxiliary processor or equivalent means) (**ASIL C/D**). **Safety Goals: 1 to 5**
    - The appropriate fault tolerant strategies are to be applied for the motor torque current calculation algorithm, such as redundancy, voting logic, or other techniques.

    - A control flow monitoring strategy is to be applied for the motor torque current calculation algorithm.
2. Critical communications and data transfer between the TICM and other EPS components are to be qualified for validity and correctness (plausibility and rationality). This includes the motor position sensor and diagnostics associated with the motor position determination/sensing mechanism (**ASIL B/C/D**). **Safety Goals: 1 to 5**
3. All single point EPS hardware faults that lead to potential violations of a safety goal are to be detected and mitigated within the FTTI (**ASIL B/C/D**).
    - In case of a failure, the system is to transition to the corresponding safe state.
    - Hardware faults include those occurring in the ICs, circuit components, printed circuit boards, I/O pins, signal connectors, and power connectors.
4. In case of a fault, the EPS is to communicate the fault to the EV PCM. The fault communication is to be checked for validity and correctness (**ASIL B/C/D**).
5. All electrical hardware and software elements associated with delivering the motor torque current to the traction motor or discharging the HV bus are to comply with A**SIL D** classification for Safety Goals 1, 4 and 6; **ASIL C** classification for Safety Goals 2, 3, and 5; and **ASIL B** classification for Safety Goals 1a and 7 unless otherwise specified. If independence of the elements (per ISO 26262) cannot be demonstrated, the higher ASIL classification is to be adopted.
6. The EPS is to deliver the motor torque current at the correct value, in the correct direction, with the correct speed increase/decrease profile, and at the correct time to the traction motor (**ASIL B/C/D**). **Safety Goals: 1 to 5**
    - The motor torque current direction is defined in terms of the intended direction of the output motor torque. This means that in case of a 3-phase current, the motor rotor position may have to be considered when establishing the current direction.
    - The transient response of the EPS is to be established to prevent a violation of any safety goal.
7. The EPS is to have motor torque current calculations and control algorithms for all motor speeds (**ASIL B/C/D**). **Safety Goals: 1 to 5**
8. If look up tables are used to determine the value of the motor torque current, the content of the tables are to be checked for correctness every time the ACS/ETC is started (**ASIL B/C/D**). **Safety Goals: 1 to 5**
9. The EPS is to deliver motor torque current to drive the motor in both the clockwise and counterclockwise directions (**ASIL B/C/D**). **Safety Goals: 1 to 5**
10. The EPS is to control the motor torque current such that the motor torque is controlled to within a pre-established tolerance band, both in magnitude and speed increase/decrease rate, based on the vehicle operating scenario. This tolerance band is not to result in a violation of a safety goal (**ASIL B/C/D**). **Safety Goals: 1 to 5**
11. The motor torque current calculations are to result in the correct torque increase/decrease rate (**ASIL C**). **Safety Goals 1 and 5**

12. The transient response of the EPS is to be established to prevent a violation of any safety goal (**ASIL B/C/D**). **Safety Goals: 1 to 5**
13. The motor speed is to be validated against the vehicle speed (**ASIL B/C/D**). **Safety Goals: 1 to 5**
14. The motor speed and torque combination is to be validated for the driver's intended direction of travel (**ASIL B/C**). **Safety Goals: 1A and 3**
15. The motor torque current value, direction, and speed increase/decrease rate are to be qualified for validity and correctness (**ASIL B/C/D**). **Safety Goals: 1 to 5**
16. The motor position sensor input is to be checked for validity and correctness (**ASIL B/C/D**). **Safety Goals: 1 to 5**
17. The motor current sensor input(s) are to be checked for validity and correctness (**ASIL B/C/D**). **Safety Goals: 1 to 5**
18. The motor position sensor end of line calibration process capability is to be monitored (**ASIL B/C/D**). **Safety Goals: 1 to 5**
19. All other critical parameters used by the motor torque current calculation algorithm that may lead to a violation of any safety goal when not correct are to be checked periodically based on the FTTI requirements (**ASIL B/C/D**). **Safety Goals: 1 to 5**
20. All faults that result in a failure to determine the motor torque current are to be detected and mitigated (**ASIL B/C/D**). **Safety Goals: 1 to 5**
    In case of a failure to in establishing the validity and correctness of the motor torque current, the ACS/ETC is to:
    - Transition into Safe State 6,
    - Issue a red-light driver warning, and
    - Set DTCs.
21. The TICM is to have a mechanism to prevent unauthorized access to the motor torque current calculations and command path (**ASIL B/C/D**).
22. All single point faults that result in a failure to prevent unauthorized access to the TICM are to be detected and mitigated (**ASIL B/C/D**).
    - In case of unauthorized access to the TICM, the ACS/ETC system is to transition to Safe State 5 within TBD ms, and a red-light driver warning is to be issued.
    - A DTC is to be set.
23. The EPS is to receive HV electric energy from the HV bus (**ASIL C/D**). **Safety Goals: 1 to 5**
    - If there is a fault in the HV system that may lead to a violation of a safety goal, the ACS/ETC is to transition into a safe state and a driver warning is to be issued.
24. The EPS is to have a mechanism to prevent unauthorized access to the HV bus (**ASIL B**). **Safety Goal: 7**
25. All single point faults that result in a failure to disconnect the EPS from the HV bus when unauthorized access occurs are to be detected and mitigated (**ASIL B**). **Safety Goal: 7**

In case of a failure that leads the EPS to be unable to disconnect from the HV bus when unauthorized access occurs, the ACS/ETC is to:

- Transition into Safe State 7 within TBD ms,
- Issue a red-light driver warning, and
- Set DTCs.

26. The EPS is to discharge the HV bus to a pre-determined level within the required time when requested by the EV PCM (**ASIL B**). **Safety Goal: 7**
27. All single point faults that result in a failure to discharge the HV bus when requested by the EV PCM are to be detected and mitigated (**ASIL B**). **Safety Goal: 7**
    In case of a failure that leads the EPS to be unable to disconnect from the HV bus when unauthorized access occurs, the ACS/ETC is to:
    - Transition into Safe State 7 within TBD ms,
    - Issue a red-light driver warning, and
    - Set DTCs.
28. Diagnostics covering the failures for the following parts of the EPS are to be implemented (**ASIL QM/A/B**).
    - Execution logic (wrong coding, wrong or no execution, execution out of order, execution too fast or too slow, stack overflow or underflow)
    - On-chip communication and bus arbitration
    - The main controller's:
        - CPU
        - processor memory
        - arithmetic logic unit
        - registers
        - A/D converter
        - signal conditioning and converting (e.g., signal filters)
        - software program execution
        - connections I/O faults (short/open/drift/oscillation)
        - power supply
        - temperature
    - If an auxiliary processor is used, then cover its:
        - CPU
        - processor memory (if auxiliary processor is used)
        - arithmetic logic unit
        - registers
        - A/D converter
        - signal conditioning and converting (e.g., signal filters)
        - software program execution
        - I/O faults (short/open/drift/oscillation)
        - power supply

        - temperature
- The motor position sensor
- The motor current sensors
- The wiring harnesses and connectors for open and short circuits
- Critical messages, including CAN messages

9.2.5 Communication Signal Functional Safety Requirements

There are five functional safety requirements for the communication signals, each corresponding to all safety goals.

The critical communication signals include the following.

- APPS signal(s) from the APPS to EV PCM
- APPS fault diagnostics signal
- BPPS signal to EV PCM
- Communication channel "secure" signals between EV PCM and EPS
- Communication channel "secure" signals between EV PCM and the following:
    - ACC/CC
    - AEB
    - RESS
    - Other systems that can request modification to the propulsion torque
- Commands/requests for propulsion torque modifications from interfacing systems to EV PCM
- Vehicle speed signal
- Vehicle direction signal
- Command for torque from the EV PCM to the EPS
- EPS fault diagnostics signals
- Motor speed sensor signal to TICM
- Motor position sensor signal to TICM
- Driver warning signals
- Unauthorized access to HV bus signal from the EPS to RESS controller
- Low voltage power loss from the low voltage power system to EV PCM signal
- Communication bus signal failure from the communication bus to the EV PCM

1. All critical communication signals are to be qualified for validity and correctness (plausibility and rationality). The ASIL classification for the signal is to correspond to the safety goal it is associated with. If a signal is associated with more than one safety goal, then it is to adhere to the higher ASIL classification. In case of a fault in any critical signal, the system detecting the fault is to (**ASIL B/C/D**):
    - Inform the EV PCM of the fault, and

- Invoke the correct failure mode effect mitigation strategy.

2. The communication bus is to support the communication of the ACS/ETC with the other vehicle systems to support the safe operation of the ACS/ETC (**ASIL B/C/D**).
3. The communication bus is to support the qualification of all critical communication signals between the ACS/ETC and the interfacing vehicle systems (**ASIL B/C/D**).
4. The communication bus is to prevent the corruption of the critical communication signals during transmission between the ACS/ETC and the interfacing vehicle systems (**ASIL B/C/D**).
5. In case of malfunction of the communication bus or communication bus module, the communication bus system is to inform the EV PCM (**ASIL B/C/D**).

9.2.6 Power Supply Functional Safety Requirements

There are six functional safety requirements for the low and high voltage power supplies. These requirements correspond to all safety goals, except where otherwise specified.

1. The low voltage power supply is to provide the ACS/ETC and interfacing systems and sensors with the required low voltage power supply for operation (**ASIL B/C/D**).
2. The ACS/ETC is to have a redundant low voltage power supply.
   - In case of a fault in the vehicle low voltage power supply system, the redundant power supply is to activate within TBD ms and sustain the low voltage power supply to the vehicle for a duration greater than the longest FTTI of the ACS/ETC (**ASIL B/C/D**).
3. The supply voltage and current are to meet the requirements on the quality parameters (levels (min, max), ripple, transient, and overshoot) as set by the ACS/ETC system components and interfacing systems and sensors. The ASIL classification of this requirement is to be based on the safety analysis and the safety goal impacted (**ASIL B/C/D**).
4. The ACS/ETC is to be notified of any malfunction or disruption in the low voltage power supply system operation (**ASIL B/C/D**).
5. All communications and data transfer sent by the low voltage power system to the EV ACS/ETS are to be qualified for validity and correctness (plausibility and rationality). This includes the low voltage power system diagnostics information (**ASIL B/C/D**).
6. All single point failure modes that cause the loss of low voltage power are to be prevented or mitigated. The ACS/ETC is to transition to Safe State 6 in case of the loss or malfunction of the vehicle's low voltage power system and red-light driver warning is to be issued to the driver (**ASIL D**).

9.2.7 Interfacing Systems Functional Safety Requirements

There are five functional safety requirements for the interfacing systems. These functional safety requirements correspond to all safety goals unless otherwise noted.

1. All requests or commands for propulsion torque modifications or HV bus discharge from vehicle interfacing systems are to be sent to the EV PCM (**ASIL B/C/D**).
    - Requests for torque increases or decreases from the CC/ACC system
    - Requests for torque reduction from the braking system including the AEB module (directly or indirectly through the braking system module)
    - Requests for torque modification from the TCS
    - Requests for torque modification from the electronic stability control system
    - Requests for regenerative braking
    - Requests for discharging the HV bus
2. All communications and data transfer regarding requests or commands for propulsion torque modifications sent by the vehicle interfacing systems to the EV PCM are to be qualified for validity and correctness (plausibility and rationality) by the sending system (**ASIL D**). **Safety Goals: 1 through 6**
3. All interfacing systems are to inform the EV PCM in case of any failure that may cause the system, and the ACS/ETC, to transition into a degraded mode of operation (**ASIL B/C/D**).
4. In case of a fault in the transmitted information to the EV PCM from the interfacing system, the correct failure mode effect mitigation strategy is to be applied (**ASIL B/C/D**).
5. When opened following a vehicle crash or HVIL fault, the contactors are to remain open until the integrity of the HV system has been confirmed. Some examples for confirming the integrity of the HV system may include successful system self-checks and removal of faults (**ASIL B**). **Safety Goal: 7**

9.3 Additional Safety Requirements beyond the Scope of the ISO 26262 Functional Safety Concept

This study performs comprehensive hazard and safety analysis. In addition, this study also considers the risk reduction measures recommended by the system safety standard—MIL-STD-882E [3] to ensure the generation of a comprehensive list of safety requirements:

- Eliminate hazards through design selection
- Reduce risk through design alteration

Subsequently, this study identifies additional 90 safety requirements related to the ACS/ETC system and components. Many of these requirements also support the main elements of the safety strategies listed in Section 8.1. They fall into the following categories.

1. General ACS/ETC System – 17 requirements
2. AP Assembly – 3 requirements
3. EV PCM – 29 requirements
4. EPS – 14 requirements
5. Communication Signals – 4 requirements

6. Power Supply (low and high voltage) – 2 requirements
7. Interfacing Systems – 21 requirements

9.3.1 General EV ACS/ETC System-Level Safety Requirements

This study identifies 17 general system-level safety requirements for the EV ACS/ETC system outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all safety goals, unless otherwise specified.

1. The packaging for the ACS/ETC components and connections is to provide sufficient static and dynamic clearances (**ASIL B/C/D**).
2. The ACS/ETC components and connections are to be protected from physical interference from foreign objects (e.g., road debris) (**ASIL B/C/D**).
3. The ACS/ETC assemblies are to be free of manufacturing defects. This includes both the component manufacturing quality as well as the quality of the connections between components in the assembly process (**ASIL B/C/D**).
4. The calibration of the safety critical sensors, safety critical actuators, and other safety critical parameters is to be checked and verified to be correct. This includes interfacing sensors and actuators that are critical to the safe functioning of the ACS/ETC (**ASIL B/C/D**).
   Typical safety critical sensors include the following.
   - APPS
   - BPPS
   - Motor speed/position sensor
   - Phase/current sensor
   - Inverter temperature sensor
   - Transmission range sensor
   - Vehicle speed sensor (may be provided by the brake/stability control module)
   - Battery state-of-charge (may be provided by the RESS control module)
   - Crash signal (may be provided by the occupant restraint system control module)

   Typical safety critical actuators include the following:
   - Inverter/converter (power stage)
   - Gate drive board
   - Inverter cooler parameters

   Other typical safety critical components include the following:
   - Traction motor parameters
5. ACS/ETC sensors are to have TBD reporting frequency such that safety critical data is updated with sufficient frequency to prevent violation of a safety goal (**ASIL B/C/D**).
   Safety Goals: 1 through 6
   Typical ACS/ETC sensors:

- APPS
- Motor speed/position sensor
- Phase/current sensor
- Inverter temperature sensor

6. The ACS/ETC components are to meet the reliability and functional degradation requirements (**ASIL B/C/D**).
7. Safety critical ACS/ETC sensors and actuators are to have TBD failure rate for 100,000 miles and under all normal (TBD) vehicle operating conditions (temperature, vibration, moisture, etc.) (**ASIL C/D**).
   Failures may include:
   - Hardware failure,
   - Degradation over time, and
   - Internal short and increased resistance.

   Safety-critical sensors may include:
   - APPS,
   - Motor speed/position sensor,
   - Phase/current sensor, and
   - Inverter temperature sensor

   Safety-critical actuators may include:
   - Inverter cooler,
   - Gate drive board, and
   - Inverter/converter (power stage).
8. The ACS/ETC components and connections are to meet the standards for EMI/EMC with the environment and the vehicle to prevent malfunctioning of the EV PCM, TICM, corruption of critical parameters including the torque maps, and corruption of software algorithms (**ASIL B/C/D**).
9. The ACS/ETC components and connections are to meet the contamination ingress protection requirements and the corrosion protection requirements. This includes moisture, corrosion, or contamination from the environment or other vehicle components (**ASIL B/C/D**).
10. The ACS/ETC components and connections are to meet the vibration and shock impact requirements (**ASIL B/C/D**).
11. The ACS/ETC components and connections are to meet the ambient temperature requirements taking into account the packaging location in the vehicle. The temperatures of the ACS/ETC components are to be monitored (**ASIL B/C/D**).
12. The ACS/ETC components and connections are to be designed to prevent organic growth from the external environment (e.g., mold) that affects the safe functioning of the ACS/ETC (**ASIL B/C/D**).

13. The ACS/ETC system and components are to mitigate the effects of magnetic interference from other vehicle components, as well as the external environment (**ASIL B/C/D**).
14. The ACS/ETC is to be designed to prevent damage to vehicle components and connections (including other ACS/ETC components and connections) by the HV circuit (electrical arcing, corona effects, back EMF, etc.). This includes damage to low-voltage electronic components, such as microprocessors (**ASIL B/C/D**).
15. Unused connection terminals are to be sealed to prevent the ingress of moisture, corrosion, and contamination from the external environment or other systems in the vehicle (**ASIL B/C/D**).
16. Third party manufactured accessories placed in the driver's foot well are not to interfere with the free movement of the AP or BP, or operation of the APPS or BPPS (**No ASIL - not within the scope of ISO 26262**). **Safety Goals: 1 through 6**
17. The AP and BP are to return to the at-rest (i.e., undepressed) position when released by the driver (**No ASIL - not within the scope of ISO 26262**). **Safety Goals: 1 through 6**

9.3.2 Accelerator Pedal Assembly Safety Requirements

This study identifies three safety requirements for the AP assembly outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all safety goals.

1. AP assembly mechanical faults that result in incorrect measurement of the APP are to be detected and mitigated (**ASIL QM**).
   - Incorrect measurements include deviations from the correct APP value or being stuck at the same value permanently or intermittently.
2. The AP assembly critical mechanical components, including the AP connection to the APPS, are to meet the life and durability requirements of TBD miles without any critical failures (**ASIL C/D**).
3. The AP assembly foot well is to allow for free AP movement and operation of the APPS in the presence of reasonable everyday objects (**No ASIL - not within the scope of ISO 26262**).

9.3.3 EV Powertrain Control Module Safety Requirements

This study identifies 29 EV PCM safety requirements outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all vehicle-level safety goals, unless otherwise specified.

1. In case of a fault in the activation delay or transition time, the ACS/ETC is to invoke the proper fault mitigation strategy including, if required, transitioning to a safe state (**ASIL B/C/D**).

2. The EV PCM is to monitor the CPU temperature and is to maintain the CPU temperature within the acceptable operating range (**ASIL B/C/D**).
3. The EV PCM software is to be secured against all unauthorized access (**ASIL B/C/D**).
4. The ACS/ETC software development process is to comply with the state-of-the-art standards for software development such as ISO/IEC 15504 and Motor Industry Software Reliability Association (MISRA) C/C++ (**ASIL B/C/D**).
5. The EV PCM software algorithm is to correctly write to memory (**ASIL B/C/D**). **Safety Goals: 1 through 6**
6. The EV PCM is to correctly calculate the motor torque required for maintaining the creep speed, and the results are to be qualified for validity and correctness under all vehicle operating conditions (**ASIL B/C/D**). **Safety Goals: 1 through 6**
7. The EV PCM is to have specific conditions for entering a degraded operating state (e.g., the “limp-home” mode), and is not to enter a degraded operating state unless these conditions are met. The driver is to be notified when the EV PCM enters a degraded operating state (**ASIL B/C/D**). **Safety Goals: 1 through 6**
8. The EV PCM software code is to be verified for correctness, including any automatically generated code (**ASIL B/C/D**).
9. The EV PCM is to verify the correctness of all clock or internal EV PCM timing signals (**ASIL B/C/D**).
10. Any unused circuits or pins in the EV PCM are to be properly managed so as to prevent unwanted signals or other interference with the EV PCM function (**ASIL B/C/D**).
11. The EV PCM is to have TBD reliability over the lifetime of the vehicle and under all vehicle operating conditions (such as temperature, vibration, moisture, etc.) (**ASIL C/D**). This includes, but is not limited to:
    - The IC board
    - The memory block
    - The CPU
    - Other electric/electronic subcomponents
12. The EV PCM is to command an increase in the traction motor torque output when the arbitration logic between the driver and other vehicle systems (including requests made when the driver is not pressing the AP) specifies an increase in torque is required and the EV PCM is in a normal operating mode. (**ASIL B/C/D**). **Safety Goals: 1 through 6**
13. The EV PCM is to command a decrease in the traction motor torque output when the arbitration logic between the driver and other vehicle systems (including requests made when the driver is not pressing the AP) specifies a decrease in torque is required and the EV PCM is in a normal operating mode. (**ASIL B/C/D**). **Safety Goals: 1 through 6**
14. The EV PCM is to communicate the correct torque direction to the TICM based on the driver’s selected gear (**ASIL B**). **Safety Goal: 3**

15. The EV PCM is to enter or exit BTO mode at the correct time when the conditions for entering or exiting BTO mode are met (dead-time, activation delay, vehicle speed, APP and BPP, etc.) (**ASIL C**). **Safety Goals: 1 through 6**
16. The EV PCM BTO control algorithm is to enter BTO mode when the driver presses both the AP and BP simultaneously and the vehicle speed is above the pre-set vehicle speed threshold value for BTO. If the vehicle speed is below the pre-set vehicle speed threshold value for BTO, then the EV PCM is not to enter BTO mode. The EV PCM is to monitor the vehicle speed (**ASIL C**). **Safety Goals: 1 through 6**
17. The EV PCM is not to enter BTO mode when the BP is not pressed (**ASIL C**). **Safety Goals: 1 through 6**
18. The EV PCM is not to exit BTO mode while both the AP and BP are still pressed (**ASIL C**). **Safety Goals: 1 through 6**
19. The EV PCM BTO control model design is to be verified and validated for correctness, including pedal sequencing, critical process parameters, and timing (**ASIL C**). **Safety Goals: 1 through 6**
20. Incorporating additional requirements into the BTO algorithm beyond the APP, BPP, and vehicle speed is not to prevent the EV PCM from entering BTO mode when the driver's intention is to stop the vehicle (**ASIL C**). **Safety Goals: 1 through 6**
21. Incorporating additional requirements into the BTO algorithm beyond the APP, BPP, and vehicle speed is not to prevent the EV PCM from exiting BTO mode when the driver's intention is to resume acceleration (**ASIL C**). **Safety Goals: 1 through 6**
22. The EV PCM is not to command an increase in the traction motor torque output while in BTO mode or while transitioning into BTO mode (**ASIL C**). **Safety Goals: 1 through 6**
23. Other vehicle systems are not to have the authority to command the EV PCM to exit BTO mode (**ASIL C**). **Safety Goals: 1 through 6**
24. The EV PCM is not to command an increase in the traction motor torque output when exiting BTO mode unless the driver increases the angular position of the AP and all other conditions for exiting BTO mode are met (**ASIL C**). **Safety Goals: 1 through 6**
25. When entering normal mode, the EV PCM is to resume responding to the driver's torque request via the AP (**ASIL C**). **Safety Goals: 1 through 6**
26. In case of a fault entering BTO mode or entering normal mode, the EV PCM is to invoke the proper fault mitigation strategy, including transitioning into a safe state, if required, and alerting the driver (**ASIL C**). **Safety Goals: 1 through 6**
27. The EV PCM is to be able to detect when the EPS does not respond properly to the EV PCM's command to enter or exit BTO mode. If the EPS is not responding properly, the ACS/ETC is to still be capable of entering BTO mode (**ASIL C**). **Safety Goals: 1 through 6**
28. The EV PCM is to supply the correct reference voltage to the ACS/ETC sensors (**ASIL B/C/D**).

29. The EV PCM is to detect disruptions in the reference voltage supplied to the ACS/ETC sensors (too high, too low, missing, etc.) and transition into the appropriate safe state (**ASIL A/B**).

9.3.4 Electric Powertrain Subsystem Safety Requirements

This study identifies 14 safety requirements for the EPS outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262 [2]). These requirements trace back to all safety goals.

1. The TICM is to have TBD reliability over the lifetime of the vehicle and under all vehicle operating conditions (temperature, vibration, moisture, etc.) (**ASIL C/D**). **Safety Goals: 1 to 5, and 7**
   This includes, but is not limited to:
   - The IC board,
   - The memory block,
   - The CPU, and
   - Other electric/electronic subcomponents.
2. The TICM is to monitor its CPU temperature and is to maintain the CPU temperature within the acceptable operating range (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
3. Any unused circuits or pins in the TICM are to be properly managed so as to prevent unwanted signals or other interference with the TICM function (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
4. The TICM is to verify the correctness of all clock or internal timing signals (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
5. The TICM software code is to be verified for correctness, including any automatically generated code (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
6. The TICM software is to be secured against all unauthorized access (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
7. The TICM software algorithm is to correctly write to memory (**ASIL B/C/D**). **Safety Goals: 1 to 5, and 7**
8. The TICM is to have specific conditions for entering a degraded operating state (e.g., “limp-home” mode) and is not to enter a degraded operating state unless these conditions are met. The EV PCM and the driver are to be notified when the TICM enters a degraded operating state (**ASIL B/C/D**).
9. The EPS is to detect erroneous torque commands issued by malicious intruders or aftermarket components, including commands to the gate drive board to disable the traction motor (**ASIL C/D**).
10. The HV power supply to the traction motor is to meet the requirements for quality (e.g., transients, phase, spikes, noise, etc.) (**ASIL QM**). **Safety Goals: 1 to 5**
11. The ACS/ETC is to maintain the inverter/converter temperature within the operating range. This includes ensuring proper calibration of safety critical parameters for the cooling system (**ASIL B/C/D)**. **Safety Goals: 1 to 5**

- If the inverter/converter temperature cannot be maintained within the acceptable operating range, the ACS/ETC is to enter the appropriate safe state and warn the driver.
- If the cooling system does not operate continually, this includes ensuring the cooling system is operated with the correct timing and duration.

12. The inverter cooling system is to provide sufficient cooling for the inverter/converter under all vehicle operating conditions. If the inverter cooling system also supplies cooling for other vehicle components (e.g., the traction motor), then cooling system is to be able to provide sufficient cooling for all connected components under all vehicle operating conditions (**ASIL B/C/D**). **Safety Goals: 1 to 5**
13. The ACS/ETC is to detect failures in the cooling system, including the coolant delivery mechanism (e.g., hoses, piping, ducts, etc.). In the event of a failure in the cooling system, the ACS/ETC is to enter the appropriate safe state to prevent further violation of any safety goals (**ASIL B/C/D**). **Safety Goals: 1 to 5**
14. The inverter temperature sensor is to be positioned to ensure accurate and representative measurements of the inverter/converter temperature (**ASIL A/B**). **Safety Goals: 1 to 5**

9.3.5 Communication Signals Safety Requirements

This study identifies four safety requirements for critical communication signals that are outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all safety goals.

The critical communication signals:

- APPS signal(s) from the APPS to EV PCM
- APPS fault diagnostics signal
- BPPS signal to EV PCM
- Communication channel “secure” signals between EV PCM and EPS
- Communication channel “secure” signals between EV PCM and the following:
  - ACC/CC
  - Rechargeable Energy Storage System (RESS)
  - Other systems that can request modification to the propulsion torque
- Commands/requests for propulsion torque modifications from interfacing systems to EV PCM
- Vehicle speed signal
- Vehicle direction signal
- Command for torque from the EV PCM to the EPS
- EPS fault diagnostics signal(s)
- Motor speed sensor signal to TICM
- Motor position sensor signal to TICM

- Driver warning signal(s)
- Unauthorized access to HV bus signal from the EPS to RESS controller
- Crash signal from the occupant restraint system control module to EV PCM
- Low voltage power loss from the low voltage power system to EV PCM signal
- Communication bus signal failure from the communication bus to the EV PCM

1. The communication bus signal prioritization strategy is to allow the TBD reporting frequency for data critical to the safe functioning of the ACS/ETC. The reporting frequency is to allow for the timely update of safety-critical data to prevent violation of any safety goals (**ASIL QM/A/B**).
2. The EV PCM is to detect intermittent communication signals in the ACS/ETC system (**ASIL QM/A/B**).
3. The communication bus is to be secured against unauthorized access (**ASIL B/C/D**).
4. Interfacing vehicle systems are to detect and inform the EV PCM of intermittent communication signals between safety critical sensors and the ACS/ETC (**ASIL QM/A/B**).

9.3.6 Power Supply Safety Requirements

This study identifies two safety requirements for the power supply that are outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all safety goals, unless otherwise specified.

1. In the event of a vehicle crash, the low voltage power supply is to maintain the low voltage power supply to the ACS/ETC for a sufficient duration to allow discharging of the HV bus and opening of the contactors (**ASIL B**). **Safety Goal: 7**
2. The necessary supply voltage is to be supplied to interfacing sensors critical to the safe operation of the ACS/ETC and is to meet the quality parameters (levels (min, max), ripple, transient, and overshoot) as set by these safety-critical sensors. The ASIL classification of this requirement is to be based on the safety analysis and the safety goal impacted. **Safety Goals: 1 to 5**
   Typical safety critical interfacing sensors:
   - BPPS
   - Transmission range sensor
   - Vehicle speed sensor (may be provided by the brake/stability control module)
   - Battery state-of-charge sensor (may be provided by the RESS control module)
   - Crash sensor (may be provided by the occupant restraint system control module)

9.3.7 Interfacing Systems Safety Requirements

This study identifies 21 safety requirements for interfacing vehicle systems that are outside the ISO 26262 Functional Safety Concept scope (Part 3 of ISO 26262). These requirements correspond to all safety goals, unless otherwise specified.

