U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 585

October 2018

Functional Safety Assessment of a Generic Accelerator Control System With Electronic Throttle Control in Diesel-Fueled Vehicles

Suggest APA Format Citation:

Van Eikema Hommes, Q. D., Becker, C., & Najm, W. (2018, October). *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.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No.0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2018		3. REPORT TYPE AND DATES COVERED
4. TITLE AND SUBTITLE Functional Safety Assessment of a Generic Accelerator Control System with Electronic Throttle Control in Diesel-Fueled Vehicles			5. FUNDING NUMBERS Intra-Agency Agreement DTNH22-13-V-00114 51HS7BA100
6. AUTHORS Qi Van Eikema Hommes, Christopher Becker, and Wassim Najm			
7. PERFORMING ORGANIZATION NAME AND ADDRESS John A. Volpe National Transportation Systems Center Cambridge, MA 02142			8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NHTSA-15-10
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT HS 812 585
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, www.ntis.gov.			12b. DISTRIBUTION CODE
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14. SUBJECT TERMS Accelerator control system, electronic throttle control, hazard and operability study, failure modes and effects analysis, systems theoretic process analysis, ISO 26262, hazard analysis, risk assessment, and safety requirements.			15. NUMBER OF PAGES 462 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

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 industry 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. Build a 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 powered by diesel internal combustion engines. The 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 methods. In total, this study identifies five vehicle-level safety goals and 204 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 ISO 26262.

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/C	air conditioning
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
BPPS	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
ECM	engine control module
EEPROM	electrically erasable programmable read-only memory
EDC	electronic diesel control
EGO	exhaust gas oxygen
EGR	exhaust gas recirculation
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESD	electrostatic discharge
ETC	electronic throttle control
FMEA	failure mode and effects analysis
FMVSS	Federal Motor Vehicle Safety Standard
FPCV	fuel rail pressure control valve
FQC	fuel quantity control
FRPS	fuel rail pressure sensor
FTTI	fault tolerant time interval
HAZOP	hazard and operability study
HEV	hybrid electric vehicle
IC	integrated circuit
ICE	internal combustion engine

IEC	International Electrotechnical Commission
I/O	input/output
ISO	International Organization for Standardization
kph	kilometers per hour
MISRA	Motor Industry Software Reliability Association
mph	miles per hour
QM	quality management
RAM	random access memory
ROM	read only memory
rpm	revolutions per minute
S	severity
SAE	SAE International
SG	safety goal
STPA	systems theoretic process analysis
TBD	to-be-determined
UCA	unsafe control action

EXECUTIVE SUMMARY

This report describes research by the Volpe National Transportation Systems Center, 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. Specifically, this report focuses on the identification of example safety requirements[1] for the ACS/ETC systems in motor vehicles powered by diesel internal combustion engines.[2] In the diesel ICE, the ETC is also referred to as electronic diesel control.

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 then 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 recommends with respect to the identified automotive safety integrity level of the item under consideration.[3] While this study does not go into implementation strategies to achieve these ASILs, the ISO 26262 process provides a flexible framework and explicit guidance for manufacturers to pursue different methods and approaches to do so. Based on their ASIL decompositions, manufacturers may employ a variety of techniques, such as driver warnings, fault detection mechanisms, plausibility checks, redundancies, etc. to achieve the necessary ASILs that effectively mitigate the underlying safety risks.

This research follows the Concept Phase process (Part 3) in ISO 26262 [1] to derive a list of potential safety requirements. Specifically, this research:

1. Defines the scope and functions of a generic common rail diesel ICE ACS/ETC, and represents the system in block diagrams.
2. Performs a vehicle-level hazard analysis using both the Hazard and Operability study and the system theoretic process analysis methods. By integrating the hazards identified in both HAZOP and STPA, the process establishes five vehicle-level hazards (Table ES-1).
    a. HAZOP identifies 112 malfunctions that may lead to vehicle-level hazards from analysis of the 16 ACS/ETC functions (see Section 4.2.3, Table 3 for details).
    b. STPA identifies 57 unsafe control actions that may lead to vehicle-level hazards from analysis of the six ACS/ETC control actions (see Section 4.3.4, Table 8 for details).