1. The interfacing system components critical to the safe functioning of the ACS/ETC are to meet the reliability and functional degradation requirements (**ASIL B/C/D**).
2. Interfacing sensors critical to the safe functioning of the ACS/ETC are to have TBD failure rate for 100,000 miles and under all normal (TBD) vehicle operating conditions (temperature, vibration, moisture, etc.) (**ASIL QM**). **Safety Goals: 1 to 5**
   Sensor failures may include the following.
   - Hardware failure
   - Degradation over time
   - Internal short and increased resistance

   Typical safety critical interfacing sensors include the following.
   - BPPS
   - Transmission range sensor
   - Vehicle speed sensor (may be provided by the brake/stability control module)
   - Battery state-of-charge sensor (may be provided by the RESS control module)
   - Crash signal (may be provided by the occupant restraint system control module)
3. The packaging for interfacing system components and connections critical to the safe functioning of the ACS/ETC is to meet the standards for packaging clearances (**ASIL B/C/D**).
4. The interfacing system components and connections critical to the safe functioning of the ACS/ETC (e.g., vehicle speed, battery state-of-charge, transmission range, etc.) are to be designed to meet the ambient temperature requirements, taking into account the packaging location in the vehicle (**ASIL B/C/D**).
   - The temperatures of the interfacing system sensors critical to the safe functioning of the ACS/ETC (e.g., transmission range sensor, vehicle speed sensor, battery state of charge sensor, etc.) are to be monitored.
5. The interfacing system components and connections critical to the safe functioning of the ACS/ETC are to be protected from physical interference from foreign objects (e.g., road debris) (**ASIL B/C/D**).
6. The interfacing system assemblies critical to the safe functioning of the ACS/ETC are to be free from manufacturing defects. This includes component and connection manufacturing quality in the assembly process (**ASIL B/C/D**).
7. The interfacing vehicle system components and connections critical to the safe functioning of the ACS/ETC are to meet the standards for EMI/EMC and other electrical interference from the environment and other components in the vehicle (**ASIL B/C/D**).

8. The interfacing system components and connections critical to the safe functioning of the ACS/ETC are to meet the contamination ingress protection requirements and the corrosion protection requirements. This includes moisture, corrosion, or contamination from the environment or other vehicle components (**ASIL B/C/D**).
9. The interfacing system components and connections critical to the safe functioning of the ACS/ETC are to meet the vibration and shock impact requirements (**ASIL B/C/D**).
10. The interfacing system components and connections are to be designed to prevent organic growth from the external environment (e.g., mold) that could affect the safe functioning of the ACS/ETC (**ASIL B/C/D**).
11. The interfacing system components critical to the safe functioning of the ACS/ETC are to mitigate the effects of magnetic interference from other vehicle components, as well as the external environment (**ASIL B/C/D**).
12. Interfacing sensors critical to the safe functioning of the ACS/ETC are to have TBD reporting frequency so that the safety critical data is updated with sufficient frequency to prevent violation of a safety goal (**ASIL B/C/D**). **Safety Goals: 1 to 5**
    Typical safety critical interfacing sensors include the following.
    - BPPS
    - Transmission range sensor
    - Vehicle speed sensor (may be provided by the brake/stability control module)
    - Battery state-of-charge sensor (may be provided by the RESS control module)
    - Crash signal (may be provided by the occupant restraint system control module)
13. Software code for control modules in interfacing systems that are critical for the safe functioning of the ACS/ETC is to be verified for correctness, including any automatically generated code (**ASIL B/C/D**).
    This may include the following control modules.
    - Brake/stability control module (if used to process and communicate vehicle speed information)
    - RESS control module (if used to process and communicate information about the status of the HV system)
    - Occupant restraint system controller (crash signal)
14. Propulsion torque modification capable systems are to correctly identify themselves according to the EV PCM prioritization strategy when issuing torque requests to the EV PCM (**ASIL B/C/D**). **Safety Goals: 1 through 6**
15. The traction motor is to prevent locked motor rotor conditions (**ASIL B/C/D**). **Safety Goals: 1 to 5**
    - In case of a failure to prevent a locked rotor condition, the vehicle system controller is to transition into Safe State 6, and a red-level driver warning is to be delivered to the driver.
16. The BPP value is to be measured, and the value is to be valid and correct (**ASIL B/C/D**). **Safety Goals: 1 to 5**

17. The BP assembly foot well is to allow for free pedal movement and operation of the BBPS in the presence of reasonable everyday objects (**No ASIL — not within the scope of ISO 26262**). **Safety Goals: 1 to 5**.
18. The BP assembly critical mechanical components, including the BP connection to the BPPS, are to meet the life and durability requirements without any critical failures (**No ASIL — not within the scope of ISO 26262**). **Safety Goals: 1 to 5**
19. BP mechanical assembly faults that result in incorrect measurement of the BPP are to be detected and mitigated (**No ASIL — not within the scope of ISO 26262**). **Safety Goals: 1 to 5**
    - Incorrect measurements include deviations from the correct BPP value or being stuck at the same value permanently or intermittently.
20. Interfacing sensors critical to the safe functioning of the ACS/ETC are to have the correct reference voltage supply (**ASIL B/C/D**). **Safety Goals: 1 to 5**
    Safety-critical interfacing sensors may include the following.
    - BPPS
    - Transmission range sensor
    - Vehicle speed sensor (may be provided by the brake/stability control module)
    - Battery state-of-charge sensor (may be provided by the RESS control module)
    - Crash signal (may be provided by the occupant restraint system control module)
21. Interfacing systems are to inform the EV PCM of any disruptions to the reference voltage supplied to sensors critical to the safe functioning of the ACS/ETC (too high, too low, missing, etc.) (**ASIL B/C/D**).

10 OBSERVATIONS

This study follows the process in the ISO 26262 Concept Phase to develop safety requirements for the ACS/ETC system. This section discusses three observations made from applying the ISO 26262's ASIL assessment approach.

10.1 Automotive Safety Integrity Level May Depend on Feature's Operational Situations

In ISO 26262 the ASIL assessment approach requires the safety analyst to review every vehicle operational situation and assign an ASIL for the hazard of interest. At the end, the hazard takes the most severe ASIL among all operational situations.

However, for a feature that may not be used in all vehicle operational situations, the ASIL could be too stringent. This project identified at least one feature that only operates in a subset of the operational situations — the Hill Holder feature only operates when the vehicle speed is zero. The ASIL for operational situations when vehicle speed is zero is much less severe than the worst-case operational situation, mainly due to the lower severity at the lower speed (this assumes the vehicle does not reach high speeds, which may have higher severity). Therefore, H1.a has an ASIL B, while H1 has an ASIL D (Table 23).

Therefore, the following approach may be considered in future ASIL assessments.

1. Treat the vehicle as a black box with no assumptions about its designs and features. Choose the most severe ASIL for each hazard.
2. When designing a vehicle feature, review the operational situations used for the ASIL assessment. If the feature only operates in a subset of the operational situations, choose the ASIL for that feature based on the most severe ASIL within that subset of operational situations.

10.2 Generation of Operational Situations

The current industry practice generates the operational situations based on safety experts' experiences as well as known drive cycles. This study initially followed this approach. After reviewing the operational situations generated relying on industry knowledge, Table 17 was generated to characterize the variables considered. Using this variable list, this study generated an exhaustive combination of all the variables and their states, and compared this exhaustive combination with the operational situations identified using industry knowledge. The comparison found additional operational situations. These additional operational situations were then further assessed and added.

Furthermore, when reviewing the variables and their states in Table 17, this study also realized that it was possible to further extend and improve this list using the variables and codes specified in NHTSA's vehicle crash databases [16]. In addition, naturalistic driving data may also help contribute to the variable list. The benefits of using the variables in the existing NHTSA databases could include the following.

- Leveraging prior work to help make the operational situations more comprehensive.
- Potentially only performing the analysis once for all vehicle motion-related hazards. The resulting comprehensive operational situations may be applicable to all current and future safety analyses.
- Connect the operational situations to crash data and naturalistic driving data, which may facilitate the quantitative analysis for severity and exposure.

Therefore, the following may be considered for future improvements of the ASIL assessment approach:

1. Develop a comprehensive variable list describing the vehicle operational situations based on NHTSA's crash databases and naturalistic driving data sets.
2. The exhaustive combinations of the identified variables and their states may create a long list of operational situations. Develop a method to efficiently examine the operational situations for each vehicle-level hazard.

10.3 Variations in the Automotive Safety Integrity Level Assessment

In the course of this study, not all safety analysts on the project team agreed to the same assessment for exposure and controllability. This is due to the fact that objective data typically do not exist to support the assessment, and expert opinions are often used. This observation corroborates previous assessments of ISO 26262 [17] [18].

ISO 26262 recommends the use of expert inputs when objective data are not available. This helps the completion of the ASIL assessment. However, there are drawbacks to this approach. With regards to exposure, psychologists studying human decision making have shown that humans are not good at predicting truly random events, especially rare events [19]. For example, the availability of an event in the risk analyst's mind, and how vividly the event is described, heavily influence the subjective probability assessment. Therefore, the assessment of exposure may vary among safety experts and it is difficult to decide who is right in the absence of objective data [17] [18].

In addition, ISO 26262 assesses controllability based on average/majority drivers' ability to retain control of the vehicle in a certain operational situation. However, the standard provides no definition on the ability of the average/majority driver.

The following may be considered to potentially improve the severity, exposure, and controllability assessments:

- Statistics from the NTHSA crash databases are available to support the assessment of severity.

- Statistics for the assessment of exposure could be derived from the naturalistic driving scenarios.
- Statistics are not publicly available for the assessment of controllability. Further investigations are needed to understand how to more rigorously assess controllability using objective data.

11 POTENTIAL USE OF STUDY RESULTS

The results of this study may be useful in the following ways:

- This study derives 202 potential safety requirements for the EV ACS/ETC system following the Concept Phase process (Part 3) in ISO 26262. These requirements may serve as an illustration of the process the automotive industry to review and compare with their own functional safety requirements.
- For practitioners who are not yet following the ISO 26262 process, this study may provide additional insights on the process of deriving functional safety requirements for an EV ACS/ETC system.
- This study applies three hazard and safety analysis methods — the HAZOP study, Functional FMEA, and STPA. While the automotive industry is familiar with the HAZOP study and Functional FMEA, STPA is a relatively new method. For those who are following the ISO 26262 process for functional safety, this study may serve as an example of the use and results of STPA.

12 CONCLUSIONS

This study followed the Concept Phase process (Part 3) in ISO 26262 to derive a list of potential safety requirements for a generic ACS/ETC system. Specifically, this research:

1. Identified seven vehicle-level safety goals and assessed their ASIL:

ID	Safety Goals	ASIL
SG 1	Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 for a period greater than TBD s is to be mitigated in accordance to the identified ASIL level.	D
SG 1a	Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than TBD m/s^2 with zero speed at start is to be mitigated in accordance to the identified ASIL level.	B
SG 2	Potential insufficient vehicle propulsion[i] is to be mitigated in accordance to the identified ASIL level.	C[ii]
SG 3	Potential vehicle movement in the wrong direction is to be mitigated in accordance to the identified ASIL level.	C
SG 4	Potential propulsion power loss/reduction resulting in vehicle deceleration greater than TBD m/s^2 is to be mitigated in accordance to the identified ASIL level.	D
SG 5	Potential insufficient vehicle deceleration[i] is to be mitigated in accordance to the identified ASIL level.	C[ii]
SG 6	The ACS/ETC control algorithm is to choose the torque command that has the highest priority for safety in accordance to the identified ASIL level.	D
SG 7	Potential electric shock is to be mitigated in accordance to the identified ASIL level.	B

i. *Insufficient vehicle propulsion/deceleration is defined as the vehicle deviating from the correctly functioning speed increase/decrease profile under any operating conditions by more than TBD sigma. These hazards specifically relate to speed increases or decreases that result from the driver increasing or decreasing the angular position of the AP.*

ii. *The ASIL assessment for the hazard associated with this safety goal varied among safety analysts in the absence of objective data. This study finds that objective data are not readily available for the assessment of the three dimensions used to determine the ASIL--severity, exposure, and controllability.*

As shown by SG 2 and SG 5 in the above table, ASIL assessments can vary between analysts without the support of objective data. Variations in the ASIL assessment may lead to different levels of safety requirements for the same hazard.

- Data to support assessment of severity may be available from NHTSA's crash databases.
- Data to support assessment of exposure are not readily available, but may be derived from naturalistic driving data sets.
- No publically available data are available to support assessment of controllability.

2. Developed the functional safety concept and identified 112 illustrative functional safety requirements by following the Concept Phase in the ISO 26262, combining the results of

the two safety analyses (Functional FMEA and STPA), and leveraging industry practice experiences. The breakdown of the number of requirements is as follows.

- General EV ACS/ETC System – 11 requirements
- AP Assembly – 8 requirements
- EV PCM – 49 requirements
- EPS – 28 requirements
- Communication Signals – 5 requirements
- Power Supply (low and high voltage) – 6 requirements
- Interfacing Systems – 5 requirements

3. Identified additional 90 illustrative safety requirements based on the comprehensive results of the safety analyses (Functional FMEA and STPA), and by following the additional safety strategy in MIL-STD-882E. The breakdown of the number of requirements is as follows.

    - General EV ACS/ETC System – 17 requirements
    - AP Assembly – 3 requirements
    - EV PCM – 29 requirements
    - EPS – 14 requirements
    - Communication Signals – 4 requirements
    - Power Supply (low and high voltage) – 2 requirements
    - Interfacing Systems – 21 requirements

    These 90 requirements are out of the scope of the Functional Safety Concept phase in ISO 26262 (Part 3 of ISO 26262). However, subsequent steps in the ISO 26262 process — Systems Engineering (Part 4), Hardware Development (Part 5), and Software Development (Part 6) — cascade the Functional Safety Concept requirements into additional development-specific safety requirements, and may identify these 90 requirements.

13 REFERENCES

[1] National Highway Traffic Safety Administration, *Notice of Proposed Rulemaking: Federal Motor Vehicle Safety Standards; Accelerator Control Systems,* [77 Federal Register 22637-22662 (April 16, 2012); DOT Docket No. NHTSA-2012-0038].

[2] ISO 26262 Road Vehicles - Functional Safety, Final Draft (FDIS), 2011.

[3] Department of Defense. (2012). Department of Defense Standard Practice: System Safety (MIT-STD-882E). Washington, DC: Author.

[4] International Electrotechnical Commission. (2001). IEC 61882: Hazard and Operability Studies (HAZOP Studies) - Application Guide, 2001-05, Edition 1.0. Geneva: Author.

[5] Leveson, N. (2012). *Engineering a safer world*. Cambridge, MA: MIT Press.

[6] SAE J1739: Potential Failure Mode and Effects Analysis in Design and Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes, 1994-07. Warrendale, PA: Society of Automotive Engineers.

[7] Thomas, J. (2013). *Extending and automating a systems-theoretic hazard analysis for requirements generation and analysis* (Ph.D. dissertation). Cambridge, MA: Massachusetts Institute of Technology.

[8] Coudert, O. (1994). Two-Level Logic Minimization: An Overview. *Integration, the VLSI Journal, 17-2*, p. 97-140.

[9] Toyota Motor Sales, UCA, Inc. (2010, March 19). Brake Override System (Web page). Retrieved from the Toyota website at http://toyota2.tekgroupweb.com/article_download.cfm?article_id=2390

[10] Rippel, W. (2007, January 9). Induction versus DC brushless motors (Web log post). Retrieved from www.teslamotors.com/blog/induction-versus-dc-brushless-motors

[11] Gordon-Bloomfield, N. (2011, June 15). Should electric cars mimic the gasoline driving experience (Green Car Reports web page). Retrieved from www.greencarreports.com/news/1061657_should-electric-cars-mimic-the-gasoline-driving-experience

[12] Solberg, G. (2007, June 9). The magic of Tesla Roadster regenerative braking (Web page). Retrieved from the Tesla Motors web site at www.teslamotors.com/blog/magic-tesla-roadster-regenerative-braking

[13] Alcala, I., Claudio, A., & Guerrero, G. V. (2005). Analysis of propulsion systems in electric vehicles. In *2nd International Conference on Electrical and Electronics Engineering*, Mexico City, Sept. 7-9, 2005.

[14] Krohn, K. (2013, September). Freescale - Building a basic inverter (Web page). Retrieved from www.freescale.com/files/training/doc/dwf/DWF13_AMF_AUT_T0144.pdf

[15] Whaling, C. (2013, December). Electric Drive Power Electronics: An Overview (Web page). IEEE Transportation Electrification.Available at https://tec.ieee.org/newsletter/december-2013/electric-drive-power-electronics-an-overview?highlight=WyJlbGVjdHJpYyIsIidlbGVjdHJpYyciLCJlbGVjdHJpYyciLCJkcml2ZSIsImRyaXZlJ3MiLCJwb3dlciIsImVsZWN0cm9uaWNzIiwiYW4iLCJvdmVydmlldyIsImVsZWN0cmljIGRyaXZlIiwiZWxlY3RyaWMgZHJpdmUgcG93ZXIiLCJkcml2ZSBwb3dlciIsImRyaXZlIHBvd2VyIGVsZWN0cm9uaWNzIiwicG93ZXIgZWxlY3Ryb25pY3MiLCJwb3dlciBlbGVjdHJvbmljcyBhbiIsImVsZWN0cm9uaWNzIGFuIiwiZWxlY3Ryb25pY3MgYW4gb3ZlcnZpZXciLCJhbiBvdmVydmlldyJd

[16] National Highway Traffic Safety Administration. (n.a.) (National Automotive Sampling System (NASS) General Estimate System (GES) Analytical User's Manual, 1988-2012 (Unnumbered, undated report). Washington DC: National Highway Traffic Safety Administration. Available at ftp://ftp.nhtsa.dot.gov/GES/GES12/GES%20Analytical%20Users%20Manual%201988-2012_FINAL-2013-10-31.pdf

[17] Van Eikema Hommes, Q. D. (2012, April 16). Review and assessment of the ISO 26262 draft road vehicle - Functional safety (Paper No. SAE 2012-01-0025). SAE 2012 World Congress & Exhibition, Detroit, MI, April 24-26, 2012. DOI: 10.4271/2012-01-0025

[18] Van Eikema Hommes, Q. D. (2016, June). *Assessment of safety standards for automotive electronic control systems*. (Report No. DOT HS 812 285). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/sites/nhtsa.dot.gov/files/812285_electronicsreliabilityreport.pdf

[19] Kahneman, D. (2013, April). *Thinking, fast and slow*. New York: Farrar, Straus, and Giroux.

[20] Robert Bosch GmbH.(2013). Gasoline Port Fuel Injection (Web page). Retrieved from the Bosch web site at www.bosch-mobility-solutions.com/media/en/ubk_europe/db_application/downloads/pdf/antrieb/de_5/pfi_full_de.pdf

[21] Clemson University Vehicular Electronics Laboratory. (n.a.). Electronic Throttle Control (Web page). Retrieved from the Clemson University web site at www.cvel.clemson.edu/auto/systems/throttle_control.html

[22] NASA Engineering and Safety Center. (2011, January 11). National Highway Traffic Safety Administration Toyota Unintended Acceleration Investigation: Technical Support to the National Highway Traffic Safety Administration (NHTSA) on the Reported Toyota Motor Corporation (TMC) Unintended Acceleration (UA) Investigation (NESC Assessment #: TI-10-00618). Hampton, VA: Author. Available at www.nhtsa.gov/staticfiles/nvs/pdf/NASA-UA_report.pdf

[23] Van Eikema Hommes, Q. D. (2014, March 27). Applying STAMP Framework to Analyze Automotive Recalls (PowerPoint presentation). MIT 3rd STAMP/STPA Workshop, Cambridge, MA, March 25-27, 2014. Available at http://psas.scripts.mit.edu/home/wp-content/uploads/2014/03/Hommes-STAMP-2014-Presentation-140327.pdf

[24] Van Eikema Hommes, Q., Becker, C., Najm, W., & Won, C. (in press). A Scientific Foundation for Analyzing Safety Issues in Automotive Electronic Control Systems. Washington, DC: National Highway Traffic Safety Administration.

[25] Lampton, C. (2009, January 23). How Regenerative Braking Works (HowStuffWorks website). Retrieved from http://auto.howstuffworks.com/auto-parts/brakes/brake-types/regenerative-braking.htm

APPENDIX A: STPA CAUSAL FACTOR GUIDEWORDS AND GUIDEWORDS SUBCATEGORIES

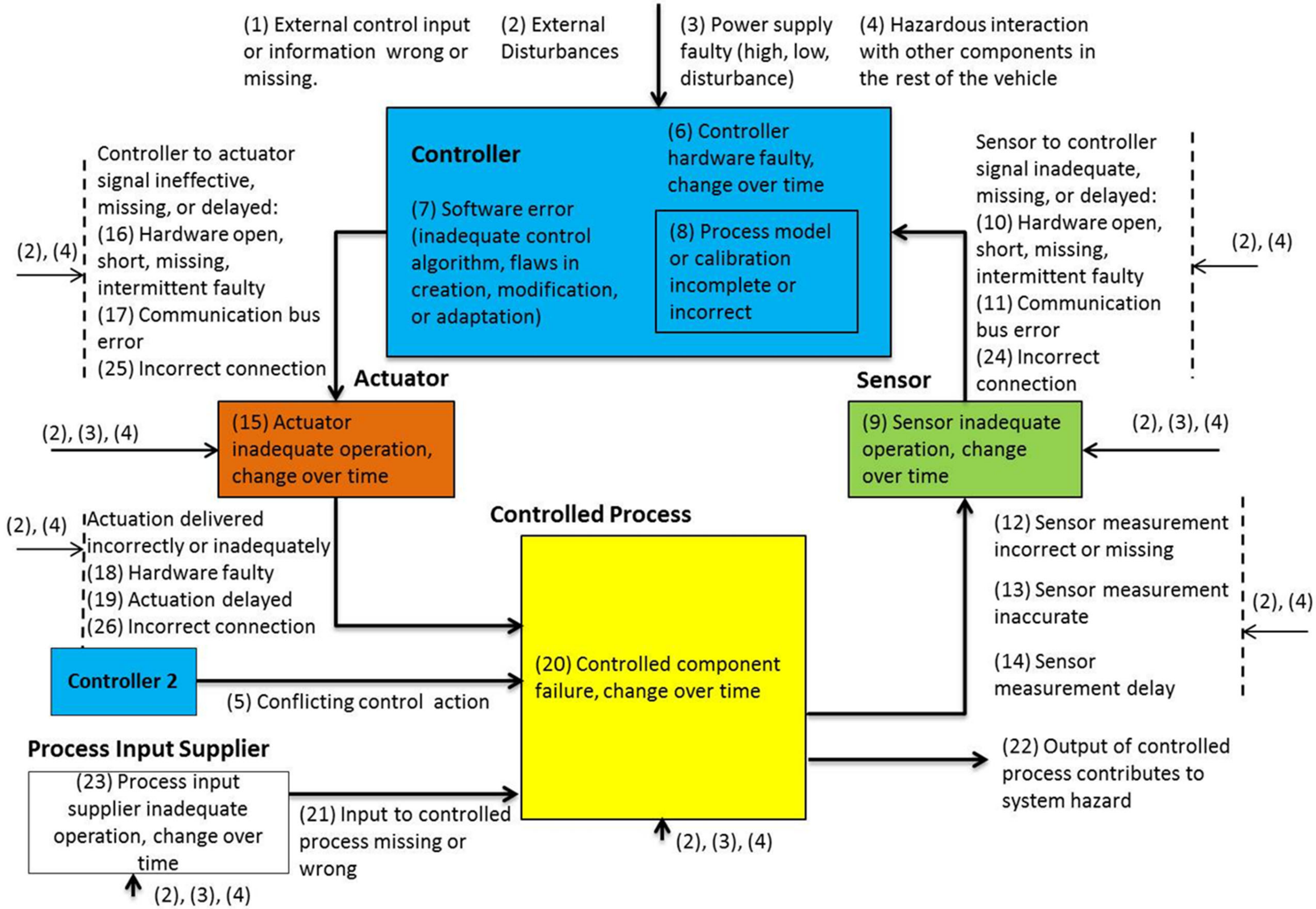

Figure A-1. Causal Factor Categories for Automotive Electronic Control Systems

Table A-1. Causal Factor Subcategories for Automotive Electronic Control Systems

The numbering in the table below corresponds to those in Figure A-10.

Components	
Controller	**(6) Controller hardware faulty, change over time**
	Internal hardware failure Overheating due to increased resistance in a subcomponent or internal shorting Over temperature due to faulty cooling system Degradation over time Faulty memory storage or retrieval Faulty internal timing clock Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters) Unused circuits in the controller
	(7) Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)
	Inadequate control algorithm Flaws in software code creation
	(8) Process model or calibration incomplete or incorrect
	Sensor or actuator calibration, including degradation characteristics Model of the controlled process, including its degradation characteristics
	(2) External control input or information wrong or missing
	Timing-related input is incorrect or missing Spurious input due to shorting or other electrical fault Corrupted signal Malicious Intruder
	(3) Power supply faulty (high, low, disturbance)
	Loss of 12-volt power Power supply faulty (high, low, disturbance)
	(2) External disturbances
	EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing)

	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Moisture, corrosion, or contamination Excessive heat from other components Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components
Sensor	**(9) Sensor inadequate operation, change over time** Internal hardware failure Overheating due to increased resistance in a subcomponent or internal shorting Degradation over time Over temperature due to faulty cooling system Reporting frequency too low
	(3) Power supply faulty (high, low, disturbance) Loss of 12-volt power Reference voltage incorrect (e.g., too low, too high) Power supply faulty (high, low, disturbance)
	(2) External disturbances EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Magnetic interference
	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Moisture, corrosion, or contamination Excessive heat from other components Magnetic interference Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components

Actuator	**(15) Actuator inadequate operation, change over time** Internal hardware failure Degradation over time Over temperature due to faulty cooling system Incorrectly sized actuator Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts Overheating due to increased resistance in a subcomponent or internal shorting
	(3) Power supply faulty (high, low, disturbance) Loss of 12-volt power Power supply faulty (high, low, disturbance)
	(2) External disturbances EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Magnetic interference
	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Moisture, corrosion, or contamination Excessive heat from other components Magnetic interference Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Unable to meet demands from multiple components (e.g., inadequate torque)
Controlled Process	**(20) Controlled component failure, change over time** Internal hardware failure Degradation over time
	(3) Power supply faulty (high, low, disturbance) Loss of 12-volt power Power supply faulty (high, low, disturbance)

Controlled Process	**(2) External disturbances** EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Magnetic interference
	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Moisture, corrosion, or contamination Excessive heat from other components Magnetic interference Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Unable to meet demands from multiple components (e.g., inadequate torque)
	(22) Output of controlled process contributing to system hazard
Process Input Supplier to Controlled Process	**(23) Process input supplier inadequate operation, change over time** Process input supplier inadequate operation, change over time Electrical noise other than EMI or ESD
	(3) Power supply faulty (high, low, disturbance) Loss of 12-volt power Power supply faulty (high, low, disturbance)
	(2) External disturbances EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Magnetic interference

	(4) Hazardous interaction with other components in the rest of the vehicle
	EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Moisture, corrosion, or contamination Excessive heat from other components Magnetic interference Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Unable to meet demands from multiple components (e.g., inadequate torque)
Connections	
Sensor to Controller, Controller to Actuator	**(10) and (16) Hardware open, short, missing, intermittent faulty**
	Connection is intermittent Connection is open, short to ground, short to battery, or short to other wires in harness Electrical noise other than EMI or ESD Connector contact resistance is too high Connector shorting between neighboring pins Connector resistive drift between neighboring pins
	(11) and (17) Communication bus error
	Bus overload or bus error Signal priority too low Failure of the message generator, transmitter, or receiver Malicious intruder
	(24) and (25) Incorrect connection
	Incorrect wiring connection Incorrect pin assignment
	(2) External disturbances
	EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Unused connection terminals affected by moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Active connection terminals affected by moisture, corrosion, or contamination

	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Unused connection terminals affected by moisture, corrosion, or contamination Excessive heat from other components Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Active connection terminals affected by moisture, corrosion, or contamination Mechanical connections affected by moisture, corrosion, or contamination
Actuator to Controlled Process	**(18) Actuation delivered incorrectly or inadequately: Hardware faulty**
	(19) Actuation delayed
	(20) Actuator to controlled process incorrect connection
	(2) External disturbances EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Unused connection terminals affected by moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Active connection terminals affected by moisture, corrosion, or contamination Mechanical connections affected by moisture, corrosion, or contamination
	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Unused connection terminals affected by moisture, corrosion, or contamination Excessive heat from other components Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Active connection terminals affected by moisture, corrosion, or contamination Mechanical connections affected by moisture, corrosion, or contamination

Controlled Process to Sensor	**(12) Sensor measurement incorrect or missing** Sensor incorrectly aligned/positioned
	(13) Sensor measurement inaccurate Sensor incorrectly aligned/positioned
	(14) Sensor measurement delay Sensor incorrectly aligned/positioned
	(2) External disturbances EMI or ESD Single event effects (e.g., cosmic rays, protons) Vibration or shock impact Manufacturing defects and assembly problems Extreme external temperature or thermal cycling Unused connection terminals affected by moisture, corrosion, or contamination Organic growth Physical interference (e.g., chafing) Active connection terminals affected by moisture, corrosion, or contamination Mechanical connections affected by moisture, corrosion, or contamination
	(4) Hazardous interaction with other components in the rest of the vehicle EMI or ESD Vibration or shock impact Physical interference (e.g., chafing) Unused connection terminals affected by moisture, corrosion, or contamination Excessive heat from other components Electrical arcing from neighboring components or exposed terminals Corona effects from high voltage components Active connection terminals affected by moisture, corrosion, or contamination Mechanical connections affected by moisture, corrosion, or contamination
Other Controller to Controlled Process	**(5) Conflicting control action**
Process Input Supplier to Controlled Process	**(21) Input to controlled process missing or wrong**

APPENDIX B: HAZOP STUDY RESULTS

Table B-1. Function 1: Command Torque From the Electric Powertrain System

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F1-1	Does not command torque	1) Propulsion power reduction/loss or vehicle stalling
F1-2	Command more torque than intended	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero 3) Insufficient vehicle deceleration
F1-3	Commands less torque than intended	1) Propulsion power reduction/loss or vehicle stalling 2) Insufficient vehicle propulsion
F1-4	Commands torque in the wrong direction	1) vehicle movement in the wrong direction 2) Propulsion power reduction/loss or vehicle stalling
F1-5	Commands torque intermittently	1) Propulsion power reduction/loss or vehicle stalling 2) Insufficient vehicle propulsion
F1-6	Commands torque when not intended	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero
F1-7	Torque command stuck at same value	1) Insufficient vehicle propulsion 2) Insufficient vehicle deceleration 3) Propulsion power reduction/loss or vehicle stalling

Table B-2. Function 2: Receive Energy From High Voltage DC Bus

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F2-1	Does not receive energy from the HVDC bus	1) Propulsion power reduction/loss or vehicle stalling
F2-2	Receives more energy from the HVDC bus than intended	N/A
F2-3	Receives less energy from the HVDC bus than intended	1) Propulsion power reduction/loss or vehicle stalling 2) Insufficient vehicle propulsion
F2-4	Receives HVDC bus energy in the wrong direction	N/A
F2-5	Receives HVDC bus energy in the intermittently	1) Propulsion power reduction/loss or vehicle stalling 2) Insufficient vehicle propulsion
F2-6	Receives HVDC bus energy when not requested	No effect
F2-7	Receives HVDC bus energy at the same level	1) Insufficient vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling

Table B-3. Function 3: Provide Accelerator Pedal Position to the Engine Control Module

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F3-1	Does not provide the APP to the ECM	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F3-2	Provides larger APP travel position than intended	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero
F3-3	Provides smaller APP travel position than intended	1) Insufficient vehicle propulsion
F3-4	Provides APP position intermittently	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero
F3-5	Provides APP travel position in the wrong direction	1) Propulsion power reduction/loss or vehicle stalling 2) Uncontrolled vehicle propulsion
F3-6	Provides APP travel position when not intended	None. This condition is for un-intended correct information.
F3-7	Does not update APP travel position (stuck)	1) Uncontrolled vehicle propulsion 2) Insufficient vehicle propulsion 3) Insufficient vehicle deceleration 4) Propulsion power reduction/loss or vehicle stalling

Table B-4. Function 4: Return Accelerator Pedal to Off (un-depressed) Position in a Specified Time (ignore this section per ISO 26262 if the function is performed through mechanical means)

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F4-1	Does not return AP to Off position within specified time	1) Vehicle speed decrease is not achieved as intended
F4-2	Returns AP to Off position too fast	1) Propulsion power reduction/loss or vehicle stalling
F4-3	Returns AP to Off position within too long time	1) Vehicle speed decrease is not achieved as intended
F4-4	Returns AP past the OFF position	Unknown
F4-5	Returns AP "short" of the Off position	1) Uncontrolled vehicle propulsion
F4-6	Returns AP to Off position intermittently	1) Uncontrolled vehicle propulsion
F4-7	Moves the AP when released in the opposite direction of the OFF position	1) Uncontrolled vehicle propulsion
F4-8	Moves the AP when released to the Off position when not intended	Not a possible failure scenario
F4-9	Does not move AP from its position when un-depressed	1) Uncontrolled vehicle propulsion

Table B-5. Function 5: Provide Accelerator Pedal Rate Limiting

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F5-1	Does not limit the AP request rate	None.
F5-2	Over-limits the AP request rate	1) Insufficient vehicle propulsion.
F5-3	Under limits the AP request rate	None.
F5-4	Limits the AP request rate intermittently	None.
F5-5	Limits the AP request rate in the opposite direction (+ vs. -)	1) Insufficient vehicle propulsion.
F5-6	Limits the AP request rate when not required	1) Insufficient vehicle propulsion.
F5-7	Limits the AP request rate using the same limit profile	None.

Table B-6. Function 6: Communicate the Delivered Torque Magnitude and Direction to the Engine Control Module

I.D.	***Malfunction***	***Potential Vehicle Level Hazard***
F6-1	Does not communicate the torque magnitude and direction to the ECM	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F6-2	Over communicates the torque magnitude and direction to the ECM	None.
F6-3	Under communicates the torque magnitude and direction to the ECM	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F6-4	Communicates the torque magnitude and direction to the ECM intermittently	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F6-5	Communicates the torque magnitude and direction to the ECM in the wrong direction	None.
F6-6	Communicates the torque magnitude and direction to the ECM when not required	None.
F6-7	Communicates the same torque magnitude and direction to the ECM (stuck)	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction

Table B-7. Function 7: Return the Torque Output to the Creep Value in Specified Time

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F7-1	Does not return torque output to creep value in the specified time	1) Insufficient vehicle deceleration.
F7-2	Takes too long to return torque output to creep value	1) Insufficient vehicle deceleration.
F7-3	Returns torque output to creep value too fast	None.
F7-4	Returns torque output to lower than creep value	None.
F7-5	Returns torque output to above creep value	1) Uncontrolled vehicle propulsion when the vehicle speed is zero. 2) Insufficient vehicle deceleration
F7-6	Returns torque output to creep value intermittently	1) Insufficient vehicle deceleration.
F7-7	Moves torque output in the opposite direction of the creep value	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero
F7-8	Returns torque output to creep value when not intended	1) Propulsion power reduction/loss or vehicle stalling
F7-9	Does not return torque output to creep value from initial position (stuck)	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Uncontrolled vehicle propulsion when the vehicle speed is zero 4) Insufficient vehicle deceleration

Table B-8. Function 8: Establish Creep Torque Value

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F8-1	Does not establish creep torque value	None.
F8-2	Sets creep torque value too high	1) Uncontrolled vehicle propulsion when the vehicle speed is zero 2) Insufficient vehicle deceleration
F8-3	Sets creep torque value too low	None.
F8-4	Sets creep torque value intermittently	1) Uncontrolled vehicle propulsion when the vehicle speed is zero 2) Propulsion power reduction/loss or vehicle stalling
F8-5	Sets creep torque value in the wrong direction	1) vehicle movement in the wrong direction
F8-6	Sets creep torque value when not required	None.
F8-7	Does not update the creep torque value	N/A

Table B-9. Function 9: Provide Creep Torque Control

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F9-1	Does not control the creep torque	1) Uncontrolled vehicle propulsion when the vehicle speed is zero 2) Propulsion power reduction/loss or vehicle stalling 3) Vehicle movement in the wrong direction 4) Insufficient vehicle deceleration
F9-2	Provides excessive control of the creep torque	None.
F9-3	Provides in-sufficient control of the creep torque	1) Uncontrolled vehicle propulsion when the vehicle speed is zero 2) Propulsion power reduction/loss or vehicle stalling 3) Vehicle movement in the wrong direction 4) Insufficient vehicle deceleration
F9-4	Provides creep torque control intermittently	1) Propulsion power reduction/loss or vehicle stalling
F9-5	Provides creep torque control in the opposite of the correct direction	1) Vehicle movement in the wrong direction 2) Propulsion power reduction/loss or vehicle stalling
F9-6	Provides creep torque control when not required	None.
F9-7	Maintains the creep torque at the same position (stuck)	N/A

Table B-10. Function 10: Provide “Brake Throttle” Override Control

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F10-1	Does not provide BTO control	1) Uncontrolled vehicle propulsion 2) Vehicle speed decrease not achieved as intended 3) Propulsion power reduction/loss or vehicle stalling 4) Uncontrolled vehicle propulsion when the vehicle speed is zero
F10-2	Provides excessive control of the BTO - Within a "grace time" period (very short overlap of AP and BP at high speed)	None.
F10-3	Provides in-sufficient control of the BTO	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero
F10-4	Provides control in the opposite of the correct direction of the BTO	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Uncontrolled vehicle propulsion when the vehicle speed is zero
F10-5	Provides BTO control intermittently	1) Uncontrolled vehicle propulsion 2) Uncontrolled vehicle propulsion when the vehicle speed is zero 3) Insufficient vehicle deceleration
F10-6	Provides BTO control when not intended	1) Propulsion power reduction/loss or vehicle stalling
F10-7	Does not update the BTO control state (stuck)	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Uncontrolled vehicle propulsion when the vehicle speed is zero 4) Propulsion power reduction/loss or vehicle stalling

Table B-11. Function 11: Store the Accelerator Pedal Position (and EPS RPM) Torque Maps

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F11-1	Does not store the APP torque maps	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F11-2	Stores values higher than the intended values of the maps	1) Uncontrolled vehicle propulsion 1) Insufficient vehicle deceleration 3) Uncontrolled vehicle propulsion when the vehicle speed is zero
F11-3	Stores values lower than the intended values in the maps	1) Propulsion power reduction/loss or vehicle stalling 2) Insufficient vehicle propulsion 3) Vehicle stalling 4) vehicle movement in the wrong direction
F11-4	Stores values in the maps intermittently	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F11-5	Stores values opposite in values than the intended values in the maps	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F11-6	Stores values when no values are intended in the maps	Not a viable condition.
F11-7	Stores the same values in all locations of the maps	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction

Table B-12. Function 12: Provide Bus Capacitance Discharge Request

I.D.	***Malfunction***	***Potential Vehicle Level Hazard***
F12-1	Does not request bus capacitance discharge	1) Exposure to high voltage
F12-2	Requests bus capacitance over-discharge	None.
F12-3	Requests bus capacitance under-discharge	1) Exposure to high voltage
F12-4	Requests bus capacitance discharge intermittently	1) Exposure to high voltage
F12-5	Requests bus capacitance charge	1) Exposure to high voltage
F12-6	Request bus capacitance discharge at the wrong time (when not required)	None
F12-7	Requests bus capacitance discharge all the time (stuck)	None

Table B-13. Function 13: Discharge the Bus Capacitance

I.D.	***Malfunction***	***Potential Vehicle Level Hazard***
F13-1	Does not discharge the bus capacitance	1) Exposure to high voltage
F13-2	Over-discharges the bus capacitance	None
F13-3	Under-discharges the bus capacitance	1) Exposure to high voltage
F13-4	Discharges the bus capacitance intermittently	1) Exposure to high voltage
F13-5	Charges the bus capacitance	1) Exposure to high voltage
F13-6	Discharges the bus capacitance when not required	None
F13-7	Discharges the bus capacitance all the time (stuck)	None

Table B-14. Function 14: Communicate with Internal Sub-systems and External Vehicle Systems

I.D.	***Malfunction***	***Potential Vehicle Level Hazard***
F14-1	Does not communicate with interfacing sub-systems and systems	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage
F14-2	Over communicates with interfacing sub-systems and systems	None.
F14-3	Under communicates with interfacing sub-systems and systems	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage
F14-4	Communicates intermittently with interfacing sub-systems and systems	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage
F14-5	Communicates with interfacing sub-systems and systems when not intended	None.
F14-6	Communicates the same messages with interfacing sub-systems and systems	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage

Table B-15. Function 15: Provide Diagnostics (DTC)

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F15-1	Does not provide diagnostics	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage
F15-2	Provides diagnostics more than intended	None
F15-3	Provides diagnostics less than intended	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction
F15-4	Provides diagnostics intermittently	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage
F15-5	Provides diagnostics when not intended	None
F15-6	Provides the same diagnostics (stuck)	1) Uncontrolled vehicle propulsion 2) Propulsion power reduction/loss or vehicle stalling 3) Insufficient vehicle propulsion 4) Insufficient vehicle deceleration 5) Uncontrolled vehicle propulsion when the vehicle speed is zero 6) Vehicle movement in the wrong direction 7) Exposure to high voltage

Table B-16. Function 16: Provide Fault Detection and Failure Mitigation

<table>
<tr><th>I.D.</th><th>Malfunction</th><th>Comment</th></tr>
<tr><td>F16-1</td><td>Does not provide fault detection and failure mitigation</td><td rowspan="6">This function is not a part of the HazOp; this function is a part of the design to mitigate the hazards resulting from the malfunctions.</td></tr>
<tr><td>F16-2</td><td>Provides fault detection and failure mitigation more than intended</td></tr>
<tr><td>F16-3</td><td>Provides fault detection and failure mitigation less than intended</td></tr>
<tr><td>F16-4</td><td>Provides fault detection and failure mitigation intermittently</td></tr>
<tr><td>F16-5</td><td>Provides fault detection and failure mitigation when not intended</td></tr>
<tr><td>F16-6</td><td>Provides the same fault detection and failure mitigation at all times</td></tr>
</table>

Table B-17. Function 17: Store Relevant Data

I.D.	*Malfunction*	*Potential Vehicle Level Hazard*
F17-1	Does not store relevant data	None
F17-2	Store more relevant data than intended	None
F17-3	Stores less relevant data than intended	None
F17-4	stores relevant data intermittently	None
F17-5	Stores relevant data when not intended	None
F17-6	Stores the same relevant data at all times	None

Table B-18. Function 18: Provide Traction Motor Current Values

I.D.	*Malfunction*	*Comment*
F18-1	Does not provide traction motor current values	This function is not a part of the HazOp; this function is a part of the design implementation.
F18-2	Provides more traction motor current values than intended	
F18-3	Provides less traction motor current values than intended	
F18-4	Provides traction motor current values intermittently	This means some analysts may consider this as integral to the TIM and not a separate function (part of torque control).
F18-5	Provides traction motor current values when not intended	
F18-6	Provides the same traction motor current value at all times	

APPENDIX C: UNSAFE CONTROL ACTION ASSESSMENT TABLES

Table C-1: UCA Assessment for the "Enter Brake Throttle Override Mode" Control Action

Context Variables (Enter BTO Mode)			**Guidewords for Assessing Whether the Control Action May Be Unsafe**								
Accelerator Pedal Position	Brake Pedal Position	Vehicle Speed *	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	Not Pressed	< 10 mph		H4	N/A	N/A	N/A	N/A	Hazardous if provided	Hazardous if provided	Hazardous if provided
Not Pressed	Not Pressed	≥ 10 mph		H4	N/A	N/A	N/A	N/A	Hazardous if provided	Hazardous if provided	Hazardous if provided
Not Pressed	Pressed	< 10 mph			N/A	N/A	N/A	N/A			
Not Pressed	Pressed	≥ 10 mph			N/A	N/A	N/A	N/A			
Pressed	Not Pressed	< 10 mph		H4	N/A	N/A	N/A	N/A	Hazardous if provided	Hazardous if provided	Hazardous if provided
Pressed	Not Pressed	≥ 10 mph		H4	N/A	N/A	N/A	N/A	Hazardous if provided	Hazardous if provided	Hazardous if provided
Pressed	Pressed	< 10 mph		H4	N/A	N/A	N/A	N/A	Hazardous if provided	Hazardous if provided	Hazardous if provided
Pressed	Pressed	≥ 10 mph	H1		N/A	N/A	N/A	N/A	H1	H4	H1
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H4: Propulsion power reduction/loss or vehicle stalling											
* Vehicle speed values are based on the maximum vehicle speed threshold for activating BTO mode, based on the 2012 FMVSS 124 NPRM. Manufacturers may elect to have an activation speed less than 10 mph.											

Table C-2: UCA Assessment for the "Enter Normal Mode" Control Action

Context Variables (Enter Normal Mode)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position	Brake Pedal Position	Vehicle Speed *	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	Not Pressed	< 10 mph			N/A	N/A	N/A	N/A		N/A	
Not Pressed	Not Pressed	≥ 10 mph			N/A	N/A	N/A	N/A		N/A	
Not Pressed	Pressed	< 10 mph			N/A	N/A	N/A	N/A		N/A	
Not Pressed	Pressed	≥ 10 mph			N/A	N/A	N/A	N/A		N/A	
Pressed	Not Pressed	< 10 mph	H2, H4		N/A	N/A	N/A	N/A	H4	N/A	H4
Pressed	Not Pressed	≥ 10 mph	H2, H4		N/A	N/A	N/A	N/A	H4	N/A	H4
Pressed	Pressed	< 10 mph		H1	N/A	N/A	N/A	N/A	Hazardous if Provided	N/A	Hazardous if provided
Pressed	Pressed	≥ 10 mph		H1	N/A	N/A	N/A	N/A	Hazardous if Provided	N/A	Hazardous if provided
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling											
* Vehicle speed values are based on the maximum vehicle speed threshold for activating BTO mode, based on the 2012 FMVSS 124 NPRM. Manufacturers may elect to have an activation speed less than 10 mph.											

Table C-3: UCA Assessment for the "Increase Current" Control Action

Context Variables (Increase Current)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Demand	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Maintain Torque		H1	Hazardous if provided	Hazardous if provided	Hazardous if Provided	Hazardous if provided	H1, H2, H4	Hazardous if Provided	Hazardous if provided
Decrease Torque		H1	Hazardous if provided	Hazardous if provided	Hazardous if Provided	Hazardous if provided	H1, H2, H4	Hazardous if provided	Hazardous if provided
Increase Torque	H2		H1	H2	H1	H2	H1, H2, H4	N/A	H2
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling									

Table C-4: UCA Assessment for the "Decrease Current" Control Actions

Context Variables (Decrease Current)	**Guidewords for Assessing Whether the Control Action May Be Unsafe**							
Torque Demand	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Maintain Torque		H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	H1, H4	Hazardous if provided	Hazardous if provided
Decrease Torque	H1		H4	H5	H4	H5	H1, H4, H5	N/A	H5
Increase Torque		H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	H1, H4	Hazardous if provided	Hazardous if provided
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling H5: Insufficient vehicle deceleration								

Table C-5: UCA Assessment of the "Increase Torque" Control Actions

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	BTO Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Mode	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Mode	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Mode	Increase	H2	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Mode	Reduce and Increase	H2	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Switching to Normal	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Switching to Normal	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Switching to Normal	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Switching to Normal	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	Normal Switching to BTO	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Switching to BTO	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Switching to BTO	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Switching to BTO	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Mode	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Mode	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Reduced Angular Position	Normal Mode	Increase	H4	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Mode	Reduce and Increase	H4	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Switching to Normal	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Switching to Normal	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Switching to Normal	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Switching to Normal	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Switching to BTO	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Switching to BTO	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Switching to BTO	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Switching to BTO	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Maintained Angular Position	BTO Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Mode	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Mode	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Increase	H4	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Reduce and Increase	H4	H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Switching to Normal	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Switching to Normal	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Maintained Angular Position	BTO Switching to Normal	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Switching to Normal	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Switching to BTO	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Switching to BTO	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Switching to BTO	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Switching to BTO	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Mode	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Mode	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Mode	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Mode	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Increased Angular Position	Normal Mode	None	H2		H1	H2	H1	H2	Hazardous if provided	N/A	H2
Increased Angular Position	Normal Mode	Reduce	H2	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Mode	Increase	H2		H1	H2	H1	H2	Hazardous if provided	N/A	H2
Increased Angular Position	Normal Mode	Reduce and Increase	H2	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	None	H2		H1	H2	H1	H2	Hazardous if provided	N/A	H2
Increased Angular Position	BTO Switching to Normal	Reduce	H2	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	Increase	H2		H1	H2	H1	H2	Hazardous if provided	N/A	H2
Increased Angular Position	BTO Switching to Normal	Reduce and Increase	H2	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Switching to BTO	None		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Switching to BTO	Reduce		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided

Context Variables (Increase Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems:	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Increased Angular Position	Normal Switching to BTO	Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Switching to BTO	Reduce and Increase		H1	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling											

Table C-6: UCA Assessment of the "Decrease Torque" Control Actions

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	BTO Mode	None							H1		
Not Pressed	BTO Mode	Reduce							H1		
Not Pressed	BTO Mode	Increase							H1		
Not Pressed	BTO Mode	Reduce and Increase							H1		
Not Pressed	Normal Mode	None							H1		
Not Pressed	Normal Mode	Reduce	H6		H5	H6	H5	H6	Hazardous if provided	N/A	H6
Not Pressed	Normal Mode	Increase		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	Normal Mode	Reduce and Increase	H6	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Not Pressed	BTO Switching to Normal	None							H1		
Not Pressed	BTO Switching to Normal	Reduce							H1		
Not Pressed	BTO Switching to Normal	Increase							H1		

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Not Pressed	BTO Switching to Normal	Reduce and Increase							H1		
Not Pressed	Normal Switching to BTO	None	H6			H6		H6	Hazardous if provided	H5	H6
Not Pressed	Normal Switching to BTO	Reduce	H6			H6		H6	Hazardous if provided	H5	H6
Not Pressed	Normal Switching to BTO	Increase	H6			H6		H6	Hazardous if provided	H5	H6
Not Pressed	Normal Switching to BTO	Reduce and Increase	H6			H6		H6	Hazardous if provided	H5	H6
Reduced Angular Position	BTO Mode	None							H1		
Reduced Angular Position	BTO Mode	Reduce							H1		
Reduced Angular Position	BTO Mode	Increase							H1		
Reduced Angular Position	BTO Mode	Reduce and Increase							H1		
Reduced Angular Position	Normal Mode	None	H6		H5	H6	H5	H6	Hazardous if provided	N/A	H6

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Reduced Angular Position	Normal Mode	Reduce	H6		H5	H6	H5	H6	Hazardous if provided	N/A	H6
Reduced Angular Position	Normal Mode	Increase	H6	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	Normal Mode	Reduce and Increase	H6	H4	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Reduced Angular Position	BTO Switching to Normal	None							H1		
Reduced Angular Position	BTO Switching to Normal	Reduce							H1		
Reduced Angular Position	BTO Switching to Normal	Increase							H1		
Reduced Angular Position	BTO Switching to Normal	Reduce and Increase							H1		
Reduced Angular Position	Normal Switching to BTO	None	H6			H6		H6	Hazardous if provided	H5	H6
Reduced Angular Position	Normal Switching to BTO	Reduce	H6			H6		H6	Hazardous if provided	H5	H6
Reduced Angular Position	Normal Switching to BTO	Increase	H6			H6		H6	Hazardous if provided	H5	H6

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Reduced Angular Position	Normal Switching to BTO	Reduce and Increase	H6			H6		H6	Hazardous if provided	H5	H6
Maintained Angular Position	BTO Mode	None							H1		
Maintained Angular Position	BTO Mode	Reduce							H1		
Maintained Angular Position	BTO Mode	Increase							H1		
Maintained Angular Position	BTO Mode	Reduce and Increase							H1		
Maintained Angular Position	Normal Mode	None		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Reduce	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Increase		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	Normal Mode	Reduce and Increase	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Maintained Angular Position	BTO Switching to Normal	None							H1		

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Maintained Angular Position	BTO Switching to Normal	Reduce							H1		
Maintained Angular Position	BTO Switching to Normal	Increase							H1		
Maintained Angular Position	BTO Switching to Normal	Reduce and Increase							H1		
Maintained Angular Position	Normal Switching to BTO	None	H6			H6		H6	Hazardous if provided	H5	H6
Maintained Angular Position	Normal Switching to BTO	Reduce	H6			H6		H6	Hazardous if provided	H5	H6
Maintained Angular Position	Normal Switching to BTO	Increase	H6			H6		H6	Hazardous if provided	H5	H6
Maintained Angular Position	Normal Switching to BTO	Reduce and Increase	H6			H6		H6	Hazardous if provided	H5	H6
Increased Angular Position	BTO Mode	None							H1		
Increased Angular Position	BTO Mode	Reduce							H1		
Increased Angular Position	BTO Mode	Increase							H1		

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Increased Angular Position	BTO Mode	Reduce and Increase							H1		
Increased Angular Position	Normal Mode	None		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Mode	Reduce	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Mode	Increase		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Mode	Reduce and Increase	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	None		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	Reduce	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	Increase		H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	BTO Switching to Normal	Reduce and Increase	H4	H5	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	N/A	Hazardous if provided
Increased Angular Position	Normal Switching to BTO	None	H6			H6		H6	Hazardous if provided	H5	H6

Context Variables (Decrease Torque)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Accelerator Pedal Position:	PCM Operating Mode:	Input from Other Vehicle Systems	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Increased Angular Position	Normal Switching to BTO	Reduce	H6			H6		H6	Hazardous if provided	H5	H6
Increased Angular Position	Normal Switching to BTO	Increase	H6			H6		H6	Hazardous if provided	H5	H6
Increased Angular Position	Normal Switching to BTO	Reduce and Increase	H6			H6		H6	Hazardous if provided	H5	H6
Vehicle Level Hazards: H1: Uncontrolled vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling H5: Insufficient vehicle deceleration H6: Potentially allowing driver's command to override active safety systems											

Table C-7: UCA Assessment of the "Provide Torque in the Forward Direction" Control Actions

Context Variables (Provide Torque in the Forward Direction)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
Driver's Selected Direction	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Drive (Forward)	H2		N/A	N/A	N/A	N/A	H2, H3	N/A	H2, H3
Reverse		H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided
Park/Neutral		H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided
Vehicle Level Hazards: H2: Insufficient vehicle propulsion H3: Vehicle movement in unexpected direction									

Table C-8: UCA Assessment for the "Provide Torque in the Reverse Direction" Control Action

Context Variables (Provide Torque in the Reverse Direction)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
Driver's Selected Direction	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Drive (Forward)		H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided
Reverse	H2		N/A	N/A	N/A	N/A	H2, H3	N/A	H2, H3
Park/Neutral		H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided
Vehicle Level Hazards: H2: Insufficient vehicle propulsion H3: Vehicle movement in unexpected direction									

Table C-9: UCA Assessment for the "Discharge the High Voltage Bus" Control Actions

Context Variables (Discharge the High Voltage Bus)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
Discharge Request from BMS	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Yes	H7			H7		H7	H7		H7
No									
Vehicle Level Hazards: H7: Exposure to high voltage									

Table C-10: UCA Assessment for the "Open Contactor" Control Actions

Context Variables (Open Contactor)		Guidewords for Assessing Whether the Control Action May Be Unsafe								
Vehicle Crash Detected	HVIL Status	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Yes	Fault	H7			H7			H7		H7
Yes	No Fault	H7			H7			H7		H7
No	Fault	H7			H7			H7		H7
No	No Fault		H4							
Vehicle Level Hazards: H4: Propulsion power reduction/Loss or vehicle stalling H7: to high voltageExposure to high voltage										

Table C-11: UCA Assessment for the "Request DC Power" Control Actions

Context Variables (Request DC Power)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
	H2, H4			H2, H4		H2, H4	H2, H4		H2, H4
Vehicle Level Hazards: H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling									

Table C-12: UCA Assessment for the "Cooler On" Control Actions

Context Variables (Cooler On)	Guidewords for Assessing Whether the Control Action May Be Unsafe								
Current Inverter Temperature	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Below High Temperature Threshold									
At or Above High Temperature Threshold	H2, H4			H2, H4		H2, H4	H2, H4		H2, H4
Vehicle Level Hazards: H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling									

Table C-13: UCA Assessment for the "Cooler Off" Control Actions

Context Variables (Cooler Off)	**Guidewords for Assessing Whether the Control Action May Be Unsafe**								
Current Inverter Temperature	Not provided in this context	Provided in this context	Provided, but duration is too long	Provided, but duration is too short	Provided, but the intensity is incorrect (too much)	Provided, but the intensity is incorrect (too little)	Provided, but executed incorrectly	Provided, but the starting time is too soon	Provided, but the starting time is too late
Below High Temperature Threshold			H2, H4						
At or Above High Temperature Threshold		H2, H4							
Vehicle Level Hazards: H2: Insufficient vehicle propulsion H4: Propulsion power reduction/Loss or vehicle stalling									

APPENDIX D: STPA STEP 1: UCAS AND MAPPING TO HAZARDS

Table D-1: Unsafe Control Actions for the "Enter Brake Throttle Override Mode" Control Action

Vehicle Level Hazard	Unsafe Control Actions (Enter BTO Mode)
H1	The ECM correctly issues the Enter BTO Mode command, but the command is executed incorrectly.
H1	The ECM issues the Enter BTO Mode command when: the accelerator pedal is pressed, the brake pedal is pressed, and the vehicle speed is 10 mph or greater, but the command is issued too late.
H1	The ECM does not issue the Enter BTO Mode command when: the accelerator pedal is pressed, the brake pedal is pressed, and the vehicle speed is 10 mph or greater.
H4	The ECM issues the Enter BTO Mode command when: the driver presses the accelerator pedal, the driver presses the brake pedal, and the vehicle speed is below 10 mph.
H4	The ECM issues the Enter BTO Mode command when: the brake pedal is not pressed.
H4	The ECM issues the Enter BTO Mode command when: the accelerator pedal is pressed, the brake pedal is pressed, and the vehicle speed is 10 mph or greater, but the command is issued too soon (i.e., before the end of the activation delay).

H1: Uncontrolled vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling

Table D-2: Unsafe Control Actions for the "Enter Normal Mode" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Enter Normal Mode)
H1	The ECM issues the Enter Normal Mode command when: the accelerator pedal is pressed, and the brake pedal is pressed.
H2, H4	The ECM does not issue the Enter Normal Mode command when: the accelerator pedal is pressed, and the brake pedal is not pressed.
H4	The ECM correctly issues the Enter Normal Mode command, but the command is executed incorrectly.
H4	The ECM issues the Enter Normal Mode command when: the accelerator pedal is pressed, and the brake pedal is not pressed, but the command is issued to late.

H1: Uncontrolled vehicle propulsion
H2: Insufficient vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling

Table D-3: Unsafe Control Actions for the "Increase Current" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Increase Current)
H2	The TICM does not increase the current to the traction motor when: the EVPCM requests an increase in torque.
H1	The TICM increases the current to the traction motor when: the EVPCM requests a decrease in torque, or does not request a change in torque.
H1, H2, H4	The inverter correctly issues the increase current command, but the command is executed incorrectly.
H1	The TICM increases the current to the traction motor when: the EVPCM requests an increase in torque, but the current is increased for too long.
H2	The TICM increases the current to the traction motor when: the EVPCM requests an increase in torque, but the current is increased for too short a period.
H1	The TICM increases the current to the traction motor when: the EVPCM requests an increase in torque, but the current is increased by too much.
H2	The TICM increases the current to the traction motor when: the EVPCM requests an increase in torque, but the current is increased by too little.
H2	The TICM increases the current to the traction motor when: the EVPCM requests an increase in torque, but the current is increased too late.

H1: Uncontrolled vehicle propulsion
H2: Insufficient vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling

Table D-4: Unsafe Control Actions for the "Decrease Current" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Decrease Current)
H1	The TICM does not decrease the current to the traction motor when: the EVPCM requests a decrease in torque.
H4	The TICM decreases the current to the traction motor when: the EVPCM requests an increase in torque, or does not request a change in torque.
H4	The TICM decreases the current to the traction motor when: the EVPCM requests a decrease in torque, but the current is decreased for too long.
H5	The TICM decreases the current to the traction motor when: the EVPCM requests a decrease in torque, but the current is decreased for too short a period.
H4	The TICM decreases the current to the traction motor when: the EVPCM requests a decrease in torque, but the current is decreased by too much.
H5	The TICM decreases the current to the traction motor when: the EVPCM requests a decrease in torque, but the current is decreased by too little.
H1, H5, H4	The inverter correctly issues the decrease current command, but the command is executed incorrectly. This could lead to uncontrolled vehicle propulsion, propulsion power reduction or loss, or insufficient vehicle deceleration.
H5	The TICM decreases the current to the traction motor when: the EVPCM requests a decrease in torque, but the current is decreased too late.

H1: Uncontrolled vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling
H5: Insufficient vehicle deceleration

Table D-5: Unsafe Control Actions for the "Increase Torque" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Increase Torque)
H2	The EVPCM does not issue the Increase Torque command when: the driver increases the angular position of the accelerator pedal and the EVPCM is in normal mode or is transitioning from BTO mode into normal mode.
H2	The EVPCM does not issue the Increase Torque command when: other vehicle systems request an increase in engine torque or request both an increase and reduction in engine torque, the driver is not pressing the accelerator pedal, and the EVPCM is in normal mode.
H6	The EVPCM does not issue the Increase Torque command when: the driver is maintaining or reducing the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems request an increase in torque or both a reduction and increase in torque.
H1	The EVPCM issues the Increase Torque command when: the EVPCM is in BTO mode or is transitioning from normal mode to BTO mode.
H1	The EVPCM issues the Increase Torque command when: the driver reduces or maintains the angular position of the accelerator pedal, or is not pressing the accelerator pedal.
H1	The EVPCM issues the Increase Torque command when: the driver increases the angular position of the accelerator pedal, the EVPCM is in normal mode or is transitioning from BTO to normal mode, other vehicle systems do not request a change in torque or request an increase in torque, but the command is issued for too long.
H2	The EVPCM issues the Increase Torque command when: the driver increases the angular position of the accelerator pedal, the EVPCM is in normal mode or is transitioning from BTO to normal mode, other vehicle systems do not request a change in torque or request an increase in torque, but the command is issued for too short a period.
H1	The EVPCM issues the Increase Torque command when: the driver increases the angular position of the accelerator pedal, the EVPCM is in normal mode or is transitioning from BTO to normal mode, other vehicle systems do not request a change in torque or request an increase in torque, but too much torque is commanded.
H2	The EVPCM issues the Increase Torque command when: the driver increases the angular position of the accelerator pedal,

	the EVPCM is in normal mode or is transitioning from BTO to normal mode,, and other vehicle systems do not request a change in torque or request an increase in torque, but too little torque is commanded.
H1, H2, H4	The EVPCM correctly issues the Increase Torque command, but the command is executed incorrectly.
H2	The EVPCM issues the Increase Torque command when: the driver increases the angular position of the accelerator pedal, the EVPCM is in normal mode or is transitioning from BTO to normal mode, other vehicle systems do not request a change in torque or request an increase in torque, but the command is issued too late.

H1: Uncontrolled vehicle propulsion
H2: Insufficient vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling
H6: Allowing the driver's command to override active safety system

Table D-6: Unsafe Control Actions for the "Decrease Torque" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Decrease Torque)
H5	The EVPCM does not issue the Decrease Torque command when: the driver is not pressing the accelerator pedal or is reducing the angular position of the accelerator pedal, the vehicle is in normal mode, and other vehicle systems are requesting a reduction or both a reduction and increase in torque.
H5	The EVPCM does not issue the Decrease Torque command when: the driver is reducing the angular position of the accelerator pedal, and the EVPCM is in normal mode.
H5	The EVPCM does not issue the Decrease Torque command when: the EVPCM is transitioning from normal to BTO mode.
H6	The EVPCM does not issue the Decrease Torque command when: the driver is maintaining or increasing the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction or both a reduction and increase in torque.
H6	The EVPCM does not issue the Decrease Torque command when: the driver is increasing the angular position of the accelerator pedal, the EVPCM is transitioning from BTO to normal mode, and other vehicle systems are requesting a reduction or both a reduction and increase in torque.
H6	The EVPCM issues the Decrease Torque command when: the driver reduces the pedal angle, the EVPCM is in normal mode, and other vehicle systems are requesting an increase or both a reduction and increase in torque.
H4	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting an increase or both a reduction and increase in torque.
H4	The EVPCM issues the Decrease Torque command when: the driver increases or maintains the angular position of the accelerator pedal, the EVPCM is in normal mode.
H4	The EVPCM issues the Decrease Torque command when: the driver increases the angular position of the accelerator pedal, the EVPCM is transitioning from BTO to normal mode.

H4	The EVPCM issues the Decrease Torque command when: the driver reduces the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, or are not requesting a change in torque, but the command is issued for too long.
H4	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, but the command is issued for too long.
H5	The EVPCM issues the Decrease Torque command when: the EVPCM is transitioning from normal mode to BTO mode, but the command is issued for too short of a period.
H5	The EVPCM issues the Decrease Torque command when: the driver is reducing the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, or are not requesting a change in torque, but the command is issued for too short of a period.
H5	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, but the command is issued for too short of a period.
H4	The EVPCM issues the Decrease Torque command when: the driver reduces the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, or are not requesting a change in torque, but too much of a decrease in torque is commanded.
H4	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, but too much of a decrease in torque is commanded.
H5	The EVPCM issues the Decrease Torque command when: the EVPCM is transitioning from normal mode to BTO mode, but too little of a decrease in torque is commanded.

H5	The EVPCM issues the Decrease Torque command when: the driver is reducing the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, or are not requesting a change in torque, but too little of a decrease in torque is commanded.
H5	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, but too little of a decrease in torque is commanded.
H1, H4, H5	The EVPCM correctly issues the Decrease Torque command, but the command is executed incorrectly.
H4	The EVPCM issues the Decrease Torque command when: the EVPCM is transitioning from normal to BTO mode, but the command is issued too soon (i.e., before the BTO activation delay elapses).
H5	The EVPCM issues the Decrease Torque command when: the EVPCM is transitioning from normal mode to BTO mode, but the command is issued too late.
H5	The EVPCM issues the Decrease Torque command when: the driver is reducing the angular position of the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, or are not requesting a change in torque, but the command is issued too late.
H5	The EVPCM issues the Decrease Torque command when: the driver is not pressing the accelerator pedal, the EVPCM is in normal mode, and other vehicle systems are requesting a reduction in torque, but the command is issued too late.

H1: Uncontrolled vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling
H5: Insufficient vehicle deceleration
H6: Allowing the driver's command to override active safety system

Table D-7: Unsafe Control Actions for the "Provide Torque in Forward Direction" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Provide Torque in Forward Direction)
H2	The EVPCM does not provide torque in the forward direction when: the driver has selected drive (forward).
H3	The EVPCM provides torque in the forward direction when: the driver has selected reverse, park, or neutral.
H2, H3	The EVPCM correctly commands torque in the forward direction, but the command is executed incorrectly.
H2, H3	The EVPCM provides torque in the forward direction when: the driver has selected drive (forward), but the command is issued too late.

H2: Insufficient vehicle propulsion
H3: Vehicle movement in unexpected direction

Table D-8: Unsafe Control Actions for "Provide Torque in Reverse Direction" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Provide Torque in Reverse Direction)
H2	The EVPCM does not provide torque in the reverse direction when: the driver selects reverse.
H3	The EVPCM provides torque in the reverse direction when: the driver selects drive (forward), park, or neutral.
H2, H3	The EVPCM correctly commands torque in the reverse direction, but the command is executed incorrectly.
H2, H3	The EVPCM provides torque in the reverse direction when: the driver has selected reverse, but the command is issued too late.

H2: Insufficient vehicle propulsion
H3: Vehicle movement in unexpected direction

Table D-9: Unsafe Control Actions for "Cooler On" Control Actions

Vehicle Level Hazards	Unsafe Control Actions (Cooler On)
H2, H4, H5*	The EVPCM does not turn the inverter cooler on when: the inverter is at or above the high temperature threshold.
H2, H4, H5*	The EVPCM turns the inverter cooler on when: the inverter is at or above the high temperature threshold, but for too short a period of time.
H2, H4, H5*	The EVPCM turns the inverter cooler on when: the inverter is at or above the high temperature threshold, but too little cooling is supplied.
H4	The EVPCM correctly issues the command to turn the inverter cooler on, but the command is executed incorrectly.
H2, H4, H5*	The EVPCM turns the inverter cooler on when: the inverter is at or above the high temperature threshold, but the cooler is turned on too late.

H2: Insufficient vehicle propulsion
H4: Propulsion power reduction/Loss or vehicle stalling
H5: Insufficient vehicle deceleration
* If re-gen braking is part of the braking strategy

Table D-10: Unsafe Control Actions for "Cooler Off" Control Actions

Vehicle Level Hazards	Unsafe Control Actions (Cooler On)
H2, H5*	The EVPCM turns the inverter cooler off when: the inverter is at or above the high temperature threshold.
H2, H5*	The EVPCM turns the inverter cooler off when: the inverter is below the high temperature threshold, but the command is issued for too long.

H2: Insufficient vehicle propulsion
H5: Insufficient vehicle deceleration
* If re-gen braking is part of the braking strategy

Table D-11: Unsafe Control Actions for "Discharge the High Voltage Bus" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Cooler On)
H7	The EVPCM does not discharge the high voltage bus when: a discharge request is issued by the BMS.
H7	The EVPCM discharges the high voltage bus when: a discharge request is issued by the BMS, but the high voltage bus is discharged for too short a period.

H7: to high voltageExposure to high voltage

Table D-12: Unsafe Control Actions for "Open Contactor" Control Action

Vehicle Level Hazards	Unsafe Control Actions (Cooler On)
H7	The EVPCM does not command the contactor to open when: the vehicle is in a crash.
H7	The EVPCM does not command the contactor to open when: the HVIL reports a fault.
H4	The EVPCM commands the contactor to open when: the vehicle is not in a crash, and the HVIL does not report a fault.
H7	The EVPCM commands the contactor to open when: the vehicle is in a crash, but the command is issued for too short a period (i.e., the contactor is allowed to close).
H7	The EVPCM commands the contactor to open when: the HVIL reports a fault, but the command is issued for too short a period (i.e., the contactor is allowed to close).
H7	The EVPCM correctly issues the command to discharge the high voltage bus, but the command is executed incorrectly.
H7	The EVPCM commands the contactor to open when: the vehicle is in a crash, but the command is issued too late.
H7	The EVPCM commands the contactor to open when: the HVIL reports a fault, but the command is issued too late.

H7: to high voltageExposure to high voltage

APPENDIX E: OPERATIONAL SITUATIONS

- Vehicle in a parking lot or drive way and starting to move; good visibility with light pedestrian traffic.
- Vehicle in a parking lot or drive way and starting to move; low visibility with light pedestrian traffic.
- Vehicle in a parking lot or drive way and starting to move; good visibility with high pedestrian traffic (mall, supermarket)
- Vehicle in a parking lot or drive way and starting to move; low visibility with high pedestrian traffic (mall, supermarket)
- Vehicle going in reverse from a stopped condition at (relatively) low speed; low/good visibility; other vehicles present (stopped or moving at low speed); slippery/good road conditions; pedestrians present.
- Driving inside the city with heavy traffic and pedestrians present, stop and go driving, good visibility, good road conditions.
- Driving inside the city with heavy traffic and pedestrians present, stop and go driving, low visibility, slippery road conditions.
- Driving inside the city with heavy traffic and negligible pedestrians present, stop and go driving, good visibility, and good road conditions.
- Driving inside the city with heavy traffic and negligible pedestrians present, stop and go driving, bad visibility, and slippery road conditions.
- Driving inside (< 40 kph) the city with heavy traffic and negligible pedestrians present, good visibility, and good road conditions.
- Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.
- Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.
- Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.
- Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.
- Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.
- Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.

- Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.
- Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.
- Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.
- Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.
- Driving at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, good visibility, and good road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.
- Driving at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.
- Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.
- Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.
- Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.
- Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.
- Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.

- Driving at high speed (100 kph < V < 130 kph), light traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.
- Overtaking another vehicle at high speed (100 kph < V < 130 kph), light traffic, low visibility, and slippery road conditions.
- Vehicle in a parking lot or drive way and starting to move; good/low visibility, good/slippery road conditions.
- Driving inside the city with heavy traffic, stop and go driving, good visibility, good road conditions.
- Driving inside the city with heavy traffic, stop and go driving, low visibility, slippery road conditions.
- Driving inside the city with light traffic, stop and go driving, good visibility, good road conditions.
- Driving inside the city with light traffic, stop and go driving, low visibility, slippery road conditions.
- Driving near rail road track, low/good visibility, good/slippery road conditions.
- Vehicle in a Park or Neutral (P or N) position; good/low visibility with low/high pedestrian traffic.
- Vehicle in a parking lot or drive way in a drive or reverse (D or R) and the brake is applied; good/slippery road conditions; good/low visibility; with low pedestrian traffic.
- Vehicle in a parking lot or drive way in a drive or reverse (D or R) and the brake is applied; good/slippery road conditions; good/low visibility; with high pedestrian traffic.
- Vehicle in a traffic stop and the brake is applied; good/slippery road conditions; good/low visibility; with light traffic.
- Vehicle in a traffic stop and the brake is applied; good/slippery road conditions; good/low visibility; with heavy traffic.
- Vehicle in hill-hold in drive position (D) with the brakes not applied
- Vehicle in a parking lot or drive way and starting to move; good/low visibility, good/slippery road conditions, with light/heavy pedestrian traffic.
- Driving inside the city with heavy traffic and pedestrians present, stop and go driving, good/low visibility, good/slippery road conditions.

- Driving inside the city (< 40 kph) with heavy traffic and negligible pedestrians present, low visibility, and slippery road conditions.
- Driving over a rail road track, low/good visibility, and good/slippery road conditions.
- Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good/low visibility, and good/slippery road conditions.
- Conducting an evasive maneuver deviating from desired path at medium speed (40 kph < V < 100 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.
- Driving at high speed (100 kph < V < 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.
- Conducting an evasive maneuver deviating from desired path at high speed (100 kph < V < 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.
- Driving at very high speed (V > 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.
- Conducting an evasive maneuver deviating from desired path at high speed (V > 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.
- Driving inside the city with heavy traffic and pedestrians present, stop and go driving above 16 KPH, good visibility, good road conditions.
- Driving inside the city with heavy traffic and pedestrians present, stop and go driving above 16 KPH, low visibility, slippery road conditions.
- Driving inside the city with heavy traffic and negligible pedestrians present, stop and go driving above 16 KPH, good visibility, and good road conditions.
- Driving inside the city with heavy traffic and negligible pedestrians present, stop and go driving above 16 KPH, bad visibility, and slippery road conditions.
- Vehicle is On but not driving, vehicle is on the road, in the garage, or in storage, a person is handling the HV wires.
- The vehicle is in a crash event with the HV bus exposed, the vehicle occupants or first responders are in or around the vehicle.
- Vehicle is moving and the system triggers a safe state that requires the discharge of the bus capacitance.

APPENDIX F: ASIL ASSESSMENT

Table F-1: Potential Uncontrolled Vehicle Propulsion Without Destabilization

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Vehicle in a parking lot or driveway and starting to move; good visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E4	S2	C2	B
	Vehicle in a parking lot or driveway and starting to move; low visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E3	S2	C2	A
	Vehicle in a parking lot or driveway and starting to move; good visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E3	S3	C2	A
	Vehicle in a parking lot or driveway and starting to move; low visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C2	A
	Vehicle going in reverse from a stopped condition at (relatively) low speed; low/good visibility; other vehicles present (stopped or moving at low speed); slippery/good road conditions; pedestrians present.	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving, good visibility, and good road conditions.	The vehicle runs into another vehicle or a pedestrian; potential for running over the pedestrian also exists.	E3	S3	C2	B
	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving, low visibility, slippery road conditions.	The vehicle runs into another vehicle or a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C2	A
	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving, good visibility, and good road conditions.	The vehicle runs into another vehicle at low speed.	E4	S1	C2	A
	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving, bad visibility, and slippery road conditions.	The vehicle runs into another vehicle at low speed.	E3	S1	C2	QM
	Driving inside (< 40 kph) the city with heavy traffic and negligible pedestrian presence, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E4	S1	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving inside the city (< 40 kph) with heavy traffic and negligible pedestrian presence, bad visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S1	C2	QM
	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E4	S3	C2	C
	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E4	S3	C2	C
	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B
	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle	E4	S3	C2	C
	Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle	E4	S3	C2	C
	Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle	E3	S3	C2	B
	Driving at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle	E3	S3	C2	B
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C1	A
	Driving at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B
	Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B
	Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E2	S3	C2	A
	Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B
	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or barrier.	E3	S3	C2	B
	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E2	S3	C2	A
	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or barrier.	E2	S3	C2	A

Table F-2: Potential Uncontrolled Vehicle Propulsion With Destabilization

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion With Destabilization)			ASIL
			Exposure	Severity	Controllability	
Hazard occurs with destabilization	Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E4	S3	C3	D
Hazard occurs with destabilization	Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E4	S3	C3	D
Hazard occurs with destabilization	Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	C
Hazard occurs with destabilization	Driving at high speed (100 kph < V < 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	C
Hazard occurs with destabilization	Overtaking another vehicle at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C2	B
Hazard occurs with destabilization	Overtaking another vehicle at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C2	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion With Destabilization)			ASIL
			Exposure	Severity	Controllability	
Hazard occurs with destabilization	Overtaking another vehicle at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C2	B
Hazard occurs with destabilization	Overtaking another vehicle at high speed (100 kph < V < 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C2	B
Hazard occurs with destabilization	Driving at very high speed V > 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	C
Hazard occurs with destabilization	Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	C
Hazard occurs with destabilization	Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E2	S3	C3	B
Hazard occurs with destabilization	Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E2	S3	C3	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Propulsion With Destabilization)			ASIL
			Exposure	Severity	Controllability	
Hazard occurs with destabilization	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	C
Hazard occurs with destabilization	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	The vehicle runs into another vehicle or a barrier.	E3	S3	C3	B
Hazard occurs with destabilization	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E2	S3	C3	B
Hazard occurs with destabilization	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	The vehicle runs into another vehicle or a barrier.	E2	S3	C3	B

Table F-3: Potential Propulsion Power Reduction/Loss Without Destabilization

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Vehicle in a parking lot or driveway and starting to move; good/low visibility, and good/slippery road conditions.	None	E3	S0		None
	Vehicle going in reverse from a stopped condition at (relatively) low speed; low/good visibility; other vehicles present (stopped or moving at low speed); slippery/good road conditions; pedestrians present.	None	E2	S0		None
	Driving inside the city with heavy traffic, stop and go driving, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind or on the side at low speed.	E4	S1	C1	QM
	Driving inside the city with heavy traffic, stop and go driving, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind or on the side at low speed.	E3	S1	C1	QM
	Driving inside the city with light traffic, stop and go driving, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind or on the side at low speed.	E4	S1	C1	QM

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving inside the city with light traffic, stop and go driving, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind or on the side at low speed.	E3	S1	C1	QM
	Driving near rail road track, low/good visibility, and good/slippery road conditions.	Vehicle stalls while stopping on rail road track and gets hit by an incoming train.	E1	S3	C3	A
	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C2	C
	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C2	C
	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B
	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C2	B
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C2	B
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C2	B
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C2	B
	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C3	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C2	C
	Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C2	C
	Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B
	Driving at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
	Driving at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B
	Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C2	B
	Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E2	S3	C2	A
	Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling Without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E2	S3	C3	B
	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E2	S3	C3	B

Table F-4: Potential Propulsion Power Reduction/Loss With Destabilization

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling With Destabilization)			ASIL
			Exposure	Severity	Controllability	
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C3	D
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E4	S3	C3	D
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C3	C

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling With Destabilization)			ASIL
			Exposure	Severity	Controllability	
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C3	C

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling With Destabilization)			ASIL
			Exposure	Severity	Controllability	
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E2	S3	C3	B
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.	E2	S3	C3	B
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E3	S3	C3	C

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling With Destabilization)			ASIL
			Exposure	Severity	Controllability	
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E2	S3	C3	B
These scenarios are associated with rear-wheel drive vehicles. Hazard occurs with destabilization.	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle loses acceleration. Another vehicle runs into the vehicle head on.	E2	S3	C3	B

Table F-5: Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Vehicle Propulsion With Zero Speed at Start)			ASIL
			Exposure	Severity	Controllability	
	Vehicle in a Park or Neutral (P or N) position; good/low visibility with low/high pedestrian traffic.	None				
The failure produces enough torque to override the braking torque that is applied to counter the creep torque.	Vehicle in a parking lot or driveway in a drive or reverse (D or R) and the brake is applied; good/slippery road conditions; good/low visibility; with low pedestrian traffic.	The vehicle moves and hits a pedestrian.	E4	S2	C1	A
The failure produces enough torque to override the braking torque that is applied to counter the creep torque.	Vehicle in a parking lot or driveway in a drive or reverse (D or R) and the brake is applied; good/slippery road conditions; good/low visibility; with high pedestrian traffic.	The vehicle moves and hits a pedestrian.	E4	S2	C2	B
The failure produces enough torque to override the braking torque that is applied to counter the creep torque.	Vehicle in a traffic stop and the brake is applied; good/slippery road conditions; good/low visibility; with light traffic.	The vehicle moves and hits another vehicle.	E4	S1	C1	QM

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Uncontrolled Vehicle Propulsion With Zero Speed at Start)			ASIL
			Exposure	Severity	Controllability	
The failure produces enough torque to override the braking torque that is applied to counter the creep torque.	Vehicle in a traffic stop and the brake is applied; good/slippery road conditions; good/low visibility; with heavy traffic.	The vehicle moves and hits another vehicle.	E4	S1	C2	A
Failures cause reduction in propulsion torque.	Vehicle in hill-hold in drive position (D) with the brakes not applied.	The vehicle rolls back.	E2	S1	C0	None

Table F-6: Potential Insufficient Vehicle Propulsion

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Vehicle in a parking lot or driveway and starting to move; good/low visibility, good/slippery road conditions, with light/heavy pedestrian traffic.	None	E4		C0	None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Vehicle going in reverse from a stopped condition at (relatively) low speed; low/good visibility; other vehicles present (stopped or moving at low speed); slippery/good road conditions; pedestrians present.	None	E2	S0		None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving, good/low visibility, and good/slippery road conditions.	None	E3		C0	None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving inside (< 40 kph) the city with heavy traffic and negligible pedestrian presence, good visibility, and good road conditions.	None	E4		C0	None

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving inside the city (< 40 kph) with heavy traffic and negligible pedestrian presence, low visibility, and slippery road conditions.	None	E3		C0	None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving over a rail road track, low/good visibility, and good/slippery road conditions.	Vehicle fails to achieve intended speed increase while driving across rail road track and gets hit by an incoming train.	E3	S3	C1	A
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed, but there is no potential for accident scenario.	E4	S2	C1	A
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Conducting an evasive maneuver deviating from desired path at medium speed (40 kph < V < 100 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into another the vehicle.	E2	S3	C1	QM

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C2	B
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C2	B
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C2	B
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C2	B
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C3	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving at high speed (100 kph < V < 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed, but there is no potential for accident scenario.	E4		C0	None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Conducting an evasive maneuver deviating from desired path at high speed (100 kph < V < 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle.	E2	S3	C2	A
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C3	C
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C3	C
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C3	C

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Driving at very high speed (V > 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed, but there is no potential for accident scenario.	E3		C0	None
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Conducting an evasive maneuver deviating from desired path at high speed (V > 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into another the vehicle.	E2	S3	C3	B
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C3	C
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E3	S3	C3	C
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at very high speed (V > 130 kph) heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E2	S3	C3	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Propulsion)			ASIL
			Exposure	Severity	Controllability	
Failure causes the vehicle speed to increase at a slower rate than it is expected based on previous driving experience/feel	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; another vehicle runs into the vehicle head on.	E2	S3	C3	B

Table F-7: Potential Insufficient Vehicle Deceleration

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. The driver reduces the accelerator pedal angle (force); or 2. BTO is invoked. 3. Failure causes the vehicle speed to decrease at a slower rate than it is expected based on previous driving experience/feel	Vehicle in a parking lot or driveway and starting to move; good visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E4	S2	C1	A
1. The driver reduces the accelerator pedal angle (force); or 2. BTO is invoked. 3. Failure causes the vehicle speed to decrease at a slower rate than it is expected based on previous driving experience/feel	Vehicle in a parking lot or driveway and starting to move; low visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E3	S2	C1	QM
1. The driver reduces the accelerator pedal angle (force); or 2. BTO is invoked. 3. Failure causes the vehicle speed to decrease at a slower rate than it is expected based on previous driving experience/feel	Vehicle in a parking lot or driveway and starting to move; good visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian at low speed.	E4	S2	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. The driver reduces the accelerator pedal angle (force); or 2. BTO is invoked. 3. Failure causes the vehicle speed to decrease at a slower rate than it is expected based on previous driving experience/feel	Vehicle in a parking lot or driveway and starting to move; low visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian at low speed.	E3	S2	C1	QM
1. The driver reduces the accelerator pedal angle (force); or 2. BTO is invoked. 3. Failure causes the vehicle speed to decrease at a slower rate than it is expected based on previous driving experience/feel	Vehicle going in reverse from a stopped condition at (relatively) low speed; low/good visibility; other vehicles present (stopped or moving at low speed); slippery/good road conditions; pedestrians present.	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving above 16 KPH, good visibility, good road conditions.	The vehicle runs into another vehicle or a pedestrian.	E4	S2	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving above 16 KPH, low visibility, slippery road conditions.	The vehicle runs into another vehicle or a pedestrian.	E3	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving above 16 KPH, good visibility, and good road conditions.	The vehicle runs into another vehicle at low speed.	E4	S1	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving above 16 KPH, bad visibility, and slippery road conditions.	The vehicle runs into another vehicle at low speed.	E3	S1	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E4	S2	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E4	S2	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E3	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E3	S2	C1	QM

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Conducting an evasive maneuver deviating from desired path at medium speed (40 kph < V < 100 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed reduction; vehicle runs into another the vehicle.	E2	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S2	C1	QM

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S2	C1	QM
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at medium speed (40 kph < V < 100 kph), country road, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at high speed (100 kph < V < 130 kph), heavy traffic, good visibility, and good road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E4	S3	C2	C
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at high speed (100 kph < V < 130 kph), light traffic, good visibility, and good road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E4	S3	C2	C
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at high speed (100 kph < V < 130 kph), heavy traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E3	S3	C2	B
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E3	S3	C2	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Conducting an evasive maneuver deviating from desired path at high speed (100 kph < V < 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed reduction; vehicle runs into another the vehicle.	E2	S3	C2	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at high speed (100 kph < V < 130 kph), country road, light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E3	S3	C2	B
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E2	S3	C2	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Driving at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	The driver responds to traffic conditions by reducing speed, but vehicle speed is not reduced as intended, and the vehicle runs into another vehicle or barrier.	E2	S3	C2	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Conducting an evasive maneuver deviating from desired path at high speed (V > 130 kph), light/heavy traffic, good/low visibility, and good/slippery road conditions.	Vehicle does not achieve its intended speed reduction; vehicle runs into another the vehicle.	E2	S3	C3	B
1. Under BTO condition 2. ASC/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, good visibility, and good road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E3	S3	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at very high speed (V > 130 kph), heavy traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E2	S3	C1	A
1. Under BTO condition 2. ACS/ETC is functioning properly. 3. AP and BP are pressed simultaneously. 4. The vehicle speed is getting reduced but not at the intended rate.	Overtaking another vehicle at very high speed (V > 130 kph), light traffic, low visibility, and slippery road conditions.	Vehicle does not achieve its intended speed; vehicle runs into another the vehicle.	E2	S3	C1	A

Table F-8: Potential Vehicle Movement in an Unintended Direction

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Vehicle Movement in the Wrong Direction)			ASIL
			Exposure	Severity	Controllability	
EPS faults and produces torque in the wrong direction	Vehicle in a parking lot or driveway and starting to move; good visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E4	S2	C3	C
EPS faults and produces torque in the wrong direction	Vehicle in a parking lot or driveway and starting to move; low visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E3	S2	C3	B
EPS faults and produces torque in the wrong direction	Vehicle in a parking lot or driveway and starting to move; good visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E3	S3	C3	C
EPS faults and produces torque in the wrong direction	Vehicle in a parking lot or driveway and starting to move; low visibility with high pedestrian traffic (mall, supermarket)	The vehicle runs into a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C3	B
EPS faults and produces torque in the wrong direction	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving, good visibility, and good road conditions.	The vehicle runs into another vehicle or a pedestrian; potential for running over the pedestrian also exists.	E3	S3	C3	C
EPS faults and produces torque in the wrong direction	Driving inside the city with heavy traffic and pedestrian presence, stop and go driving, low visibility, slippery road conditions.	The vehicle runs into another vehicle or a pedestrian; potential for running over the pedestrian also exists.	E2	S3	C3	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Vehicle Movement in the Wrong Direction)			ASIL
			Exposure	Severity	Controllability	
EPS faults and produces torque in the wrong direction	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving, good visibility, and good road conditions.	The vehicle runs into another vehicle at low speed.	E4	S1	C3	B
EPS faults and produces torque in the wrong direction	Driving inside the city with heavy traffic and negligible pedestrian presence, stop and go driving, bad visibility, and slippery road conditions.	The vehicle runs into another vehicle at low speed.	E3	S1	C3	A

Table F-9: Potential Exposure to high voltage

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Exposure to high voltage)			ASIL
			Exposure	Severity	Controllability	
A situation requiring a discharge of the bus capacitance but the EPS fails to discharge the bus.	1. Vehicle is On but not driving 2. Vehicle is on the road, in the garage, or in storage 3. A person is handling the HV wires.	The person is exposed to the HV before the HV bus capacitance is discharged to a safe level	E2	S3	C3	B
A situation requiring a discharge of the bus capacitance but the EPS fails to discharge the bus.	The vehicle is in a crash event with the HV bus exposed; the vehicle occupants or first responders are in or around the vehicle.	A person is exposed to the HV before the HV bus capacitance is discharged to a safe level	E1	S3	C3	A
A situation requiring a discharge of the bus capacitance but the EPS fails to discharge the bus.	Vehicle is moving and the system triggers a safe state that requires the discharge of the bus capacitance	Exposure to high voltage in this scenario is almost impossible	E0			

APPENDIX G: FMEA

Table G-1. FMEA for H1: Potential Uncontrolled Vehicle Propulsion

(Malfunction: Commands More Torque Than Requested)

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
Engine Control Module	Commands more torque than the torque requested by the driver	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Misinterprets the APPS input	HW or SW fault (covered above)			
	BTO control fault	BTO algorithm fault	Three level Monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		BPPS fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		To: Traction controller	Critical messages/data transfer qualification		Communication fault
		From: APPS	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)				
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		From: Vehicle direction sensor	Critical messages/data transfer qualification		Communication fault
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
	Other failures	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
EPS	Delivers more torque than requested by the ECM	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Current sensor failure		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque calculation algorithm fault	Three level monitoring	SW diagnostics	System fault

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		SW parameters corrupted		Periodic checks	
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output direction to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates regen torque value to the ECM	Critical messages/data transfer qualification		Communication fault
		Rotor position sensor failure		HW diagnostics	
		Rotor position sensor supply power out of range		Supply power value	Loss of power

System/Sub-					
		EMC/EMI fault		HW/SW diagnostics	System fault
		NVH fault			
		Aging (durability)			
		Manufacturing variability			
	Mechanical failure	Out of scope			
APP Sensor	APP value interpreted higher than actual	Sensor fault:	Fault tolerant redundancy	Sensor diagnostics	APP sensor fault
		Internal connection fault (short or open)		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Short in APP sensor I/O connections to ground or voltage	Critical messages/data transfer qualification		I/O fault
		Short in APP sensor I/O connections to another connection			
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		APP calculation algorithm fault		SW diagnostics	
		SW parameters corrupted		Periodic checks	
		Supply power out of range		Supply power value	Loss of power
		Supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	AP ss not returned to idle position correctly	AP-mechanical Failure-Out of scope			
	APP communicates with ECM incorrectly	HW or SW fault (covered above)			
	AP assembly-mechanical	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Direction Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

Table G-2. FMEA H1a: Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero

(Malfunction: Commands More Torque Than Requested)

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands more torque than the torque requested by the driver	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Misinterprets the APPS input	HW or SW fault (covered above)			
	Incorrectly establishes idle torque	HW or SW fault (covered above)			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	To: Traction controller	Critical messages/data transfer qualification		Communication fault
		From: APPS	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)				
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Delivers more torque than requested by the ECM	Traction inverter fault:			TCM fault

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Current sensor failure		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Mechanical failure	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
BPP Sensor	Provides incorrect input to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Brake System fault
	Other failures	Out of scope			
APP Sensor	APP value interpreted higher than actual	Sensor fault:	Fault tolerant redundancy	Sensor diagnostics	APP sensor fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	
		Internal connection fault (short or open)		HW diagnostics	
		Break in APP sensor I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in APP sensor I/O connections to ground or voltage	Critical messages/data transfer qualification		I/O fault
		Short in APP sensor I/O connections to another connection			
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		APP calculation algorithm fault		SW diagnostics	
		SW parameters corrupted		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Supply power out of range		Supply power value	Loss of power
		Supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	AP ss not returned to idle position correctly	AP-mechanical Failure-Out of scope			
	APP communicates with ECM incorrectly	HW or SW fault (covered above)			
	AP assembly-mechanical	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

Table G-3. FMEA for H2: Potential Insufficient Vehicle Propulsion

(Malfunction: Commands Less Torque Than Requested)

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands smaller amount of torque than requested by the driver	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Misinterprets the APP	HW or SW fault (covered above)			
	APP rate-limiting fault (over-limiting)	HW or SW fault (covered above)			
	BTO control fault	BTO algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		BPPS fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault
		To: Traction controller	Critical messages/data transfer qualification		Communication fault
		From: APPS	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)	From: RESS controller	Critical messages/data transfer qualification		Communication fault
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		from: Vehicle direction sensor	Critical messages/data transfer qualification		Communication fault
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Delivers more torque than requested by the ECM	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Current sensor failure		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Torque calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		HV supply power out of range		Supply power value	Loss of power
		HV supply power quality failure		Supply power quality	Loss of power
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output direction to the ECM	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Miscommunicates regen torque value to the ECM	Critical messages/data transfer qualification		Communication fault
		Rotor position sensor failure		HW diagnostics	
		Rotor position sensor supply power out of range		Supply power value	Loss of power
		Rotor position sensor supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Mechanical failure	Out of scope			
BPP Sensor	Provides incorrect input to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Brake System fault
		Out of scope			
APP Sensor	APP value interpreted lower than actual	Sensor fault:	Fault tolerant redundancy	Sensor diagnostics	APP sensor fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Internal connection fault (short or open)		HW diagnostics	
		Break in APP sensor I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in APP sensor I/O connections to ground or voltage	Critical messages/data transfer qualification		I/O fault
		Short in APP sensor I/O connections to another connection			
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		APP calculation algorithm fault		SW diagnostics	
		SW parameters corrupted		Periodic checks	
		Supply power out of range		Supply power value	Loss of power
		Supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	APP communicates with ECM incorrectly	HW or SW fault (covered above)			
	AP assembly-mechanical	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Direction Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
RESS Controller	Communicates incorrect state of charge to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Propulsion)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
CC/ACC	Provides request for incorrect (less) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault

Table G-4. FMEA for H3: Potential Vehicle Movement in an Unintended Direction

(Malfunction: Delivers Torque in the Opposite Direction than Requested)

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands more torque in the wrong direction	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Service/Maintenance			
	Incorrectly establishes idle torque	HW or SW fault (covered above)			
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault
		To: Traction controller	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)	From: RESS controller	Critical messages/data transfer qualification		Communication fault
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		From: Vehicle direction sensor	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Delivers torque in the opposite direction than commanded by the ECM	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Current sensor failure		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Miscommunicates torque output direction to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates regen torque value to the ECM	Critical messages/data transfer qualification		Communication fault
		Rotor position sensor failure		HW diagnostics	
		Rotor position sensor supply power out of range		Supply power value	Loss of power
		Rotor position sensor supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Mechanical failure	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Vehicle Movement in an Unintended Direction)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	**Diagnostics**	**DTC**
Vehicle Direction Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

Table G-5. FMEA for H4: Potential Propulsion Power Reduction/Loss

(Malfunction: Commands Less Torque Than Requested)

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands lower torque value than the torque requested by the driver	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Misinterprets the APP	HW or SW fault (covered above)			
	Commands incorrect fuel amount	HW or SW fault (covered above)			
	Incorrectly establishes idle torque	HW or SW fault (covered above)			
	BTO control fault	BTO algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		BPPS fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault
		To: Traction controller	Critical messages/data transfer qualification		Communication fault
		From: APPS	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)	From: RESS controller	Critical messages/data transfer qualification		Communication fault
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		From: Vehicle direction sensor	Critical messages/data transfer qualification		Communication fault
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Delivers less torque than requested by the ECM	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Current sensor failure		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Torque calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		HV supply power out of range		Supply power value	Loss of power
		HV supply power quality failure		Supply power quality	Loss of power
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output direction to the ECM	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Miscommunicates regen torque value to the ECM	Critical messages/data transfer qualification		Communication fault
		Rotor position sensor failure		HW diagnostics	
		Rotor position sensor supply power out of range		Supply power value	Loss of power
		Rotor position sensor supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Fails to maintain idle torque	HW or SW fault (covered above)			
	Mechanical failure	Out of scope			
BPP Sensor	Provides incorrect input to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Brake System fault
		Out of scope			
APP Sensor	APP value interpreted lower than actual	Sensor fault:	Fault tolerant redundancy	Sensor diagnostics	APP sensor fault

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	
		Internal connection fault (short or open)		HW diagnostics	
		Break in APP sensor I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in APP sensor I/O connections to ground or voltage	Critical messages/data transfer qualification		I/O fault
		Short in APP sensor I/O connections to another connection			
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		APP calculation algorithm fault		SW diagnostics	
		SW parameters corrupted		Periodic checks	
		Supply power out of range		Supply power value	Loss of power
		Supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	AP ss not returned to idle position correctly	AP-mechanical Failure-Out of scope			
	APP communicates with ECM incorrectly	HW or SW fault (covered above)			
	AP assembly-mechanical	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Direction Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Propulsion Power Reduction/Loss)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Other failures	Out of scope			
RESS Controller	Communicates incorrect state of charge to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (less) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
CC/ACC	Command/Request for braking from CC/ACC to ECM failure	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

Table G-6. FMEA for H5: Potential Insufficient Vehicle Deceleration

(Malfunction: Commands More Torque Than Requested)

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands larger amount of torque than requested by the driver	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque command calculation algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		Arbitration logic fault	Three level monitoring		System fault
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Misinterprets the APP	HW or SW fault (covered above)			
	APP rate-limiting fault (over-limiting)	HW or SW fault (covered above)			
	Incorrectly Establishes Idle Position	HW or SW fault (covered above)			
	BTO control fault	BTO algorithm fault	Three level monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		BPPS fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	APP-torque map corrupted	HW fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault
		To: Traction controller	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		From: APPS	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)	From: RESS controller	Critical messages/data transfer qualification		Communication fault
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
		from: Vehicle direction sensor	Critical messages/data transfer qualification		Communication fault
		From: CC/ACC	Critical messages/data transfer qualification		Communication fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Delivers more torque than requested by the ECM	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Internal connection fault (short or open)		HW diagnostics	
		Current sensor failure		HW diagnostics	
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		Torque calculation algorithm fault	Three level Monitoring	SW diagnostics	System fault
		SW parameters corrupted		Periodic checks	
		LV supply power out of range		Supply power value	Loss of power

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		LV supply power quality failure		Supply power quality	Loss of power
		Misinterprets torque command from ECM	Critical messages/data transfer qualification		Communication fault
		Misinterprets motor position sensor input	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output value to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates torque output direction to the ECM	Critical messages/data transfer qualification		Communication fault
		Miscommunicates regen torque value to the ECM	Critical messages/data transfer qualification		Communication fault
		Rotor position sensor failure		HW diagnostics	
		Rotor position sensor supply power out of range		Supply power value	Loss of power
		Rotor position sensor supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Mechanical failure	Out of scope			
BPP Sensor	Provides incorrect input to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Brake System fault
	Other failures	Out of scope			
APP Sensor	APP value interpreted higher than actual	Sensor fault:	Fault tolerant redundancy	Sensor diagnostics	APP sensor fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	
		Internal connection fault (short or open)		HW diagnostics	
		Break in APP sensor I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in APP sensor I/O connections to ground or voltage	Critical messages/data transfer qualification		I/O fault
		Short in APP sensor I/O connections to another connection			

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		APP calculation algorithm fault		SW diagnostics	
		SW parameters corrupted		Periodic checks	
		Supply power out of range		Supply power value	Loss of power
		Supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	AP ss not returned to idle position correctly	AP-mechanical Failure-Out of scope			
	APP communicates with ECM incorrectly	HW or SW fault (covered above)			
	AP assembly-mechanical	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Insufficient Vehicle Deceleration)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
	Other failures	Out of scope			
Vehicle Direction Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
RESS Controller	Communicates incorrect state of charge to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Other (Interfacing) vehicle systems	Provides request for incorrect (more) propulsion torque	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
CC/ACC	Command/Request for braking from CC/ACC to ECM failure	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

Table G-7. FMEA for H7: Potential Exposure to high voltage

(Malfunction: Does not command the discharge the HV bus capacitance)

System/Sub-system	Potential Failure Mode (Potential Exposure to high voltage)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Fails to command a discharge of the HV bus capacitance	ECM fault:	Three level monitoring		ECM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards…)		HW diagnostics	ECM fault
		Internal connection fault (short or open)		HW diagnostics	ECM fault
		Break in ECM I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in ECM I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in ECM I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	
		Power connector connection failure		HW diagnostics	
		SW parameters corrupted		Periodic checks	
		Arbitration logic fault	Three level monitoring		System fault

System/Sub-system	Potential Failure Mode (Potential Exposure to high voltage)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	ECM fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Miscommunicates with internal sub-systems (this may be CAN like communication or PWM or else)	From: Traction controller	Critical messages/data transfer qualification		Communication fault
		To: Traction controller	Critical messages/data transfer qualification		Communication fault
	Miscommunication with external systems (this may be CAN like communication or PWM or else)	From: RESS controller	Critical messages/data transfer qualification		Communication fault
		From: Vehicle speed sensor	Critical messages/data transfer qualification		Communication fault

System/Sub-system	Potential Failure Mode (Potential Exposure to high voltage)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		From: Engine rpm sensor	Critical messages/data transfer qualification		Communication fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
EPS	Does not discharge the HV bus capacitance	Traction inverter fault:			TCM fault
		Hardware fault (sensors, ICs, circuit components, circuit boards, power switches…)		HW diagnostics	TCM fault
		Internal connection fault (short or open)		HW diagnostics	TCM fault
		Break in I/O connections	Critical messages/data transfer qualification	Stuck open/short	I/O fault
		Short in I/O connections to ground or low voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to high voltage	Critical messages/data transfer qualification		I/O fault
		Short in I/O connections to another connection	Critical messages/data transfer qualification		I/O fault
		Signal connector connection failure		HW diagnostics	

System/Sub-system	Potential Failure Mode (Potential Exposure to high voltage)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
		Power connector connection failure		HW diagnostics	
		SW parameters corrupted		Periodic checks	
		HV supply power out of range		Supply power value	Loss of power
		HV supply power quality failure		Supply power quality	Loss of power
		LV supply power out of range		Supply power value	Loss of power
		LV supply power quality failure		Supply power quality	Loss of power
		EMC/EMI fault		HW/SW diagnostics	System fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
	Mechanical failure	Out of scope			
Vehicle Speed Sensor	Provides incorrect vehicle speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

System/Sub-system	Potential Failure Mode (Potential Exposure to high voltage)	Potential Causes/Mechanisms of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer in the ASC/ETC_EV, and from and to the ACS/ETC_EV and interfacing vehicle modules	Communication faults	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			
RESS Controller		Communication fault to ECM	Critical messages/data transfer qualification		Communication fault
	Other failures	Out of scope			

APPENDIX H: STPA STEP 2: CAUSAL FACTORS

Table H-1: Accelerator Pedal

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal)
151	Actuator inadequate operation, change over time	Degradation over time	The accelerator pedal assembly hardware may degrade over time (e.g., increased friction). This may cause the accelerator pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the accelerator pedal to become stuck in a position. If the accelerator pedal intermittently activates the pedal position sensor, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
153	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects could prevent the accelerator pedal from properly activating the accelerator pedal position sensor. This may cause the accelerator pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the accelerator pedal to become stuck in a position.
154	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference with other vehicle components (e.g., floor mats) could affect the accelerator pedal. The pedal may become stuck at a position (e.g., not move when released by the driver).
771	Controlled component failure, change over time	Internal hardware failure	Failure of the accelerator pedal assembly hardware could cause the accelerator pedal to become dislodged. This may cause the accelerator pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the accelerator pedal to become stuck in a position. If the accelerator pedal intermittently activates the pedal position sensor, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
773	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could cause the accelerator pedal mechanism to not respond to how the driver presses on it.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal)
974	Actuator inadequate operation, change over time	Incorrectly sized actuator	The return mechanism for the accelerator pedal may be undersized (preventing or delaying the return of the accelerator pedal) or oversized (causing the pedal to return too quickly or making the pedal difficult to actuate).
975	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the motion of the accelerator pedal (e.g., expansion or contraction of mechanical components). The accelerator pedal may move by the incorrect amount, may have intermittent or delayed movement, or may become stuck at a position.
977	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may cause the accelerator pedal assembly hardware to move in a different manner than commanded by the driver or to become damaged (e.g., vibration causing damage to the pedal hardware). In regard to mode switching: If the mode switching algorithm uses a minimum pedal angle that signifies "pressed", vibration may cause the pedal angle to fall below this threshold. This may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
978	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the motion of the accelerator pedal (e.g., increased or decreased friction). The accelerator pedal may move by the incorrect amount, may have intermittent or delayed movement, or may become stuck at a position.
979	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the motion of the accelerator pedal (e.g., causing interference or increased friction of the pedal). The accelerator pedal may move by the incorrect amount, may have intermittent or delayed movement, or may become stuck at a position.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal)
980	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components may cause the accelerator pedal assembly hardware to move in a different manner than commanded by the driver or to become damaged (e.g., vibration causing damage to the pedal hardware). In regard to mode switching: If the mode switching algorithm uses a minimum pedal angle that signifies "pressed", vibration may cause the pedal angle to fall below this threshold. This may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
981	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the motion of the accelerator pedal (e.g., increased or decreased friction). The accelerator pedal may move by the incorrect amount, may have intermittent or delayed movement, or may become stuck at a position.

Table H-2: Accelerator Pedal Position Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
164	Sensor inadequate operation, change over time	Degradation over time	The accelerator pedal position sensor may degrade over time, affecting its function (e.g., a short or open circuit, tin whisker, etc.). This could cause the sensor to stop functioning, incorrectly or intermittently measure the pedal position, or become stuck at a value (e.g., not pressed). If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
781	Sensor inadequate operation, change over time	Internal hardware failure	An internal hardware failure (e.g., short circuit, open circuit, increased resistance in a subcomponent) may affect the accelerator pedal position sensor. This could cause the sensor to stop functioning, incorrectly or intermittently measure the accelerator pedal position, delay reporting a measurement, or become stuck at a value (e.g., not pressed). If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
782	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The accelerator pedal position sensor may overheat due to increased resistance in a subcomponent or internal shorting.
785	Sensor inadequate operation, change over time	Reporting frequency too low	The accelerator pedal position sensor reporting frequency may be too low.
786	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the accelerator pedal position sensor. If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
787	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) may affect the accelerator pedal position sensor.
788	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the accelerator pedal position sensor. If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
789	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the accelerator pedal position sensor.
790	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the accelerator pedal position sensor.
791	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the accelerator pedal position sensor. This could cause the sensor to stop functioning, incorrectly or intermittently measure the pedal position, or become stuck at a value (e.g., not pressed). If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
792	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the accelerator pedal position sensor.
793	External disturbances	Magnetic interference	Magnetic interference from the external environment may affect the accelerator pedal position sensor.
794	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the accelerator pedal position sensor (e.g., unable to transmit a signal to the EVPCM).
795	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A reference voltage that is too low or too high may affect the accelerator pedal position sensor.
797	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A power supply disturbance may affect the accelerator pedal position sensor (e.g., causing intermittent operation). If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
798	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the accelerator pedal position sensor. If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
799	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the accelerator pedal position sensor.
800	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the accelerator pedal position sensor. If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
801	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components (e.g., A/C condensation) may affect the accelerator pedal position sensor. If the accelerator pedal position sensor signal becomes intermittent, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
802	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the accelerator pedal position sensor.
803	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other components may affect the accelerator pedal position sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
804	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the accelerator pedal position sensor.
805	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the accelerator pedal position sensor.
986	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the accelerator pedal position sensor (e.g., causing shorting).

Table H-3: Battery Management System

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System)
1128	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12-volt power supply or power spike may disrupt components in the battery management system (e.g., a BMS fault). This may cause the battery management system to initiate a shutdown of the high voltage system.
1129	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If components in the battery management system lose 12-volt power, the battery management system may initiate a shutdown of the high voltage system.
1130	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1131	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) could affect the battery management system controller, causing the system to initiate a shutdown of the high voltage system.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System)
1132	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system (e.g., causing a crash sensor to incorrectly indicate the vehicle was in a crash).
1133	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1134	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1135	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1136	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect components or connections in the battery management system (e.g., causing a short in the system). This may cause the battery management system to initiate a shutdown of the high voltage system.
1137	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1138	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1139	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system (e.g., cause a crash sensor to incorrectly report the vehicle was in a crash).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System)
1140	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1141	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1142	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1143	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1144	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect components or connections in the battery management system, causing the system to initiate a shutdown of the high voltage system.
1145	Controller hardware faulty, change over time	Internal hardware failure	Components in the battery management system may have internal hardware faults that affect their function. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.
1146	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	Components in the battery management system may overheat due to increased resistance in a subcomponent or internal shorting. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.
1147	Controller hardware faulty, change over time	Over temperature due to faulty cooling system	Components in the battery management system may overheat due to faulty cooling systems. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.
1148	Controller hardware faulty, change over time	Degradation over time	Components in the battery management system may degrade over time. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System)
1149	Controller hardware faulty, change over time	Faulty memory storage or retrieval	Faulty memory storage or retrieval may affect data stored or retrieved by the battery management system controller. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system (e.g., if fault parameters are stored in memory).
1150	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	Faulty signal conditioning or converting may cause the battery management system controller to misinterpret sensor signals (e.g., crash sensor). This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.
1151	Controller hardware faulty, change over time	Unused circuits in the controller	Unused circuits in the battery management system controller may affect the function of the battery management system. This may cause the battery management system to incorrectly initiate a shutdown of the high voltage system.
1152	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The battery management system controller may have an inadequate control algorithm that results in the system incorrectly initiating a shutdown of the high voltage system.
1153	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Flaws in software code creation	If automated code generation is used, flaws may be introduced into the battery management system controller during code creation. These flaws may result in the battery management system incorrectly initiating a shutdown of the high voltage system.
1154	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The battery management system sensor and actuator calibrations in the battery management system controller may be incorrect. This may result in the battery management system incorrectly initiating a shutdown of the high voltage system (e.g., crash sensor calibration).
1155	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The battery management system controller may have an incorrect model of the high voltage and battery system. This may result in the battery management system incorrectly initiating a shutdown of the high voltage system.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System)
1156	External control input or information wrong or missing	Spurious input due to shorting or other electrical fault	The battery management system controller may act on a spurious input due to shorting or other electrical faults. This may result in the battery management system initiating a shutdown of the high voltage system.
1157	External control input or information wrong or missing	Corrupted input signal	An input signal to the battery management system controller may become corrupted. This may result in the battery management system initiating a shutdown of the high voltage system.
1158	External control input or information wrong or missing	Malicious Intruder	A malicious intruder or aftermarket component may send a signal to the battery management system controller that mimics a fault. This may result in the battery management system initiating a shutdown of the high voltage system.

Table H-4: Brake/Vehicle Stability Assist Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
45	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The brake/VSA control module may have software programming errors or faulty logic. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
46	Controller hardware faulty, change over time	Degradation over time	Degradation of internal subcomponents could affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
47	Controller hardware faulty, change over time	Internal hardware failure	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) may affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
48	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The wheel speed sensor calibrations in the brake/VSA control module may be incorrect. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
49	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) can affect the brake/VSA control module, causing internal short or open circuits, or other failure of the control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
50	External disturbances	EMI or ESD	EMI or ESD from the external environment can affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
51	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., damaged subcomponents) could affect the function of the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
52	External disturbances	Vibration or shock impact	Vibration or shock impact could damage internal subcomponents in the brake/VSA control module (e.g., solder breaks). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
53	External disturbances	Extreme external temperature or thermal cycling	An extreme external temperature (e.g., heat or cold) or thermal cycling may damage the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
54	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the brake/VSA control module loses 12V power, it would be unable to compute and report a vehicle speed measurement. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
55	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
56	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) may affect the brake/VSA control module, causing internal short or open circuits, or other failure of the control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
57	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components may affect the brake/VSA control module (e.g., damaging electronic subcomponents). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1187	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disturbance in the power supply (e.g., voltage spike) could affect the brake/VSA control module (e.g., erase data stored in memory) or cause damage to the controller. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1188	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) could affect the brake/VSA control module. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
1189	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the brake/VSA control module (e.g., cause internal shorting). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1190	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the brake/VSA control module. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1191	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO Mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
1192	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the brake/VSA control module (e.g., cause the controller to overheat). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1193	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1194	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the brake/VSA control module. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
1195	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The brake/VSA control module may overheat due to increased resistance in a subcomponent or internal shorting. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1196	Controller hardware faulty, change over time	Over temperature due to faulty cooling system	The brake/VSA control module may overheat due to a faulty cooling system. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1197	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The brake/VSA control module may have an error storing or retrieving data from memory (e.g., individual wheel speed data). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module)
1198	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	Faulty signal conditioning or converting (e.g., an analog to digital converter) may affect the brake/VSA control module's ability to compute the vehicle speed. This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1199	Controller hardware faulty, change over time	Unused circuits in the controller	Unused circuits in the controller could affect the brake/VSA control module (e.g., a signal may short onto an unused circuit pathway). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1200	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Flaws in software code creation	Flaws may be introduced into the brake/VSA control module during software code creation (e.g., if code is automatically generated). This could cause the brake/VSA control module not to report an average wheel speed/vehicle speed, to report the incorrect average wheel speed/vehicle speed, or to become stuck reporting the same average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Table H-5: Brake Pedal Assembly

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Assembly)
1	Actuator inadequate operation, change over time	Internal hardware failure	Failure of the brake pedal assembly hardware could cause the brake pedal to become dislodged. This may cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
2	Actuator inadequate operation, change over time	Degradation over time	The brake pedal assembly may degrade over time (e.g., wear of the contact point with the brake pedal position sensor, failure of the return spring). This may prevent the brake pedal from activating the pedal position sensor, cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
3	External disturbances	Physical interference (e.g., chafing)	Foreign objects in the driver's footwell could affect the motion of the brake pedal. This may prevent the brake pedal from activating the pedal position sensor, cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
4	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects (e.g., exceeding tolerances) could affect the brake pedal assembly. This may prevent the brake pedal from activating the pedal position sensor, cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
5	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Other vehicle components may interfere with the brake pedal assembly (e.g., floor mats). This may prevent the brake pedal from activating the pedal position sensor, cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Assembly)
146	External disturbances	Vibration or shock impact	Vibration may cause excessive motion of the brake pedal, leading to intermittent activation of the brake pedal position sensor. The EVPCM may remain in BTO mode without a consistent signal that the brake pedal is released (e.g., if the brake must be pressed for a certain period of time before exiting BTO mode).

Table H-6: Brake Pedal Position Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
34	Sensor inadequate operation, change over time	Degradation over time	The brake pedal position sensor hardware could degrade over time (e.g., carbonization of electrical contacts). This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
35	Sensor inadequate operation, change over time	Internal hardware failure	The brake pedal position sensor could have an internal hardware failure (e.g., flawed design, plunger breaks). This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
37	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects (e.g., improper installation) could affect the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
38	External disturbances	Moisture, corrosion, or contamination	Corrosion or contamination from the external environment (e.g., moisture, dirt, salt, and corrosion) could affect the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
39	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
40	External disturbances	Vibration or shock impact	Vibration could cause the brake pedal position sensor to become misaligned. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
41	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature (e.g., heat or cold) may cause the brake pedal position sensor to overheat, affecting its function. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
42	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components (e.g., inadequate clearance) could damage the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
43	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
44	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could affect the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
58	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the brake pedal position sensor loses 12V power, this could cause the sensor to stop functioning.
124	Sensor inadequate operation, change over time	Reporting frequency too low	If the brake pedal position sensor reading frequency is too low, there may be a delay before the EVPCM realizes the brake pedal position has changed.
149	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the supply voltage (e.g., voltage fluctuation, voltage spike, etc.) could affect the brake pedal position sensor measurement. This could cause the sensor to stop functioning or to incorrectly measure the brake pedal position.
1123	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The brake pedal position sensor may overheat due to increased resistance of internal subcomponents (e.g., a short). This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.
1124	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive temperatures from other vehicle components could damage the brake pedal position sensor. This could cause the sensor to stop functioning, report the wrong amount of pedal travel, incorrectly or intermittently report the pedal position, or become stuck at a value.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
1217	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	The reference voltage for the brake pedal position sensor may be too high or too low, resulting in an inaccurate measurement of the brake pedal position.
1218	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the brake pedal position sensor.
1219	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the brake pedal position sensor.
1220	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the brake pedal position sensor (e.g., if this is a hall-effect type sensor).
1221	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the brake pedal position sensor.
1222	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the brake pedal position sensor.
1223	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the brake pedal position sensor.
1224	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the brake pedal position sensor.

Table H-7: Contactor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Contactor)
1236	External disturbances	Vibration or shock impact	Vibration or shock impact may affect the contactor (e.g., damage or dislodge the contactor).
1237	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the contactor.
1238	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion or contamination from the external environment could affect the contactor.
1239	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the contactor.
1240	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the contactor.
1241	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the contactor (e.g., damage or dislodge the contactor).
1242	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the contactor.
1243	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the contactor.
1244	Actuator inadequate operation, change over time	Internal hardware failure	An internal hardware failure could affect the function of the contactor.
1245	Actuator inadequate operation, change over time	Degradation over time	The contactor may degrade over time, affecting the DC flow between the battery and the power stage.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Contactor)
1246	Actuator inadequate operation, change over time	Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts	The contactor may not energize, or may not de-energize or become welded shut. This may prevent DC flow to the power stage or may result in continuous DC flow to the power stage.

Table H-8: Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
13	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the EVPCM, causing internal short or open circuits, or other failures of the control module.
15	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects could affect the function of the EVPCM.
17	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the EVPCM.
18	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture or other fluids from other vehicle components (e.g., A/C condensation) could affect the EVPCM, causing internal short or open circuits, or other failures of the control module.
20	Controller hardware faulty, change over time	Internal hardware failure	The EVPCM may be affected by a faulty electronic subcomponent or electrical connection in the EVPCM (e.g., a transistor is not switched off or soldering breaks).
21	Controller hardware faulty, change over time	Degradation over time	Internal subcomponents in the EVPCM may degrade over time, affecting the function of the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
27	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the EVPCM from switching into BTO mode when the driver presses both pedals and the vehicle speed is over 10 mph.
28	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The sequence of pedal application is not considered or is incorrectly considered in the software logic for entering BTO or Normal mode.
30	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the EVPCM process model considers variables beyond the accelerator pedal position, brake pedal position, and the vehicle speed, this may make the conditions for entering BTO mode too stringent.
31	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM process model may have an incorrect value for determining the pedal application sequence.
33	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If the EVPCM does not receive updated sensor data (e.g., motor speed), it may continue to operate using the last available data, which may be outdated.
118	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12V power supply may damage the EVPCM, cause the EVPCM to erase information stored in volatile memory (e.g., sensor data or operating mode), or cause the EVPCM to delay issuing a control action (e.g., switching operating modes).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
142	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic may prevent storing the current EVPCM mode (e.g., writing to memory) after the EVPCM issues the command to switch.
143	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the EVPCM process model does not consider vehicle speed or considers a vehicle speed below 10 mph, the EVPCM may switch into BTO mode when the driver presses both pedals and the vehicle speed is below 10 mph.
161	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the EVPCM process model considers variables beyond the accelerator pedal position, brake pedal position, and the vehicle speed, this may make the conditions for entering Normal mode too stringent.
176	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The software algorithm may incorporate a delay before exiting BTO mode. This delay timing may be incorrectly programmed.
179	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to switch into Normal mode when both the accelerator pedal and brake pedal are pressed.
180	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The software algorithm allows the EVPCM to exit BTO mode when one pedal drops below an angular position threshold (e.g., below 25%), and does not require BTO mode to persist until the pedal conflict is removed (i.e., one pedal is released).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
181	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The software algorithm may allow other vehicle systems to command the EVPCM to exit BTO mode while a pedal conflict still exists.
182	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the EVPCM process model considers conditions other than the brake and accelerator pedal positions for exiting BTO mode (e.g., drive power or engine speed), then the EVPCM may prematurely enter Normal mode.
226	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the EVPCM.
227	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) may affect the EVPCM.
228	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the EVPCM.
230	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the EVPCM.
232	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the EVPCM.
234	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the EVPCM.
235	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the EVPCM.
237	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
238	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the EVPCM.
239	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the EVPCM.
241	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	Overheating due to increased resistance in a subcomponent or internal shorting may affect the EVPCM.
242	Controller hardware faulty, change over time	Over temperature due to faulty cooling system	Controller over temperature due to a faulty cooling system may affect the EVPCM.
244	Controller hardware faulty, change over time	Faulty memory storage or retrieval	Faulty memory storage or retrieval may affect the EVPCM.
245	Controller hardware faulty, change over time	Faulty internal timing clock	A faulty internal timing clock may affect the EVPCM.
246	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters) may affect the EVPCM.
398	External control input or information wrong or missing	Timing related input is incorrect or missing	If the EVPCM requires a timing signal from an external source (e.g., a central timing module), this signal may be incorrect or missing.
399	External control input or information wrong or missing	Spurious input due to shorting or other electrical fault	The EVPCM may receive and act on a spurious input (e.g., due to shorting or other electrical faults) which mimics an incoming torque request.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
400	External control input or information wrong or missing	Corrupted input signal	A torque request from another vehicle system may not reach the EVPCM or may be corrupted before reaching the EVPCM (e.g., electrical noise, chafed wiring, contamination or corrosion, etc.).
401	External control input or information wrong or missing	Malicious Intruder	The EVPCM may receive and act on a signal that mimics an incoming torque request (e.g., from an aftermarket component or a malicious intruder).
409	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the EVPCM.
412	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Flaws in software code creation	Flaws in software code creation may affect the EVPCM.
413	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	Sensor or actuator calibration in the EVPCM may be incorrect. This may cause the EVPCM to misinterpret sensor measurements or may cause the actuator output to differ from the output expected by the EVPCM.
415	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM has the wrong understanding of how the inverter/converter is cooled by the inverter cooler (e.g., cooling rate, lag time before cooling takes effect, etc.).
433	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If the inverter cooler can provide a varying amount of cooling, an inadequate control algorithm could result in the EVPCM commanding too little cooling. This could cause the inverter to overheat.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
435	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic may make the EVPCM turn the inverter cooler off when the inverter temperature is still at or above the high temperature threshold (e.g., there may be a time limit on how long the cooler is operated).
436	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The control algorithm for turning the inverter cooler on or off may incorporate a delay (e.g., to prevent rapid cycling of the pump). This delay may be too long.
758	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	An inadequate control algorithm may result in the EVPCM increasing the torque when the EVPCM is in BTO mode or is transitioning from normal mode to BTO mode.
766	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to give precedence to torque requests from other vehicle systems instead of the driver's request via the accelerator pedal.
768	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to not recognize that an incoming torque request is from an active safety system.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
898	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm causes the EVPCM to incorrectly translate the torque requests from other vehicle systems into a torque command (e.g., too much or too little torque required).
916	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic affects how much the EVPCM decreases the net power delivered to the wheels when transitioning into BTO mode.
945	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the EVPCM from increasing the torque when exiting BTO mode.
947	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the EVPCM to increase the torque without a clear request from the driver or other vehicle systems.
951	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to incorrectly reconcile the magnitude of multiple torque requests in the same direction, causing the EVPCM not to issue a control action (e.g., inaction) or to compute the incorrect net torque (e.g., it may add the magnitude of torque reduction requests from two systems).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
957	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to incorrectly reconcile the magnitude of multiple torque requests in opposite directions, causing the EVPCM not to issue a control action (i.e., inaction) or to issue an unsafe control action (e.g., increasing instead of reducing the torque).
958	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic may introduce a delay in reducing the torque when transitioning from normal mode to BTO mode.
959	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm affects how the EVPCM translates a change in the angular position of the accelerator pedal into a torque request (e.g., too much or too little power, or wrong direction).
960	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes a delay when the EVPCM tries to reconcile the magnitude of multiple torque requests.
962	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If the BTO control algorithm incorporates a delay before entering BTO mode, a programming error or flaw in software logic may affect the length of the delay (e.g., an incorrect parameter value may cause the delay to be too short).
965	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the EVPCM, causing internal shorting or other failures of the control module.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
966	Controller hardware faulty, change over time	Unused circuits in the controller	Unused circuits in the controller could affect the EVPCM (e.g., a signal may short onto an unused circuit pathway).
1125	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM has the wrong understanding of how the traction inverter controller adjusts the current to the motor (e.g., lag time before the current effects a change in the motor, physical limitations of the inverter/converter and motor, etc.).
1264	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	An inadequate control algorithm prevents the EVPCM from decreasing the torque when transitioning from normal to BTO mode.
1265	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to give precedence to the driver's input via the accelerator pedal instead of a torque request from an active safety system.
1266	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The control algorithm may only turn the cooler on when the power stage temperature crosses the high temperature threshold; it may not activate if the temperature is already above the threshold, preventing the cooler from turning back on (e.g., if it was incorrectly turned off).
1267	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The EVPCM may operate the inverter cooler in response to conditions other than the inverter temperature.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
1268	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to switch into BTO mode when the driver presses both pedals, but the vehicle speed is below 10 mph.
1269	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the EVPCM to switch into BTO mode when the brake pedal is not pressed.
1270	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the EVPCM from switching into Normal mode when the driver presses the accelerator pedal and releases the brake pedal.
1271	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The EVPCM may not assign or issue torque if it mistakenly believes a diagnostic trouble code (DTC) has been issued by the traction inverter controller.
1272	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The EVPCM may incorrectly request a torque appropriate for a "limp-home" mode (i.e., the EVPCM incorrectly thinks the vehicle is in "limp-home" mode). The "limp-home" mode may be given precedence over BTO mode, causing the EVPCM to adopt a torque delivery appropriate for "limp-home" mode when it should be entering BTO mode.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
1273	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The EVPCM does not check for consistency between the vehicle speed, motor speed, and power delivered from the inverter/converter.
1274	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may prevent the EVPCM from responding to torque requests from other vehicle systems when the driver is not pressing the accelerator pedal.
1275	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm causes the EVPCM to increase the torque by the wrong amount when transitioning from BTO mode into Normal mode.
1276	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If the EVPCM is designed to simulate an "idle creep speed", a programming error or faulty software logic may cause the EVPCM to request the wrong "creep speed" torque. This causal factor may also apply to BTO mode if the motor operates at the simulated "idle creep speed" when in BTO mode.
1382	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM has the wrong understanding of the current torque output from the motor (e.g., the traction inverter controller provides the EVPCM with the wrong information).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
1385	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The control algorithm may prevent the EVPCM from changing the direction the motor is rotating if the vehicle is moving in the opposite direction at high speeds.
1436	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may have an incorrect understanding of which direction the traction motor is currently rotating (e.g., if the traction inverter controller reports the wrong information).
1437	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may have the wrong understanding of the selected gear.
1439	Actuator inadequate operation, change over time	Other	All UCAs related to EVPCM torque control actions apply.
1440	External control input or information wrong or missing	Other	The EVPCM may not recognize that another vehicle system has entered into a different operating mode (e.g., safe state).
1448	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may have an incorrect model for discharging the high voltage bus (e.g., discharge rate, amount of energy stored in capacitors, etc.).
1453	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may incorrectly think the vehicle was in a crash and open the contactor. For example, the deceleration value programmed into the EVPCM may be triggered by deceleration resulting from hard braking.
1510	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may not realize the vehicle was in a crash (e.g., the deceleration value programmed in the EVPCM may be too high).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module)
1513	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The EVPCM control algorithm may require additional inputs beyond the HVIL sensor signal to determine if there is an HVIL fault.
1514	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The EVPCM may incorrectly perceive the fault state to be cleared.

Table H-9: Gate Drive Board

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board)
373	Actuator inadequate operation, change over time	Internal hardware failure	An internal hardware failure may affect the gate drive board.
374	Actuator inadequate operation, change over time	Degradation over time	Degradation over time may affect the gate drive board.
375	Actuator inadequate operation, change over time	Over temperature due to faulty cooling system	A faulty cooling system (probably a heat sink) may lead to the gate drive board becoming too hot which in turn may affect its functionality.
376	Actuator inadequate operation, change over time	Incorrectly sized actuator	If the wrong subcomponents are installed on the gate drive board, it may not function correctly.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board)
377	Actuator inadequate operation, change over time	Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts	Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts may affect the gate drive board's ability to control the inverter's power stage.
378	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the gate drive board.
379	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) may affect the gate drive board.
380	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the gate drive board.
381	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the gate drive board.
382	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the gate drive board.
383	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the gate drive board.
384	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the gate drive board.
385	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the gate drive board.
439	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A faulty power supply may cause actuation delay or no actuation which will affect the gate drive board.
441	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the gate drive board.
442	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board)
443	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the gate drive board.
444	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the gate drive board.
446	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the gate drive board.
447	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the gate drive board.
969	Actuator inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	Overheating due to increased resistance in a subcomponent or internal shorting may affect the Gate Drive Board.
970	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the gate drive board, causing internal shorting or other failures.
1317	Actuator inadequate operation, change over time	Other	If the gate drive board provides electrical isolation between the inverter/converter (power stage). and the traction inverter controller, the isolation technology may be inadequate (e.g., allow high voltage feedback to the traction inverter controller, introduce a delay in the signal, etc.).

Table H-10: Inverter Cooler

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Cooler)
206	Actuator inadequate operation, change over time	Internal hardware failure	The inverter cooler has an internal hardware failure.
207	Actuator inadequate operation, change over time	Degradation over time	The inverter cooler degrades over time.
208	Actuator inadequate operation, change over time	Incorrectly sized actuator	The inverter cooler is incorrectly sized to adequately cool the inverter.
209	Actuator inadequate operation, change over time	Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts	The relays controlling the inverter cooler pump's motor fail (assuming the inverter is liquid cooled).
212	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the inverter cooler.
213	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the inverter cooler.
214	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the inverter cooler.
215	External disturbances	Organic growth	Organic growth may affect the inverter cooler.
216	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the inverter cooler.
217	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the inverter cooler.
218	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A power supply that's too low, causing actuation delay or no actuation may affect the inverter cooler.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Cooler)
429	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the inverter cooler.
430	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect the inverter cooler.
431	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the inverter cooler.
432	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the inverter cooler.
971	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the inverter cooler (e.g., causing seals on the pump to fail).
972	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the inverter cooler.
973	Hazardous interaction with other components in the rest of the vehicle	Unable to meet demands from multiple components (e.g., inadequate torque)	If the inverter cooler system is also used to cool other vehicle components, the inverter cooler may be unable to supply sufficient cooling to all of these components.
1012	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the inverter cooler.
1013	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the inverter cooler.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Cooler)
1014	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the inverter cooler.
1441	Actuator inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The inverter cooler may overheat due to increased resistance in a subcomponent or internal shorting.
1446	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	If there is a disturbance in the power supply to the inverter cooler, the inverter cooler function may be affected and it may not supply coolant to the power stage.

Table H-11: Inverter Temperature Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Temperature Sensor)
185	Sensor inadequate operation, change over time	Internal hardware failure	An internal hardware failure may affect the inverter temperature sensor.
186	Sensor inadequate operation, change over time	Degradation over time	The inverter temperature sensor may fail due to degradation over time.
188	Sensor inadequate operation, change over time	Reporting frequency too low	The inverter temperature sensor may have too low of a reporting frequency.
189	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the inverter temperature sensor reading.
191	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the inverter temperature sensor reading.
192	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the inverter temperature sensor reading.
193	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the inverter temperature sensor reading.
194	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the inverter temperature sensor reading.
195	External disturbances	Organic growth	Organic growth may affect the inverter temperature sensor reading.
196	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the inverter temperature sensor reading.
197	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	The reference voltage being too low or too high may affect the inverter temperature sensor reading.
199	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A power supply disturbance, causing intermittent operation may affect the inverter temperature sensor reading.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Temperature Sensor)
200	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the inverter temperature sensor reading.
201	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the inverter temperature sensor reading.
202	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the inverter temperature sensor reading.
203	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the inverter temperature sensor reading.
204	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the inverter temperature sensor reading.
205	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the inverter temperature sensor reading.
438	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	Overheating due to increased resistance in a subcomponent or internal shorting can affect the inverter temperature sensor.
982	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the inverter temperature sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (inverter Temperature Sensor)
983	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the inverter temperature sensor.

Table H-12: Inverter/Converter (Power Stage)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage))
483	Actuator inadequate operation, change over time	Internal hardware failure	Internal hardware failure may affect the inverter/converter (power stage). .
484	Actuator inadequate operation, change over time	Degradation over time	The inverter/converter (power stage). may degrade over time.
486	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the inverter/converter (power stage). .
488	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the inverter/converter (power stage). .
489	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the inverter/converter (power stage). .
490	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the inverter/converter (power stage). .
491	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the inverter/converter (power stage). .
492	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the inverter/converter (power stage). .
493	External disturbances	Magnetic interference	Magnetic interference from the external environment may affect the inverter/converter (power stage). .

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage))
496	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the inverter/converter (power stage). .
497	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the inverter/converter (power stage). .
498	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the inverter/converter (power stage). .
499	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the inverter/converter (power stage). .
500	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other components may affect the inverter/converter (power stage). .
501	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the inverter/converter (power stage). .
502	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the inverter/converter (power stage). .
503	Hazardous interaction with other components in the rest of the vehicle	Unable to meet demands from multiple components (e.g., inadequate torque)	The inverter/converter (power stage). may be unable to meet the demands from multiple components (e.g., not enough DC may be available to power multiple traction motors or to power auxiliary devices and the traction motor).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage))
1015	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the Inverter/Converter (Power Stage), causing internal shorting or other failures of the control module.
1021	Input to controlled process missing or wrong	Input to controlled process missing or wrong	The inverter/converter (power stage). may not receive a direct current power supply from the high voltage battery.
1022	Output of controlled process contributes to system hazard	Output of controlled process contributes to system hazard	The inverter/converter (power stage). may not output the correct current to the traction motor. This could result in the traction motor not functioning or functioning irregularly.
1308	Actuator inadequate operation, change over time	Incorrectly sized actuator	The inverter/converter may have the incorrect transistors (e.g., wrong type, wrong size, etc.), affecting the power flow to the traction motor.
1309	Actuator inadequate operation, change over time	Relay failure modes, including: (1) does not energize, (2) does not de-energize, and (3) welded contacts	Relays or switches in the inverter/converter (power stage). may fail. For example, relays may not energize, may not de-energize, or may become welded shut (e.g., stuck). This may affect the power flow to the traction motor.
1310	Actuator inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The inverter/converter (power stage). may overheat due to increased resistance in a subcomponent or internal shorting.
1312	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the inverter/converter (power stage). (e.g., causing the power stage to overheat).
1313	Actuator inadequate operation, change over time	Over temperature due to faulty cooling system	If the inverter/converter (power stage). has a passive cooling system (i.e., not controlled through the EVPCM), the inverter/converter may overheat if this cooling system is faulty.
1314	Output of controlled process contributes to system hazard	Output of controlled process contributes to system hazard	The inverter/converter (power stage). may not output the correct AC to the traction motor. This could result in the traction motor not functioning or functioning irregularly.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage))
1315	Conflicting control action	Conflicting control action	The inverter/converter (power stage). may respond to a control action from another vehicle controller (e.g., a battery management system controller) instead of the command from the traction inverter controller.
1447	Controlled component failure, change over time	Other	A failure in the power stage may cause a temperature increase that cannot be mitigated by the inverter cooling subsystem.
1449	Conflicting control action	Conflicting control action	The inverter/converter (power stage). may receive a conflicting command from another vehicle system to retain power on the high voltage bus.
1450	Controlled component failure, change over time	Other	The inverter/converter may not be physically capable of discharging the high voltage bus or receiving the command to discharge the high voltage bus (e.g., damage from a vehicle crash).
1451	Output of controlled process contributes to system hazard	Output of controlled process contributes to system hazard	The inverter/converter may not fully discharge the bus when requested.

Table H-13: Motor Position/Speed Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor)
1044	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the motor position/speed sensor loses 12-volt power it may not be able to measure or report the motor speed or position.
1045	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12-volt power supply could affect the motor position/speed sensor (e.g., delay a measurement).
1046	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the motor position/speed sensor.
1047	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the motor position/speed sensor.
1048	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the motor position/speed sensor.
1049	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the motor position/speed sensor.
1050	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the motor position/speed sensor.
1051	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the motor position/speed sensor.
1052	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the motor position/speed sensor.
1053	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the motor position/speed sensor.
1054	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from the external environment could affect the motor position/speed sensor.
1055	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from the external environment could affect the motor position/speed sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor)
1056	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the motor position/speed sensor.
1057	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the motor position/speed sensor.
1058	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the motor position/speed sensor.
1059	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the motor position/speed sensor.
1060	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the motor position/speed sensor.
1061	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the motor position/speed sensor.
1062	Sensor inadequate operation, change over time	Internal hardware failure	Internal hardware failure may affect the motor position/speed sensor.
1063	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The motor position/speed sensor may overheat due to increased resistance in a subcomponent or internal shorting.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor)
1064	Sensor inadequate operation, change over time	Degradation over time	The motor position/speed sensor may degrade overtime.
1065	Sensor inadequate operation, change over time	Reporting frequency too low	The reporting frequency of the motor position/speed sensor may be too low.

Table H-14: Motor Temperature Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor)
1023	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the motor temperature sensor loses 12-volt power it may be unable to measure or report the motor temperature.
1024	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12-volt power supply may damage the motor temperature sensor or cause a delay in measuring or reporting the motor temperature.
1025	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	If the reference voltage to the motor temperature sensor is incorrect, it may report too high or too low of a motor temperature.
1026	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the motor temperature sensor.
1027	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the motor temperature sensor (e.g., dislodge the sensor).
1028	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the motor temperature sensor.
1029	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the motor temperature sensor (e.g., cause an inaccurate reading).
1030	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the motor temperature sensor (e.g., cause internal shorting).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor)
1031	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the motor temperature sensor.
1032	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the motor temperature sensor.
1033	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the motor temperature sensor.
1034	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the motor temperature sensor (e.g., dislodge the sensor).
1035	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the motor temperature sensor.
1036	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the motor temperature sensor (e.g., cause internal shorting).
1037	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the motor temperature sensor (e.g., cause an inaccurate reading).
1038	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components could affect the motor temperature sensor.
1039	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the motor temperature sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor)
1040	Sensor inadequate operation, change over time	Internal hardware failure	An internal hardware failure could affect the motor temperature sensor.
1041	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The motor temperature sensor may overheat due to internal shorting or increased resistance in a subcomponent.
1042	Sensor inadequate operation, change over time	Degradation over time	The motor temperature sensor may degrade over time.
1043	Sensor inadequate operation, change over time	Reporting frequency too low	The reporting frequency of the motor temperature sensor may be too low.

Table H-15: Phase/Current Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor)
460	Sensor inadequate operation, change over time	Internal hardware failure	An internal hardware failure may affect the phase/current sensor.
461	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The phase/current sensor may overheat due to increased internal resistance in a subcomponent or internal shorting.
462	Sensor inadequate operation, change over time	Degradation over time	The phase/current sensor may degrade over time.
463	Sensor inadequate operation, change over time	Reporting frequency too low	The reporting frequency of the phase/current sensor may be too low.
464	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the phase/current sensor.
466	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the phase/current sensor.
467	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the phase/current sensor.
468	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the phase/current sensor.
469	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the phase/current sensor.
470	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the phase/current sensor.
471	External disturbances	Magnetic interference	Magnetic interference from the external environment may affect the phase/current sensor.
472	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the phase/current sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor)
473	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A reference voltage that is too low or too high may affect the phase/current sensor.
475	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A power supply disturbance may affect the phase/current sensor (e.g., causing intermittent operation).
476	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the phase/current sensor.
477	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the phase/current sensor.
478	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the phase/current sensor.
479	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the phase/current sensor.
480	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other components may affect the phase/current sensor.
481	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the phase/current sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor)
482	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the phase/current sensor.
984	External disturbances	Organic growth	Organic growth may affect the phase/current sensor (e.g., causing shorting).
985	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the phase/current sensor.

Table H-16: Traction Inverter Controller

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
344	External disturbances	Single event effects (e.g., cosmic rays, protons)	Single event effects (e.g., cosmic rays, protons) may affect the traction inverter controller (e.g., cause temporary faults in software logic or memory corruption).
351	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	Fluctuations in the power supply, including power spikes, may affect traction inverter controller (e.g., damaging the controller or affecting stored memory).
359	Controller hardware faulty, change over time	Internal hardware failure	Faulty hardware or an internal hardware failure could affect the traction inverter controller.
360	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	Overheating due to increased resistance in a subcomponent or internal shorting may affect the traction inverter controller.
361	Controller hardware faulty, change over time	Over temperature due to faulty cooling system	The traction inverter controller may overheat due to a faulty cooling system (e.g., faulty heat sink).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
362	Controller hardware faulty, change over time	Degradation over time	Controller hardware degradation over time may affect the tranction inverter controller output.
363	Controller hardware faulty, change over time	Faulty internal timing clock	If the traction inverter controller uses internal timing for determining when to issue a control action, faulty electronic subcomponents in the timing module could cause the control action to be issued too soon or too late.
364	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters) may affect the traction inverter controller output.
369	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	Incomplete or incorrect sensor or actuator calibration in the traction inverter controller, including degradation characteristics, may cause the traction inverter controller to misinterpret sensor measurements or may cause the actuator output to differ from the output expected by the traction inverter controller.
371	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The traction inverter controller's model of the the traction motor may be incorrect (e.g., incorrect relationship between current input and torque output).
386	External control input or information wrong or missing	Timing related input is incorrect or missing	If the traction inverter controller requires a timing input from an external source, the timing signal may be incorrect or missing.
387	External control input or information wrong or missing	Spurious input due to shorting or other electrical fault	The traction inverter controller may respond to a spurious input from another vehicle system (e.g., an input that mimics a torque request).
388	External control input or information wrong or missing	Corrupted input signal	The input signal to the traction inverter controller from another vehicle system may become corrupted.
389	External control input or information wrong or missing	Malicious Intruder	A malicious intruder or aftermarket component may send a signal to the traction inverter controller that mimics a torque request.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
393	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Flaws in software code creation	Flaws in software code creation may result in the traction inverter controller incorrectly issuing a control action.
394	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the traction inverter controller to decrease the current to the traction motor without a clear command to decrease torque from the EVPCM.
449	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the traction inverter controller to increase the current to the traction motor without a clear command to increase torque from the EVPCM.
452	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The traction inverter controller may incorrectly compute the current required to provide the torque commanded by the EVPCM (e.g., wrong amount of current).
839	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the traction inverter controller.
841	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the traction inverter controller.
842	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the traction inverter controller.
843	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
844	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the traction inverter controller.
845	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the traction inverter controller.
850	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	Loss of 12-volt power may affect the traction inverter controller.
853	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the traction inverter controller.
854	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the traction inverter controller.
855	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other components may affect the traction inverter controller.
856	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other components may affect the traction inverter controller.
857	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the traction inverter controller.
859	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
860	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the traction inverter controller.
939	Controller hardware faulty, change over time	Faulty memory storage or retrieval	Faulty memory storage or retrieval may cause the traction inverter controller to incorrectly issue a control action.
941	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the traction inverter controller to adjust the current to the traction motor for the wrong duration (e.g., increases the current for too short a period).
942	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may introduce a delay when calculating the current required to provide the torque commanded by the EVPCM.
967	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the Traction Inverter Controller, causing internal shorting or other failures of the control module.
968	Controller hardware faulty, change over time	Unused circuits in the controller	Unused circuits in the controller could affect the traction inverter controller (e.g., a signal may short onto an unused circuit pathway).
1350	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the traction inverter controller to restrict the current flow to the motor (e.g., the traction inverter controller thinks there is a discrepancy between the current supplied to the motor and the motor position/speed).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller)
1351	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or flaw in software logic may cause the traction inverter controller to disconnect the high voltage and discharge the high voltage bus (e.g., incorrectly detects a fault in the system).
1383	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The traction inverter controller does not compare the phase/current supplied to the traction motor and the speed/position output of the traction motor.
1384	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The traction inverter controller may incorrectly think there is a problem with the traction motor (e.g., over temperature).
1438	Actuator inadequate operation, change over time	Other	All UCAs related to the traction inverter controller apply.

Table H-17: Transmission Range Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor)
1386	Sensor inadequate operation, change over time	Internal hardware failure	The transmission range sensor may have an internal hardware failure, affecting its ability to detect or report the gear stick position.
1387	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The transmission range sensor may overheat due to increased resistance in a subcomponent or internal shorting.
1388	Sensor inadequate operation, change over time	Degradation over time	The transmission range sensor may degrade over time, affecting its ability to detect or report the gear stick position.
1389	Sensor inadequate operation, change over time	Reporting frequency too low	The reporting frequency for the transmission range sensor may be too low.
1390	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the transmission range sensor.
1391	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the transmission range sensor.
1392	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the transmission range sensor.
1393	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the transmission range sensor.
1394	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the transmission range sensor.
1395	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the transmission range sensor (e.g., cause internal shorting).
1396	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the transmission range sensor.
1397	External disturbances	Magnetic interference	Magnetic interference could affect the transmission range sensor (e.g., if the sensor is a hall effect type).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor)
1398	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the transmission range sensor loses 12-volt power, it may be unable to report the current gear stick position.
1399	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disturbance in the power supply to the transmission range sensor may affect the sensor's ability to report the current gear stick position (e.g., delay).
1400	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the transmission range sensor.
1401	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the transmission range sensor.
1402	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference with other vehicle components could affect the transmission range sensor.
1403	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the transmission range sensor.
1404	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the transmission range sensor.
1405	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the transmission range sensor (e.g., if the sensor is a hall effect type).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor)
1406	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the transmission range sensor.
1407	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the transmission range sensor.

Table H-18: Wheel Speed Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor
59	Sensor inadequate operation, change over time	Internal hardware failure	The wheel speed sensor may have an internal hardware failure. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
60	Sensor inadequate operation, change over time	Degradation over time	The wheel speed sensor may degrade over time. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor
61	Sensor inadequate operation, change over time	Internal hardware failure	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) could cause the wheel speed sensor to overheat, affecting its function. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
62	External disturbances	Moisture, corrosion, or contamination	Contamination or corrosion from the external environment (e.g., dirt or rust build-up) could affect the wheel speed sensor. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
63	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the wheel speed sensor. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor
64	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects (e.g., improper installation) could affect the function of the wheel speed sensor. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
65	External disturbances	Vibration or shock impact	Vibration could affect the wheel speed sensor (e.g., dislodge the sensor). This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
66	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature (e.g., heat or cold) could cause the wheel speed sensor to overheat, affecting its function. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor
67	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The wheel speed sensor could lose 12V power. This could cause the sensor not to report the wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
68	Hazardous interaction with other components in the rest of the vehicle	Moisture, corrosion, or contamination	Moisture or other fluids from other vehicle components (e.g., A/C condensation, hydraulic brake fluid) could affect the wheel speed sensor. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)
69	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	The wheel speed sensor could become dislodged due to physical interference with other vehicle components (e.g., inadequate clearance). This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor
70	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the wheel speed sensor. This could cause the sensor not to report the wheel speed, to incorrectly or intermittently report the wheel speed, or to become stuck reporting the same wheel speed. This applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. (Note: Since FMVSS does not specify a BTO design, OEMs may use different sensors for developing a BTO strategy.)

Table H-19: Accelerator Pedal to Accelerator Pedal Position Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal to Accelerator Pedal Position Sensor)
156	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	If the accelerator pedal and accelerator pedal position sensor are misaligned, the sensor may incorrectly measure the pedal position.
806	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The accelerator pedal position sensor may be incorrectly aligned or positioned on the accelerator pedal, resulting in an incorrect or missing measurement (e.g., measurement outside range).
807	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect how the accelerator pedal position sensor measures the position of the accelerator pedal.
808	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems (e.g., exceeded tolerance) may affect how the accelerator pedal position sensor measures the position of the accelerator pedal. If the accelerator pedal intermittently activates the pedal position sensor, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal to Accelerator Pedal Position Sensor)
809	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components may affect how the accelerator pedal position sensor measures the position of the accelerator pedal.
810	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components (e.g., insufficient clearance) may affect how the accelerator pedal position sensor measures the position of the accelerator pedal (e.g., the sensor and pedal become misaligned). If the accelerator pedal intermittently activates the pedal position sensor, this may cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
1006	Sensor measurement delay	Sensor incorrectly aligned or positioned	The accelerator pedal position sensor may be incorrectly aligned or positioned on the accelerator pedal, resulting in a delayed measurement (e.g., the shaft slips before engaging the potentiometer).
1007	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) could cause the connection between the accelerator pedal and accelerator pedal position sensor to degrade. This may cause the sensor to incorrectly or intermittently measure the accelerator pedal position; delay reporting changes in the pedal position; or fail to detect changes in the pedal position (e.g., stuck at a value).
1008	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could affect the connection between the accelerator pedal and accelerator pedal position sensor (e.g., causing binding). This may cause the sensor to incorrectly or intermittently measure the accelerator pedal position; delay reporting changes in the pedal position; or fail to detect changes in the pedal position (e.g., stuck at a value).
1009	Hazardous interaction with other components in the rest of the vehicle	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could cause the connection between the accelerator pedal and accelerator pedal position sensor to degrade. This may cause the sensor to incorrectly or intermittently measure the accelerator pedal position; delay reporting changes in the pedal position; or fail to detect changes in the pedal position (e.g., stuck at a value).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal to Accelerator Pedal Position Sensor)
1126	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures could affect the connection between the accelerator pedal and accelerator pedal position sensor (e.g., deformation may affect how the sensor measures changes in the accelerator pedal position).
1127	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the accelerator pedal and accelerator pedal position sensor (e.g., deformation may affect how the sensor measures changes in the accelerator pedal position).

Table H-20: Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
126	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the accelerator pedal position sensor to the EVPCM is transmitted over the communication bus, a communication bus error or overload could affect the accelerator pedal position signal. The EVPCM may not receive a pedal position measurement, may receive an incorrect or intermittent pedal position measurement, or the pedal position measurement may not update (i.e., stuck at value). In regard to mode switching: If the signal from the APPS becomes intermittent, this could cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
127	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the accelerator pedal position sensor to the EVPCM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the accelerator pedal position signal. The EVPCM may not receive a pedal position measurement, may receive an incorrect or intermittent pedal position measurement, or the pedal position measurement may not update (i.e., stuck at value). In regard to mode switching: If the signal from the APPS becomes intermittent, this could cause the EVPCM to think the pedal conflict is removed and exit BTO mode; the EVPCM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
130	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the accelerator pedal position sensor (APPS) and EVPCM. The EVPCM may not receive a pedal position measurement, may receive an incorrect or intermittent pedal position measurement, or the pedal position measurement may not update (i.e., stuck at value).
131	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the accelerator pedal position sensor (APPS) and EVPCM. The EVPCM may not receive a pedal position measurement, may receive an incorrect or intermittent pedal position measurement, or the pedal position measurement may not update (i.e., stuck at value).
173	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment in the connection between the accelerator pedal position sensor and EVPCM could cause the EVPCM to have the wrong accelerator pedal position information. The EVPCM may not receive a pedal position measurement, may receive an incorrect pedal position measurement, or the pedal position measurement may not update (i.e., stuck at value).
811	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	An intermittent connection may affect the signals from the accelerator pedal position sensor to the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
812	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the accelerator pedal position sensor to the EVPCM.
813	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD may affect the signals from the accelerator pedal position sensor to the EVPCM.
814	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect the signal from the accelerator pedal position sensor to the EVPCM.
815	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect the signal from the accelerator pedal position sensor to the EVPCM.
816	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift in the connectors may affect the signal from the accelerator pedal position sensor to the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
818	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the accelerator pedal position sensor and EVPCM are connected with the communication bus, the accelerator pedal position sensor signal priority may be too low.
820	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the accelerator pedal position sensor and EVPCM are connected with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the accelerator pedal position sensor signal.
821	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	An incorrect wiring connection may affect the signals from the accelerator pedal position sensor to the EVPCM.
825	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the signals from the accelerator pedal position sensor to the EVPCM.
826	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the signals from the accelerator pedal position sensor to the EVPCM.
827	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the signals from the accelerator pedal position sensor to the EVPCM.
828	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the accelerator pedal position sensor and the EVPCM.
829	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the signals from the accelerator pedal position sensor to the EVPCM (e.g., damage the wiring).
830	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the accelerator pedal position sensor or the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
832	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the signals from the accelerator pedal position sensor to the EVPCM.
833	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect the signals from the accelerator pedal position sensor to the EVPCM.
834	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the accelerator pedal position sensor and the EVPCM.
835	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the signals from the accelerator pedal position sensor to the EVPCM.
836	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the signals from the accelerator pedal position sensor to the EVPCM.
837	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of accelerator pedal position sensor or the EVPCM.
995	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection between the accelerator pedal position sensor and the EVPCM (e.g., causing shorting between pins).
996	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the accelerator pedal position sensor and the EVPCM (e.g., damage wiring).

Table H-21: Battery Management System to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System to Electric Vehicle Powertrain Control Module)
1159	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the Battery Management System (BMS) and the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and discharge the high voltage bus.
1160	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the Battery Management System (BMS) and the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1161	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the Battery Management System (BMS) and the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1162	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1163	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect unused connection terminals in the wiring harness connecting the Battery Management System (BMS) and the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1164	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the connection terminals of the Battery Management System (BMS) or EVPCM (e.g., causing shorting). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System to Electric Vehicle Powertrain Control Module)
1165	External disturbances	Organic growth	Organic growth in the connection terminals could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1166	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1167	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1168	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1169	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1170	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the wiring harness connecting the Battery Management System (BMS) and the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System to Electric Vehicle Powertrain Control Module)
1171	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection terminals of the Battery Management System (BMS) or the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1172	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1173	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1174	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1175	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the Battery Management System (BMS) and EVPCM are connected over the communication bus, a bus overload or bus error could affect the signal from the BMS to the EVPCM. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1176	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the Battery Management System (BMS) and EVPCM are connected over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the BMS signal to shut down the high voltage system. The EVPCM may act on this incorrect signal and shutdown the high voltage system (e.g., discharge the high voltage bus).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System to Electric Vehicle Powertrain Control Module)
1177	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the Battery Management System (BMS) and EVPCM are connected over the communication bus, a failure of the message generator, transmitter, or receiver may prevent a signal from the BMS from reaching the EVPCM. Without a signal from the BMS, the EVPCM may decide to shutdown the high voltage system (e.g., discharge the high voltage bus).
1178	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the Battery Management System (BMS) and EVPCM are connected over the communication bus, the signal priority of the BMS may be too low. Without a signal from the BMS, the EVPCM may decide to shutdown the high voltage system (e.g., discharge the high voltage bus).
1179	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD could affect the connection between the Battery Management System (BMS) and the EVPCM (e.g., damage wiring). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1180	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the Battery Management System (BMS) and the EVPCM could become open, short to ground, short to battery, or short to other wires in the connection harness. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1181	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the Battery Management System (BMS) and the EVPCM could become intermittent. A disrupted signal from the BMS may cause the EVPCM to shutdown the high voltage system (e.g., discharge the high voltage bus).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Battery Management System to Electric Vehicle Powertrain Control Module)
1182	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connectors of the Battery Management System (BMS) or EVPCM may be too high, causing the EVPCM to receive an incorrect signal. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1183	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connectors of the Battery Management System (BMS) or EVPCM may develop a short between neighboring pins. The EVPCM may act on an incorrect signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1184	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift may occur between neighboring pins in the connectors of the Battery Management System (BMS) or EVPCM. The EVPCM may act on an incorrect signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1185	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the Battery Management System (BMS) and EVPCM may be incorrectly wired (e.g., reversed wires). The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).
1186	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	The Battery Management System (BMS) or EVPCM may have an incorrect pin assignment. The EVPCM may act on an incorrect or missing signal from the BMS and shutdown the high voltage system (e.g., discharge the high voltage bus).

Table H-22: Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
83	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, in addition to EMI/ESD, could affect the signal from the brake/VSA control module to the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
84	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the brake/VSA control module to EVPCM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the vehicle speed signal. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
85	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the brake/VSA control module to EVPCM is transmitted over the communication bus, a bus overload or error could affect the vehicle speed signal. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
86	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the brake/VSA control module to EVPCM is transmitted over the communication bus, the vehicle speed signal priority on the communication bus may not be high enough. The EVPCM may not receive a vehicle speed measurement or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
87	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection from the brake/VSA control module to the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
88	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the connection terminals of the brake/VSA control module or EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
89	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect unused connection terminals in the wiring harness connecting the brake/VSAVSA control module and EVPCM, causing shorts between pins. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
90	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the brake/VSA control module or EVPCM to wear over time, causing shorting to other pins. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
91	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection from the brake/VSA control module to the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
92	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could affect the connection terminals of the brake/VSA control module or EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
93	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could affect the unused connection terminals in the wiring harness connecting the brake/VSAVSA control module and EVPCM, causing shorts between pins. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
94	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or interference from other vehicle components could affect the connection between the brake/VSAVSA control module and EVPCM (e.g., wiring is cut). The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
96	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	An open or short circuit develops in the connection between the brake/VSAVSA control module and EVPCM. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an incorrect or intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
97	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the brake/VSA control module to EVPCM is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics a vehicle speed measurement. This could cause the EVPCM not to receive the average wheel speed/vehicle speed, to receive an incorrect or intermittent average wheel speed/vehicle speed, or to receive a constant average wheel speed/vehicle speed (e.g., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
139	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	An intermittent fault could develop in the wiring or connectors between the brake/VSAVSA control module and the EVPCM. The EVPCM may receive an incorrect or intermittent vehicle speed measurement. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1204	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the brake/VSAVSA control module and the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
1205	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the connection between the brake/VSAVSA control module and the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1206	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection between the brake/VSA control module and the EVPCM (e.g., causing shorting between pins). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1207	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing could affect the connection between the brake/VSAVSA control module and the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
1208	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the brake/VSAVSA control module and the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1209	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the brake/VSAVSA control module and the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1210	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the brake/VSAVSA control module and the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
1211	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the brake/VSAVSA control module and the EVPCM. The EVPCM may not receive a vehicle speed measurement, may receive an incorrect or intermittent vehicle speed measurement, or the vehicle speed measurement may not update (i.e., stuck at value). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1212	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connectors of the brake/VSAControl Module or EVPCM may be too high. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1213	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connectors for the brake/VSA control module or EVPCM may develop shorting between pins. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Electric Vehicle Powertrain Control Module)
1214	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift may occur between neighboring pins in the connection terminals of the brake/VSA control module or EVPCM. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1215	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the brake/VSAVSA control module and EVPCM may be incorrectly wired. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
1216	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection between the brake/VSAVSA control module and EVPCM may have an incorrect pin assignment. This could cause the EVPCM not to receive the average wheel speed/vehicle speed or to receive an intermittent average wheel speed/vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Table H-23: Brake Pedal Assembly to Brake Pedal Position Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Assembly to Brake Pedal Position Sensor)
6	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The brake pedal and brake pedal position sensor could become misaligned (e.g., driver pulls upward on the brake pedal). This may cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
7	External disturbances	Physical interference (e.g., chafing)	Foreign objects in the driver's footwell could cause the brake pedal and brake pedal position sensor to become misaligned. This may cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.
8	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference with other vehicle components could cause the brake pedal and brake pedal position sensor to become misaligned. This may cause the brake pedal to inadvertently or intermittently activate the pedal position sensor, prevent activation of the pedal position sensor, or cause the brake pedal to become stuck in the "pressed" position.

Table H-24: Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
71	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the brake pedal position sensor and EVPCM could develop a short to ground or short to other wires in the harness. This could cause the EVPCM to not receive a signal or to receive an incorrect signal from the brake pedal position sensor. An intermittent signal may not persist long enough to engage BTO (i.e., the switching algorithm may require a minimum period of brake activation). Alternatively, an intermittent connection failure may cause the EVPCM to think the pedal conflict has cleared. The EVPCM may not re-engage BTO if the pedal application sequence requires the brake pedal to be pressed first.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
73	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the brake pedal position sensor to the EVPCM is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the brake pedal position sensor signal.
74	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	If the connection from the brake pedal position sensor to the EVPCM is incorrectly wired, the EVPCM may receive an incorrect signal (e.g., that the brake is not pressed instead of pressed) or may receive the wrong magnitude of brake pedal travel.
75	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) could affect the connection terminals of the brake pedal position sensor or EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
76	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) could affect unused connection terminals in the wiring harness connecting the brake pedal position sensor and EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
77	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the brake pedal position sensor and EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
78	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the brake pedal position sensor or EVPCM (e.g., fretting). This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
79	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the brake pedal position sensor and EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
80	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components could affect the connection between the brake pedal position sensor and EVPCM (e.g., wiring is cut). This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
81	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could affect the connection terminals of the brake pedal position sensor or EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
82	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) could affect unused connection terminals on the wiring harness connecting the brake pedal position sensor and EVPCM. This could cause the EVPCM to receive no signal or an incorrect, intermittent, or delayed signal from the brake pedal position sensor.
95	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the brake pedal position sensor to EVPCM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the sensor signal. The EVPCM may not receive the brake pedal position, may receive an incorrect or intermittent brake pedal position, or the brake pedal position may not update (i.e., stuck at value).
99	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the brake pedal position sensor to EVPCM is transmitted over the communication bus, a bus overload or error could affect the sensor signal. The EVPCM may not receive the brake pedal position, may receive an incorrect or intermittent brake pedal position, or the brake pedal position may not update (i.e., stuck at value).
100	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The brake pedal position sensor or EVPCM connection terminals could have an incorrect pin assignment. The EVPCM may not receive the brake pedal position or may receive an incorrect brake pedal position.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
125	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, other than EMI or ESD, could affect the signal from the brake pedal position sensor to the EVPCM. This could cause the EVPCM to not receive a signal, receive an incorrect or intermittent signal, or receive a constant signal (e.g., stuck at value).
177	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the brake pedal position sensor to EVPCM is transmitted over the communication bus, the brake pedal position signal priority on the communication bus may not be high enough. The EVPCM may not receive a pedal position measurement or the pedal position measurement may not update (i.e., stuck at value).
1225	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the brake pedal position sensor and the EVPCM.
1226	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the connection between the brake pedal position sensor and the EVPCM.
1227	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminals of the brake pedal position sensor or the EVPCM (e.g., causing shorting between pins).
1228	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing by foreign objects could affect the connection between the brake pedal position sensor and the EVPCM.
1229	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the brake pedal position sensor and the EVPCM (e.g., cause wiring to come loose).
1230	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the brake pedal position sensor and the EVPCM (e.g., melt the wiring).
1231	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the brake pedal position sensor and the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Electric Vehicle Powertrain Control Module)
1232	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the brake pedal position sensor and the EVPCM.
1233	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connection terminals of the brake pedal position sensor or EVPCM may be too high. This could cause the EVPCM to not receive a signal or to receive an incorrect signal from the brake pedal position sensor.
1234	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connectors of the brake pedal position sensor or EVPCM may develop shorting between neighboring pins. This could cause the EVPCM to not receive a signal or to receive an incorrect signal from the brake pedal position sensor.
1235	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift may occur between neighboring pins in the connectors of the brake pedal position sensor or EVPCM. This could cause the EVPCM to not receive a signal or to receive an incorrect signal from the brake pedal position sensor.

Table H-25: Contactor to Inverter/Converter (Power Stage)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Contactor to Inverter/Converter (Power Stage))
1247	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1248	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1249	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1250	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling may affect the power flow between the contactor and the inverter/converter (power stage). (e.g., accelerated degradation). This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1251	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination may affect unused connection terminals in the wiring harness connecting the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1252	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination may affect the active connection terminals of the contactor or the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1253	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection terminals of the contactor or the inverter/converter (power stage). (e.g., causing shorting between pins). This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Contactor to Inverter/Converter (Power Stage))
1254	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing from the external environment could affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1255	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1256	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1257	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1258	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1259	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect the connection between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1260	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components may affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1261	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the power flow between the contactor and the inverter/converter (power stage). . This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Contactor to Inverter/Converter (Power Stage))
1262	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the power flow between the contactor and the inverter/converter (power stage). (e.g., damage the power cable). This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.
1263	Input to controlled process missing or wrong	Input to controlled process missing or wrong	The direct current flowing between the contactor and the inverter/converter (power stage). may be altered. This may impact the amount of power supplied to the traction motor or the ability to recharge the high voltage battery.

Table H-26: Crash Sensor (Occupant Restraint Control Module) to EVPCM

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Crash Sensor to Electric Vehicle Powertrain Control Module)
1471	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Active connection terminals in the wiring harness connecting the crash sensor and the EVPCM could be affected by moisture, corrosion, or contamination.
1464	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the signal between the crash sensor and the EVPCM.
1467	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the signal between the crash sensor and the EVPCM.
1466	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the crash sensor and the EVPCM.
1469	External disturbances	Organic growth	Organic growth (e.g., mold) could affect the connection terminals of the crash sensor or EVPCM (e.g., causing shorts between pins).
1470	External disturbances	Physical interference (e.g., chafing)	Physical interference could affect the connection between the crash sensor and EVPCM (e.g., wire chafing).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Crash Sensor to Electric Vehicle Powertrain Control Module)
1468	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Unused connection terminals in the wiring harness connecting the crash sensor and EVPCM could be affected by moisture, corrosion, or contamination (e.g., causing shorts between pins).
1465	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the signal between the crash sensor and the EVPCM (e.g., connection becomes loose).
1479	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the active connection terminals of the crash sensor or EVPCM.
1478	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the crash sensor and EVPCM (e.g., degrade insulation).
1477	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from other vehicle components could affect the connection terminals of the crash sensor or EVPCM.
1472	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the signal from the crash sensor to the EVPCM.
1476	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the crash sensor and EVPCM (e.g., melt the wiring harness).
1481	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the connection between the crash sensor and the EVPCM (e.g., wire chafing).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Crash Sensor to Electric Vehicle Powertrain Control Module)
1480	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the wiring harness connecting the crash sensor and the EVPCM.
1473	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the crash sensor and EVPCM (e.g., connection becomes loose).
1511	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the crash sensor is transmitted over the communication bus, a bus overload or bus error may prevent the crash sensor signal from reaching the EVPCM.
1461	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the crash sensor is transmitted over the communication bus, failure of the message generator, transmitter, or receiver may affect the signal from the crash sensor.
1460	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the crash sensor is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics a crash signal.
1512	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the crash sensor is transmitted over the communication bus, the crash sensor signal priority may be too low.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Crash Sensor to Electric Vehicle Powertrain Control Module)
1459	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the crash sensor to the EVPCM may become intermittent.
1454	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the crash sensor to the EVPCM may become open, or may develop a short to ground, short to the battery, or short to other wires in the harness.
1456	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connection terminals of the crash sensor or EVPCM may be too high, affecting the signal.
1458	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift between neighboring pins may affect the connection terminals of the crash sensor or EVPCM.
1457	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between pins may develop in the connection terminals of the crash sensor or EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Crash Sensor to Electric Vehicle Powertrain Control Module)
1455	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD may affect the connection between the crash sensor and the EVPCM.
1463	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection between the crash sensor and EVPCM may have the incorrect pin assignment
1462	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the crash sensor and EVPCM may be incorrectly wired.

Table H-27: Electric Vehicle Powertrain Control Module to Gate Drive Board

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1277	External disturbances	EMI or ESD	EMI or ESD may affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1278	External disturbances	Single event effects (e.g., cosmic rays, protons)	If the EVPCM and gate drive board share a circuit board, single event effects (e.g., cosmic rays or protons) could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1279	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the EVPCM and gate drive board (e.g., fretting). This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1280	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1281	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1282	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect unused connection terminals in the wiring harness connecting the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1283	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the connection terminal of the EVPCM or gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1284	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminal of the EVPCM or gate drive board (e.g., causing shorting). This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1285	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1286	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1287	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1288	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the EVPCM and gate drive board (e.g., melting wiring). This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1289	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the wiring harness connecting the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1290	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection terminals of the EVPCM or gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1291	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1292	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1293	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1294	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the EVPCM and gate drive board are connected over the communication bus, a bus overload or bus error could prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1295	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the EVPCM and gate drive board are connected over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the EVPCM's command to disable the traction motor.
1296	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the EVPCM and gate drive board are connected over the communication bus, a failure of the message generator, transmitter, or receiver could prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1297	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the EVPCM and gate drive board are connected over the communication bus, the EVPCM's signal priority may be too low. This could prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1298	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD could affect the connection between the EVPCM and gate drive board. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1299	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the EVPCM and gate drive board may develop a short to ground, short to battery, short to other wires in the harness, or may become open. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1300	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the EVPCM and gate drive board may become intermittent. This may delay the EVPCM's command or prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1301	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contactor resistance in the connection terminals of the EVPCM or gate drive board may be too high. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Gate Drive Board)
1302	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the EVPCM or gate drive board may develop shorts between pins. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1303	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift between pins in the connection terminals of the EVPCM or gate drive board may affect the connection. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1304	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Other	If the EVPCM and gate drive board share a circuit board, unused circuits on the board may affect the connection between the EVPCM and gate drive board (e.g., the signal may jump to an unused circuit). This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1305	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	The EVPCM or gate drive board may have an incorrect pin assignment. This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.
1306	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect wiring connection	The EVPCM and gate drive board may be incorrectly wired (e.g., reversed wiring). This may cause the gate drive board to receive an errant command to disable the traction motor or may prevent the EVPCM's command to disable the traction motor from reaching the gate drive board.

Table H-28: Electric Vehicle Powertrain Control Module to Inverter Cooler

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Inverter Cooler)
247	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	An intermittent connection may affect communications between the EVPCM and the inverter cooler.
248	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the EVPCM and the inverter cooler.
249	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	An electrical noise other than EMI or ESD may affect communications between the EVPCM and the inverter cooler.
250	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect communications between the EVPCM and the inverter cooler.
251	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect communications between the EVPCM and the inverter cooler.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Inverter Cooler)
252	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift in the connectors may affect the signal from the EVPCM to the inverter cooler.
253	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the EVPCM and inverter cooler are connected over the communication bus, a bus overload or bus error may affect communications between the EVPCM and the inverter cooler.
254	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the EVPCM and inverter cooler are connected over the communication bus, the EVPCM signal priority may be too low.
255	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the EVPCM and inverter cooler are connected over the communication bus, failure of the message generator, transmitter, or receiver may affect communications between the EVPCM and the inverter cooler.
257	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the EVPCM and inverter cooler are connected over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the EVPCM signal to the inverter cooler.
258	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect wiring connection	An incorrect wiring connection (e.g., reversed wires) may affect communications between the EVPCM and the inverter cooler.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Inverter Cooler)
259	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment may affect communications between the EVPCM and the inverter cooler.
260	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect communications between the EVPCM and the inverter cooler.
262	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect communications between the EVPCM and the inverter cooler.
263	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect communications between the EVPCM and the inverter cooler.
264	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect communications between the EVPCM and the inverter cooler.
265	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the EVPCM and inverter cooler.
266	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect communications between the EVPCM and the inverter cooler (e.g., damage the wiring).
267	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the EVPCM or inverter cooler.
268	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect communications between the EVPCM and the inverter cooler.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Inverter Cooler)
269	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect communications between the EVPCM and the inverter cooler (e.g., causing the connectors to come loose).
270	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect communications between the EVPCM and the inverter cooler (e.g., damaging wiring).
271	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the EVPCM and inverter cooler.
272	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect communications between the EVPCM and the inverter cooler (e.g., melting the wiring).
273	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect communications between the EVPCM and the inverter cooler.
274	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect communications between the EVPCM and the inverter cooler.
275	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the EVPCM or inverter cooler.
987	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminals of the EVPCM or inverter cooler (e.g., causing shorting between pins).

Table H-29: Electric Vehicle Powertrain Control Module to Traction Inverter Controller

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Traction Inverter Controller)
862	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	An intermittent connection may affect communications between the EVPCM and the traction inverter controller.
863	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the EVPCM and the traction inverter controller.
864	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD may affect communications between the EVPCM and the traction inverter controller.
865	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect communications between the EVPCM and the traction inverter controller.
866	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect communications between the EVPCM and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Traction Inverter Controller)
867	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift in the connectors may affect the signal from the EVPCM to the traction inverter controller.
868	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the EVPCM and traction inverter controller are connected over the communication bus, a bus overload or bus error may affect communications between the EVPCM and the traction inverter controller.
869	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the EVPCM and traction inverter controller are connected over the communication bus, the EVPCM signal priority may be too low.
870	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the EVPCM and traction inverter controller are connected over the communication bus, a failure of the message generator, transmitter, or receiver may affect communications between the EVPCM and the traction inverter controller.
871	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the EVPCM and traction inverter controller are connected over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the EVPCM signal to the traction inverter controller.
872	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment may affect communications between the EVPCM and the traction inverter controller.
873	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect communications between the EVPCM and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Traction Inverter Controller)
875	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect communications between the EVPCM and the traction inverter controller.
876	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect communications between the EVPCM and the traction inverter controller.
877	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the EVPCM and the traction inverter controller.
878	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect communications between the EVPCM and the traction inverter controller.
879	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the EVPCM or the traction inverter controller.
880	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect communications between the EVPCM and the traction inverter controller.
881	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect communications between the EVPCM and the traction inverter controller.
882	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect communications between the EVPCM and the traction inverter controller.
883	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the EVPCM and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Electric Vehicle Powertrain Control Module to Traction Inverter Controller)
884	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect communications between the EVPCM and the traction inverter controller.
885	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect communications between the EVPCM and the traction inverter controller.
886	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect communications between the EVPCM and the traction inverter controller.
887	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the EVPCM or the traction inverter controller.
889	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect wiring connection	An Incorrect wiring connection may affect communications between the EVPCM and the traction inverter controller.
890	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect communications between the EVPCM and the traction inverter controller.
992	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminals of the EVPCM or traction inverter controller (e.g., causing shorting between pins).
1307	External disturbances	Single event effects (e.g., cosmic rays, protons)	If the EVPCM and traction inverter controller are on the same circuit board, single event effects (e.g., cosmic rays, protons) may affect the signal from the EVPCM to the traction inverter controller.

Table H-30: Gate Drive Board to Inverter/Converter (Power Stage)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board to Inverter/Converter (Power Stage))
528	Actuation delivered incorrectly or inadequately: Hardware faulty	Actuation delivered incorrectly or inadequately: Hardware faulty	Faulty hardware (e.g., damaged wiring or broken soldering) may affect the connection between the gate drive board and the inverter/converter (power stage). . This may prevent the signal from the gate drive board from being delivered or cause the signal from the gate drive board to be delivered incorrectly.
529	Actuation delivered incorrectly or inadequately: Actuation delayed	Actuation delivered incorrectly or inadequately: Actuation delayed	The signal from the gate drive board to the inverter/converter (power stage). may be delayed.
530	Actuation delivered incorrectly or inadequately: Incorrect connection	Actuation delivered incorrectly or inadequately: Incorrect connection	An incorrect connection may affect the signal from the gate drive board to the inverter/converter (power stage). .
531	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the connection between the gate drive board and the inverter/converter (power stage). .
533	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the connection between the gate drive board and the inverter/converter (power stage). .
534	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the connection between the gate drive board and the inverter/converter (power stage). .
535	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the connection between the gate drive board and the inverter/converter (power stage). .
536	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the connection between the gate drive board and the inverter/converter (power stage). .
537	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the gate drive board or the inverter/converter (power stage). .

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board to Inverter/Converter (Power Stage))
538	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the connection between the gate drive board and the inverter/converter (power stage). .
539	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the connection between the gate drive board and the inverter/converter (power stage). .
540	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect the connection between the gate drive board and the inverter/converter (power stage). .
541	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the connection between the gate drive board and the inverter/converter (power stage). .
542	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the connection between the gate drive board and the inverter/converter (power stage). .
543	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the gate drive board or the inverter/converter (power stage). .
993	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection terminals of the gate drive board or the inverter/converter (power stage). (e.g., causing shorting).
994	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components may affect the connection between the gate drive board and inverter/converter (power stage). .

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Gate Drive Board to Inverter/Converter (Power Stage))
1316	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components (e.g., A/C condensation) may affect unused connection terminals in the wiring harness connecting the gate drive board and the inverter/converter (power stage). .
1318	External disturbances	Single event effects (e.g., cosmic rays, protons)	If the gate drive board and the inverter/converter (power stage). share a circuit board, single event effects (e.g., cosmic rays, protons) could affect the signal from the gate drive board.
1323	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the gate drive board and inverter/converter (power stage).

Table H-31: HVIL to EVPCM

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (High Voltage Interlock Loop to EV Powertrain Control Module
1501	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect the connection terminals of the HVIL sensor or EVPCM.
1494	External disturbances	EMI or ESD	EMI or ESD may affect the connection between the HVIL sensor and EVPCM.
1497	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling may affect the connection between the HVIL sensor and EVPCM.
1496	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may affect the connection between the HVIL sensor and the EVPCM.
1499	External disturbances	Organic growth	Organic growth (e.g., mold) may affect the connection terminals of the HVIL sensor and EVPCM (e.g., causing shorting between pins).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (High Voltage Interlock Loop to EV Powertrain Control Module
1500	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment (e.g., road debris) may affect the connection between the HVIL sensor and EVPCM.
1498	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Unused connection terminals in the wiring harness connecting the HVIL sensor and EVPCM may be affected by moisture, corrosion, or contamination from the external environment.
1495	External disturbances	Vibration or shock impact	Vibration or shock impact may affect the connection between the HVIL sensor and EVPCM (e.g., connection becomes loose).
1509	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection terminals of the HVIL sensor and EVPCM.
1508	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the HVIL sensor and EVPCM (e.g., damage the insulation).
1507	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components could affect the connection terminals of the HVIL sensor or EVPCM.
1502	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components may affect the signal between the HVIL sensor and EVPCM.
1506	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components may affect the connection between the HVIL sensor and EVPCM (e.g., melt the wiring).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (High Voltage Interlock Loop to EV Powertrain Control Module
1504	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components may affect the connection between the HVIL sensor and EVPCM (e.g., wire chafing).
1505	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Unused connection terminals in the wiring harness connecting the HVIL sensor and EVPCM may be affected by moisture, corrosion, or contamination from other vehicle components.
1503	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components may affect the connection between the HVIL sensor and EVPCM (e.g., connection becomes loose).
1488	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the HVIL sensor to the EVPCM is transmitted over the communication bus, a bus overload or error could affect transmission of the HVIL fault signal (e.g., signal not transmitted when a fault occurs or HVIL sensor response to a query may not be received).
1490	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the HVIL sensor to the EVPCM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver may prevent the HVIL signal from reaching the EVPCM (e.g., signal not transmitted when a fault occurs or HVIL sensor response to a query may not be received).
1491	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the HVIL sensor to the EVPCM is transmitted over the communication bus, a malicious intruder or aftermarket component may issue a signal that mimics the HVIL fault signal.
1489	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the HVIL sensor to the EVPCM is transmitted over the communication bus, the HVIL fault signal priority may be too low (e.g., signal not transmitted when a fault occurs or HVIL sensor response to a query may not be received).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (High Voltage Interlock Loop to EV Powertrain Control Module
1482	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the HVIL sensor and EVPCM may become intermittent.
1483	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the HVIL sensor and EVPCM may become open, or develop a short to ground, battery, or other wires in the connection harness.
1485	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connection terminals for the HVIL sensor or EVPCM may be too high.
1487	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift between neighboring pins in the connection terminals of the HVIL sensor or EVPCM may occur.
1486	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the HVIL sensor or EVPCM may develop shorts between neighboring pins.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (High Voltage Interlock Loop to EV Powertrain Control Module
1484	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, other than EMI or ESD, could affect the signal from the HVIL sensor to the EVPCM.
1493	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The HVIL sensor or EVPCM may have an incorrect pin assignment.
1492	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the HVIL sensor and EVPCM may be incorrectly wired.

Table H-32: Inverter Cooler to Inverter/Converter (Power Stage)

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Cooler to Inverter/Converter (Power Stage))
338	Actuation delivered incorrectly or inadequately: Incorrect connection	Actuation delivered incorrectly or inadequately: Incorrect connection	The inverter cooler hoses are incorrectly connected to the inverter.
1324	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). (e.g., dislodge the cooling hoses).
1325	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .
1326	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .
1327	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .
1328	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .
1329	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). (e.g., dislodge the cooling hoses).
1330	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). (e.g., reduce the effectiveness of cooling).
1331	Hazardous interaction with other components in the rest of the vehicle	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Cooler to Inverter/Converter (Power Stage))
1332	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). (e.g., crimp the cooling hoses).
1333	Actuation delivered incorrectly or inadequately: Hardware faulty	Actuation delivered incorrectly or inadequately: Hardware faulty	Faulty hardware (e.g., damaged cooling hoses) may affect the delivery of cooling fluid from the inverter cooler to the inverter/converter (power stage). .
1442	External disturbances	Physical interference (e.g., chafing)	If foreign objects enter the coolant delivery system, they may cause a blockage that would reduce the effectiveness of the coolant delivery system.
1443	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature may reduce the effectiveness of the coolant delivery system.
1444	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could cause damage to the coolant delivery system (e.g., degradation of tubing).
1445	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could cause damage to the coolant delivery system (e.g., damage tubing).

Table H-33: Inverter Temperature Sensor to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Temperature Sensor to Electric Vehicle Powertrain Control Module)
286	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the inverter temperature sensor and EVPCM may become intermittent.
288	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to the battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the inverter temperature sensor to the EVPCM.
289	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD may affect the signal from the inverter temperature sensor to the EVPCM.
290	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect the signal from the inverter temperature sensor to the EVPCM.
291	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect the signal from the inverter temperature sensor to the EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Temperature Sensor to Electric Vehicle Powertrain Control Module)
292	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift between neighboring pins in the connectors may affect the signal from the inverter temperature sensor to the EVPCM.
293	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the inverter temperature sensor is connected to the EVPCM with the communication bus, a bus overload or a bus error may affect the signal between the inverter temperature sensor and EVPCM.
294	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the inverter temperature sensor is connected to the EVPCM with the communication bus, the inverter temperature sensor signal priority may be too low.
295	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the inverter temperature sensor is connected to the EVPCM with the communication bus, failure of the message generator, transmitter, or receiver may affect the signal between the inverter temperature sensor and EVPCM.
296	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the inverter temperature sensor is connected to the EVPCM with the communication bus, a malicious Intruder or aftermarket component may write a signal to the communication bus that mimics the inverter temperature sensor.
297	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	An incorrect wiring connection may affect the signal between the inverter temperature sensor and EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Temperature Sensor to Electric Vehicle Powertrain Control Module)
298	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment may affect the signal between the inverter temperature sensor and EVPCM.
299	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the signal from the inverter temperature sensor to the EVPCM.
301	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the signal from the inverter temperature sensor to the EVPCM.
302	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems could affect the signal from the inverter temperature sensor to the EVPCM.
303	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the signal from the inverter temperature sensor to the EVPCM.
304	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the inverter temperature sensor and EVPCM.
305	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could affect the signal from the inverter temperature sensor to the EVPCM.
306	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the inverter temperature sensor or EVPCM.
307	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components may affect the signal between the inverter temperature sensor and EVPCM (e.g., loss of signal).
308	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components may affect the signal between the inverter temperature sensor and EVPCM.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter Temperature Sensor to Electric Vehicle Powertrain Control Module)
309	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components may affect the signal between the inverter cooler sensor and EVPCM.
310	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the inverter temperature sensor and EVPCM.
311	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other components may affect the signal between the inverter temperature sensor and EVPCM.
312	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the signal between the inverter temperature sensor and EVPCM.
313	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the signal between the inverter temperature sensor and EVPCM.
314	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the inverter temperature sensor or EVPCM.
997	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection between the inverter temperature sensor and EVPCM (e.g., cause shorting between pins).

Table H-34: Inverter/Converter (Power Stage) to Phase/Current Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage) to Phase/Current Sensor)
546	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The phase/current sensor may be incorrectly aligned or positioned relative to the inverter/converter (power stage). , resulting in an incorrect or missing measurement (e.g., measurement outside range).
547	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The phase/current sensor may be incorrectly aligned or positioned relative to the inverter/converter (power stage). , resulting in an inaccurate measurement.
548	Sensor measurement delay	Sensor incorrectly aligned or positioned	The phase/current sensor may be incorrectly aligned or positioned relative to the inverter/converter (power stage). , resulting in a delayed measurement.
549	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
551	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the connection between the inverter/converter (power stage). and the phase/current sensor (e.g., cause the phase/current sensor to become incorrectly positioned).
552	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
553	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
554	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
556	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
557	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the connection between the inverter/converter (power stage). and the phase/current sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage) to Phase/Current Sensor)
558	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
559	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
560	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect the connection between the inverter/converter (power stage). and the phase/current sensor.
1002	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion or contamination from the external environment could affect the connection between the inverter/converter (power stage). and the phase/current sensor (e.g., corrode the sensor mounting).
1003	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the inverter/converter (power stage). and the phase/current sensor.
1004	Hazardous interaction with other components in the rest of the vehicle	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect the connection between the inverter/converter (power stage). and the phase/current sensor.

Table H-35: Inverter/Converter (Power Stage) to Traction Motor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage) to Traction Motor)
1319	Actuation delivered incorrectly or inadequately: Hardware faulty	Other	The alternating current supplied from the inverter/converter (power stage). may be altered while being transmitted to the traction motor. This could result in the traction motor receiving the incorrect power input.
1320	Actuation delivered incorrectly or inadequately: Incorrect connection	Actuation delivered incorrectly or inadequately: Incorrect connection	The power supply harness connecting the inverter/converter (power stage). and the traction motor may be incorrectly connected (e.g., wiring for the three phases is in the wrong order). This could in the traction motor receiving the incorrect power input.
1321	Actuation delivered incorrectly or inadequately: Actuation delayed	Actuation delivered incorrectly or inadequately: Actuation delayed	The power supply harness connecting the inverter/converter (power stage). and the traction motor may introduce a delay into the power input into the traction motor.
1322	Actuation delivered incorrectly or inadequately: Hardware faulty	Actuation delivered incorrectly or inadequately: Hardware faulty	The power supply harness connecting the inverter/converter (power stage). and the traction motor may be faulty. This could in the traction motor receiving the incorrect power input.
1334	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1335	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor (e.g., cause the harness to come loose).
1336	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1337	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage) to Traction Motor)
1338	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect unused terminals in the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1339	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect active connection terminals in the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1340	External disturbances	Organic growth	Organic growth could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor (e.g., cause shorting).
1341	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1342	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1343	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor (e.g., cause the harness to come loose).
1344	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1345	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1346	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect active connection terminals in the power supply harness connecting the inverter/converter (power stage). and the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Inverter/Converter (Power Stage) to Traction Motor)
1347	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1348	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.
1349	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the power supply harness connecting the inverter/converter (power stage). and the traction motor.

Table H-36: Motor Position/Speed Sensor to Traction Inverter Controller

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1066	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1067	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1068	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1069	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1070	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect unused connection terminals in the wiring harness connecting the motor position/speed sensor and traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1071	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1072	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1073	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing may affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1074	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1075	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1076	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1077	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the wiring harness connecting the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1078	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1079	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1080	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1081	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1082	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the motor position/speed sensor and the traction inverter controller are connected by the communication bus, a bus overload or error may affect the motor position or speed signal. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1083	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the motor position/speed sensor and the traction inverter controller are connected by the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the motor position/speed sensor. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1084	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the motor position/speed sensor and the traction inverter controller are connected by the communication bus, failure of the message generator, transmitter, or receiver may affect the motor position or speed signal. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1085	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the motor position/speed sensor and the traction inverter controller are connected by the communication bus, the motor position/speed sensor signal priority may be too low. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1086	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, other than EMI or ESD, could affect the signal from the motor position/speed sensor to the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1087	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the motor position/speed sensor and the traction inverter controller may become open, shorted to ground, shorted to the battery, or shorted to other wires in the harness. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1088	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the motor position/speed sensor and the traction inverter controller may become intermittent. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1089	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connector of the motor position/speed sensor or traction inverter controller may be too high. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1090	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connection terminals could affect the signal between the motor position/speed sensor and the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1091	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift between neighboring pins in the connectors may affect the signal from the motor position/speed sensor to the traction inverter controller. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Position/Speed Sensor to Traction Inverter Controller)
1092	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection terminals of the motor position/speed sensor or traction inverter controller may be incorrectly wired. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.
1093	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The motor position/speed sensor or traction inverter controller may have an incorrect pin assignment. This may cause the traction inverter controller to issue a DTC (e.g., motor speed and current do not match) or incorrectly adjust the current supply to the motor.

Table H-37: Motor Temperature Sensor to Traction Inverter Converter

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor to Traction Inverter Converter)
1094	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the motor temperature sensor and the traction inverter controller.
1095	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the motor temperature sensor and the traction inverter controller.
1096	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the motor temperature sensor and the traction inverter controller.
1097	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the connection between the motor temperature sensor and the traction inverter controller.
1098	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect unused connection terminals (e.g., causing shorting) in the wiring harness connecting the motor temperature sensor and the traction inverter controller.
1099	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the connection terminals of the motor temperature sensor or the traction inverter controller.
1100	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminals of the motor temperature sensor or the traction inverter controller.
1101	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing from the external environment could affect the connection between the motor temperature sensor and the traction inverter controller.
1103	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the motor temperature sensor and the traction inverter controller.
1104	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the motor temperature sensor and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor to Traction Inverter Converter)
1105	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the motor temperature sensor and the traction inverter controller.
1106	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused terminals (e.g., causing shorting) in the wiring harness connecting the motor temperature sensor and the traction inverter controller.
1107	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection between the motor temperature sensor and the traction inverter controller.
1108	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components could affect the connection between the motor temperature sensor and the traction inverter controller.
1109	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the motor temperature sensor and the traction inverter controller.
1110	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the motor temperature sensor and the traction inverter controller (e.g., damage the wiring).
1111	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the motor temperature sensor and the traction inverter controller are connected by the communication bus, a bus overload or error could affect the signal from the motor temperature sensor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor to Traction Inverter Converter)
1112	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the motor temperature sensor and the traction inverter controller are connected by the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the motor temperature signal.
1113	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the motor temperature sensor and the traction inverter controller are connected by the communication bus, failure of the message generator, transmitter, or receiver could affect the signal from the motor temperature sensor.
1114	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the motor temperature sensor and the traction inverter controller are connected by the communication bus, the motor temperature sensor signal priority may be too low.
1115	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, other than EMI or ESD, may affect the connection between the motor temperature sensor and the traction inverter controller.
1116	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the motor temperature sensor and the traction inverter controller may become open, shorted to ground, shorted to the battery, or shorted to other wires in the harness.
1117	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the motor temperature sensor and the traction inverter controller may become intermittent (e.g., frayed wiring).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Motor Temperature Sensor to Traction Inverter Converter)
1118	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connection terminals of the motor temperature sensor or traction inverter controller may be too high.
1119	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connection terminals could affect the signal between the motor temperature sensor and the traction inverter controller.
1120	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resisting drift between neighboring pins in the connection terminals could affect the signal between the motor temperature sensor and the traction inverter controller.
1121	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the motor temperature sensor and traction inverter controller may be incorrectly wired (e.g., reversed wiring).
1122	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The motor temperature sensor or traction inverter controller may have an incorrect pin assignment.

Table H-38: Phase/Current Sensor to Traction Inverter Controller

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor to Traction Inverter Controller)
562	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the phase/current sensor and the traction inverter controller may become intermittent.
563	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the phase/current sensor and the traction inverter controller.
564	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD can lead to incorrect, missing, or delayed signals between the phase/current sensor and the traction inverter controller.
565	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect the signal from the phase/current sensor to the traction inverter controller.
566	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect the signal from the phase/current sensor to the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor to Traction Inverter Controller)
567	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift in the connectors may affect the signal from the phase/current sensor to the traction inverter controller.
568	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the phase/current sensor is connected to the traction inverter controller with the communication bus, a bus overload or bus error can lead to incorrect, missing, or delayed signals between the phase/current sensor and the traction inverter controller.
569	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the phase/current sensor is connected to the traction inverter controller with the communication bus, the phase/current sensor signal priority may be too low. This can lead to missing or delayed signals between the phase/current sensor and the traction inverter controller.
570	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the phase/current sensor is connected to the traction inverter controller with the communication bus, failure of the message generator, transmitter, or receiver can lead to incorrect, missing, or delayed signals between the phase/current sensor and the traction inverter controller.
571	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the phase/current sensor is connected to the traction inverter controller with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the phase/current sensor.
572	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	An incorrect wiring connection can lead to incorrect or missing signals between the phase/current sensor and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor to Traction Inverter Controller)
573	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment can lead to incorrect or missing signals between the phase/current sensor and the traction inverter controller.
574	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the connection between the phase/current sensor and the traction inverter controller.
576	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the connection between the phase/current sensor and the traction inverter controller.
577	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect the connection between the phase/current sensor and the traction inverter controller.
578	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect the connection between the phase/current sensor and the traction inverter controller.
579	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the connection between the phase/current sensor and the traction inverter controller.
580	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the phase/current sensor or the traction inverter controller.
581	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect the connection between the phase/current sensor and the traction inverter controller.
582	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect the connection between the phase/current sensor and the traction inverter controller.
583	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect the connection between the phase/current sensor and the traction inverter controller.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Phase/Current Sensor to Traction Inverter Controller)
584	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect connection between phase/current sensor and traction inverter controller.
585	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the phase/current sensor or the traction inverter controller.
586	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect the connection between the phase/current sensor and the traction inverter controller.
998	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the phase/current sensor and the traction inverter controller.
999	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection between the phase/current sensor and the traction inverter controller.
1000	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the phase/current sensor and the traction inverter controller.
1001	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the phase/current sensor and traction inverter controller.

Table H-39: Traction Inverter Controller to Gate Drive Board

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller to Gate Drive Board)
391	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	An intermittent connection may affect communication between the traction inverter controller and the gate drive board.
504	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	A connection that is open, shorted to ground, shorted to battery, or shorted to other wires in harness can lead to incorrect, missing, or delayed signals between the traction inverter controller and the gate drive board.
505	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise other than EMI or ESD may affect communications between the traction inverter controller and the gate drive board.
506	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	A connector contact resistance that is too high may affect communications between the traction inverter controller and the gate drive board.
507	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting between neighboring pins in the connector may affect communications between the traction inverter controller and the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller to Gate Drive Board)
508	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift in the connectors may affect the signal from the traction inverter controller to the gate drive board.
509	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the traction inverter controller and gate drive board are connected by the communication bus, a bus overload or bus error may affect communications between the traction inverter controller and the gate drive board.
510	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the traction inverter controller and gate drive board are connected by the communication bus, the traction inverter controller signal priority may be too low.
511	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the traction inverter controller and gate drive board are connected by the communication bus, failure of the message generator, transmitter, or receiver may affect communications between the traction inverter controller and the gate drive board.
512	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the traction inverter controller and gate drive board are connected by the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the traction inverter controller signal to the gate drive board.
513	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect wiring connection	An incorrect wiring connection (e.g., reversed wiring) may affect communications between the traction inverter controller and the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller to Gate Drive Board)
514	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	An incorrect pin assignment may affect communications between the traction inverter controller and the gate drive board.
515	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect communications between the traction inverter controller and the gate drive board.
517	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect communications between the traction inverter controller and the gate drive board.
518	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects and assembly problems may affect communications between the traction inverter controller and the gate drive board.
519	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling may affect communications between the traction inverter controller and the gate drive board.
520	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect communications between the traction inverter controller and the gate drive board (e.g., damage to wiring).
521	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect active connection terminals of the traction inverter controller or gate drive board.
522	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other components may affect communications between the traction inverter controller and the gate drive board.
523	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other components may affect communications between the traction inverter controller and the gate drive board.
524	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other components may affect communications between the traction inverter controller and the gate drive board.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Inverter Controller to Gate Drive Board)
525	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals may affect communications between the traction inverter controller and the gate drive board.
526	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components may affect communications between the traction inverter controller and the gate drive board.
527	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect active connection terminals of the traction inverter controller or the gate drive board.
988	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment may affect unused connection terminals in the wiring harness connecting the traction inverter controller and gate drive board.
989	External disturbances	Organic growth	Organic growth (e.g., fungal growth) may affect the connection terminals of the traction inverter controller or gate drive board (e.g., causing shorting between pins).
990	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components may affect unused connection terminals in the wiring harness connecting the traction inverter controller and gate drive board.
991	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the traction inverter controller and gate drive board (e.g., melt the wiring).
1352	External disturbances	Single event effects (e.g., cosmic rays, protons)	If the traction inverter controller and gate drive board share the same circuit board, single event effects (e.g., cosmic rays, protons) could affect the signal from the traction inverter controller to the gate drive board.

Table H-40: Traction Motor to Motor Position/Speed Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Motor to Motor Position/Speed Sensor)
1353	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the motor position/speed sensor's measurement of the traction motor.
1354	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the motor position/speed sensor's measurement of the traction motor.
1355	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the motor position/speed sensor's measurement of the traction motor.
1356	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the motor position/speed sensor's measurement of the traction motor.
1357	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the motor position/speed sensor's measurement of the traction motor.
1358	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the motor position/speed sensor's measurement of the traction motor (e.g., creating a bias or deformation of mechanical components).
1359	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the motor position/speed sensor's measurement of the traction motor.
1360	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the motor position/speed sensor's measurement of the traction motor.
1361	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the motor position/speed sensor's measurement of the traction motor (e.g., creating a bias or deformation of mechanical components).
1362	Hazardous interaction with other components in the rest of the vehicle	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the motor position/speed sensor's measurement of the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Motor to Motor Position/Speed Sensor)
1363	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the motor position/speed sensor's measurement of the traction motor.
1364	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the motor position/speed sensor's measurement of the traction motor.
1365	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the motor position/speed sensor's measurement of the traction motor.
1366	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The motor position/speed sensor may be incorrectly aligned or positioned relative to the traction motor shaft, resulting in an incorrect or missing measurement (e.g., a measurement outside the calibrated range).
1367	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The motor position/speed sensor may be incorrectly aligned or positioned relative to the traction motor shaft, resulting in an inaccurate measurement (e.g., measurement is in range, but not correct).
1368	Sensor measurement delay	Sensor incorrectly aligned or positioned	The motor position/speed sensor may be incorrectly aligned or positioned relative to the traction motor shaft, resulting in a delayed measurement.

Table H-41: Traction Motor to Motor Temperature Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Motor to Motor Temperature Sensor)
1369	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the motor temperature sensor's measurement of the traction motor temperature (e.g., dislodge the sensor).
1370	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the motor temperature sensor's measurement of the traction motor temperature.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Motor to Motor Temperature Sensor)
1371	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the motor temperature sensor's measurement of the traction motor temperature.
1372	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the motor temperature sensor's measurement of the traction motor temperature.
1373	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the motor temperature sensor's measurement of the traction motor temperature.
1374	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the motor temperature sensor's measurement of the traction motor temperature.
1375	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the motor temperature sensor's measurement of the traction motor temperature.
1376	Hazardous interaction with other components in the rest of the vehicle	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the motor temperature sensor's measurement of the traction motor temperature.
1377	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components could affect the motor temperature sensor's measurement of the traction motor temperature.
1378	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the motor temperature sensor's measurement of the traction motor temperature.
1379	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The motor temperature sensor may be incorrectly aligned or positioned relative to the traction motor, resulting in an incorrect or missing measurement (e.g., measurement outside calibration range).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Traction Motor to Motor Temperature Sensor)
1380	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The motor temperature sensor may be incorrectly aligned or positioned relative to the traction motor, resulting in an inaccurate measurement (e.g., sensor measurement in range, but inaccurate).
1381	Sensor measurement delay	Sensor incorrectly aligned or positioned	The motor temperature sensor may be incorrectly aligned or positioned relative to the traction motor, resulting in a delayed temperature measurement.

Table H-42: Transmission Range Sensor to Electric Vehicle Powertrain Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor to Electric Vehicle Powertrain Control Module)
1408	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the transmission range sensor and the EVPCM. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).
1409	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the connection between the transmission range sensor and the EVPCM (e.g., the connection comes loose). This may affect how the EVPCM operates the traction motor (e.g., the EVPCM may think a gear is not selected).
1410	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).
1411	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1412	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination may affect unused connection terminals in the wiring harness connecting the transmission range sensor and EVPCM (e.g., causing shorting). This may affect how the EVPCM operates the traction motor.
1413	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination may affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor to Electric Vehicle Powertrain Control Module)
1414	External disturbances	Organic growth	Organic growth (e.g., fungal growth) could affect the connection terminals of the transmission range sensor or EVPCM (e.g., causing shorting). This may affect how the EVPCM operates the traction motor.
1415	External disturbances	Physical interference (e.g., chafing)	Physical interference or chafing from the external environment could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1416	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1417	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1418	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components could affect the connection between the transmission range sensor and EVPCM (e.g., melt the wiring). This may affect how the EVPCM operates the traction motor.
1419	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect unused connection terminals in the wiring harness connecting the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1420	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from other vehicle components could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1421	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference or chafing from other vehicle components could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor to Electric Vehicle Powertrain Control Module)
1422	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	Electrical arcing from neighboring components or exposed terminals could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1423	Hazardous interaction with other components in the rest of the vehicle	Corona effects from high voltage components	Corona effects from high voltage components could affect the connection between the transmission range sensor and EVPCM. This may affect how the EVPCM operates the traction motor.
1424	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the transmission range sensor is connected to the EVPCM with the communication bus, a bus overload or error may affect the signal from the transmission range sensor. This may affect how the EVPCM operates the traction motor (e.g., the EVPCM may not know a gear is selected).
1425	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the transmission range sensor is connected to the EVPCM with the communication bus, a malicious intruder or aftermarket component may write a signal to the bus that mimics the transmission range sensor. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).
1426	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the transmission range sensor is connected to the EVPCM with the communication bus, failure of the message generator, transmitter, or receiver may affect the gear stick position signal. This may affect how the EVPCM operates the traction motor.
1427	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the transmission range sensor is connected to the EVPCM with the communication bus, the transmission range sensor signal priority may be too low. This may affect how the EVPCM operates the traction motor (e.g., the EVPCM may not know that a gear is selected).

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor to Electric Vehicle Powertrain Control Module)
1428	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, other than EMI or ESD, could affect the connection between the transmission range sensor and the EVPCM. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).
1429	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the transmission range sensor and EVPCM may become open, shorted to ground, shorted to the battery, or shorted to other wires in the harness. This may affect how the EVPCM operates the traction motor (e.g., the EVPCM may not know that a gear is selected).
1430	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the transmission range sensor and EVPCM may become intermittent. This may affect how the EVPCM operates the traction motor (e.g., the EVPCM may intermittently shut off the motor).
1431	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance in the connection terminals of the transmission range sensor or EVPCM may be too high. This may affect how the EVPCM operates the traction motor.
1432	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	Shorting may develop between neighboring pins in the connection terminals of the transmission range sensor or EVPCM. This may affect how the EVPCM operates the traction motor.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Transmission Range Sensor to Electric Vehicle Powertrain Control Module)
1433	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector resistive drift between neighboring pins	Resistive drift may occur between neighboring pins in the connection terminals of the transmission range sensor or EVPCM. This may affect how the EVPCM operates the traction motor.
1434	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the transmission range sensor and EVPCM may be incorrectly wired. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).
1435	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The transmission range sensor or EVPCM may have an incorrect pin assignment. This may affect how the EVPCM operates the traction motor (e.g., reverse instead of forward).

Table H-43: Vehicle to Wheel Speed Sensor

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (vehicle to Wheel Speed Sensor)
9	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The wheel speed sensor may be incorrectly mounted relative to the vehicle's wheels or axle. This could cause the sensor to not report the wheel speed, to incorrectly or intermittently report the wheel speed, or to report a constant wheel speed (e.g., stuck). This could affect the vehicle speed calculation.
10	External disturbances	Vibration or shock impact	Vibrations may cause the wheel speed sensor to become incorrectly positioned relative to the vehicle's wheels or axle. This could cause the sensor to not report the wheel speed, to incorrectly or intermittently report the wheel speed, or to report a constant wheel speed (e.g., stuck). This could affect the vehicle speed calculation.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (vehicle to Wheel Speed Sensor)
11	External disturbances	Manufacturing defects and assembly problems	The wheel speed sensor may be incorrectly positioned as a result of flaws in the manufacturing process. This could cause the sensor to not report the wheel speed, to incorrectly or intermittently report the wheel speed, or to report a constant wheel speed (e.g., stuck). This could affect the vehicle speed calculation.
12	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle systems may cause the wheel speed sensor to become incorrectly positioned relative to the vehicle's wheels or axle. This could cause the sensor to not report the wheel speed, to incorrectly or intermittently report the wheel speed, or to report a constant wheel speed (e.g., stuck). This could affect the vehicle speed calculation.

Table H-44: Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
101	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	An open circuit could develop in the connection between the wheel speed sensor and brake/VSA control module. This could cause the brake/VSA control module to not report a vehicle speed to the EVPCM or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
102	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Electrical noise other than EMI or ESD	Electrical noise, in addition to EMI/ESD, could affect the signal from the wheel speed sensor to the brake/VSA control module. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate a vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
103	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the wheel speed sensor measurement is transmitted to the brake/VSA control module over the communication bus, a bus overload or error could affect the wheel speed signal. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate a vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
104	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the wheel speed sensor measurement is transmitted to the brake/VSA control module over the communication bus, a failure of the message generator, transmitter, or receiver could affect the wheel speed signal. This could cause the brake/VSA control module to not report a vehicle speed to the EVPCM, to incorrectly report a vehicle speed to the EVPCM, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
105	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the wheel speed sensor measurement is transmitted to the brake/VSA control module over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the wheel speed measurement. This could cause the brake/VSA control module to not report a vehicle speed to the EVPCM, to incorrectly report a vehicle speed to the EVPCM, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
106	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the wheel speed sensor measurement is transmitted to the brake/VSA control module over the communication bus, the wheel speed measurement priority on the communication bus may not be high enough. This could cause the brake/VSA control module to not calculate a vehicle speed or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
107	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	If the wheel speed sensor connections to the brake/VSAVSA control module are reversed (e.g., the front wheel speed sensor is connected as a rear wheel speed sensor), the brake/VSA control module may calculate the incorrect vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
108	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The wheel speed sensor or brake/VSA control module could have an incorrect pin assignment. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
109	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the wheel speed sensor and brake/VSA control module. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
110	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Contamination or corrosion from the external environment (e.g., moisture, salt corrosion) could affect unused connection terminals in the wiring harness connecting the wheel speed sensor and brake/VSA control module, causing shorts between pins. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
111	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Contamination or corrosion from the external environment (e.g., moisture, salt corrosion) could affect the connection terminals of the wheel speed sensor or brake/VSA control module. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
112	External disturbances	Vibration or shock impact	Vibration could cause the connection terminals of the wheel speed sensor or brake/VSA control module to wear over time, causing shorting to other pins. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
113	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the connection between the wheel speed sensor and brake/VSA control module. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
114	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or interference from other vehicle components could cause an open circuit to develop in the connection between the wheel speed sensor and brake/VSA control module (e.g., wiring is cut). This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
115	Hazardous interaction with other components in the rest of the vehicle	Active connection terminals affected by moisture, corrosion, or contamination	Moisture or other fluids from other vehicle components (e.g., A/C condensation) could affect the connection terminals of the wheel speed sensor or brake/VSA control module. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID Number	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Wheel Speed Sensor to Brake/Vehicle Stability Assist Control Module)
116	Hazardous interaction with other components in the rest of the vehicle	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture or other fluids from other vehicle components (e.g., A/C condensation) could affect unused connection terminals of the wiring harness connecting the wheel speed sensor and brake/VSA control module, causing shorts between pins. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate the vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.
145	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is open, short to ground, short to battery, or short to other wires in harness	The connection between the wheel speed sensor and the brake/VSA control module could develop a short to other wires in the harness. This could cause the brake/VSA control module to not calculate a vehicle speed, to incorrectly calculate a vehicle speed, or to become stuck reporting a constant vehicle speed to the EVPCM. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate throttle position when in BTO mode. This analysis assumes the brake/VSAVSA control module provides the average vehicle speed to the EVPCM; other vehicle configurations may use other components to compute the vehicle speed.

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