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[1] All requirements presented in this section are not actual compliance requirements currently in effect in an existing FMVSS. Instead, they 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 regulatory requirements for production ACS/ETC systems.
[2] Vehicle-level hazards and requirements identified in this study are based on the analysis of a generic ACS/ETC. More complex systems (e.g., with integrated Advanced Driver Assist Systems) may result in additional hazards and functional safety requirements.

3. Applies the ASIL assessment[3] approach in ISO 26262 to evaluate the risks associated with each of the identified hazards. In total, 71 operational situations are evaluated for each vehicle-level hazard. Following the practice in the ISO 26262 process, the most severe ASIL is chosen for each of the five vehicle-level hazards. Table ES-1 summarizes the outcome.
4. Performs safety analysis using both a functional failure mode and effects analysis and the STPA method.
   a. The functional FMEA identifies 30 failure modes and 91 causes (see Section 7.1, Table 20 for details).
   b. STPA identifies 841 causes that may lead to 57 UCAs (see Section 7.2, Table 22 for details).

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 propulsion power reduction/loss or vehicle stalling	D
H4	Potential insufficient vehicle deceleration	C[ii]
H5	Potentially allowing driver's command to override active safety systems[iv]	D[iii]

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 which prevents a car from rolling backward on a hill when the brake pedal is released. However, it is recognized that under certain conditions anomalous vehicle behavior, such as unintended acceleration, may pose a danger to people in close proximity to the vehicle.*
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 H5 are contained in H1, H2, H3, and H4. Therefore, H5 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.*

5. Identifies 204 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 106 example functional safety requirements by following the Concept Phase in ISO 26262.
   b. This study derived 98 examples of additional safety requirements by following the additional safety strategies in the military standard MIL-STD-882E [2]. These 98 requirements are outside the scope of the Functional Safety Concept phase in ISO 26262 (Part 3 of ISO 26262). However, subsequent steps in the ISO 26262 process—

[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. There are four ASIL levels that are assigned a letter value "A" through "D" according to increasing hazard criticality.

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 98 requirements.

Table ES-2 provides a breakdown of the 106 example functional safety requirements and 98 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 (AP) Assembly	8	4
Engine Control Module (ECM)	49	45
Fuel Delivery Subsystem	17	2
Communication Signals	5	7
Power Supply	6	1
Brake Pedal (BP) Assembly	1	5
Interfacing Systems	9	17

While 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 (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.
    - 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 diesel ICE 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 the National Highway Traffic Safety Administration, the Volpe National Transportation Systems Center 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.

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 to:

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 ISO 26262 Concept Phase (Part 3) and other system safety standards, such as MIL-STD-882E [2].

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

1. Gasoline internal combustion engine
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 ACS/ETC in light motor vehicles (i.e., passenger cars, vans, minivans, SUVs, and pickup trucks with gross vehicle weight ratings of 10,000 pounds or less) powered by diesel ICEs. 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.
- Section Three: provides the description of a generic ACS/ETC system in motor vehicles powered by diesel ICEs. 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.

[4] All requirements presented in this section are not actual compliance requirements currently in effect in an existing FMVSS. Instead, they 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 on or regulatory requirements for producing ACS/ETC systems.

- 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 made from this study regarding the application of ISO Standard 26262.
- Section Eleven: considers potential uses of the results of this study.

Sections two, five, six, ten, and eleven of this report are essentially unchanged from a report published as part of this project titled *Functional Safety Assessment of a Generic Accelerator Control System with Electronic Throttle Control in Gasoline Internal Combustion Engine Vehicles* (Volpe Report DOT-VNTSC-NHTSA-15-06, NHTSA Report No. DOT HS 812 585, in press). These sections are reproduced in this report so that this report can serve as a stand-alone document.

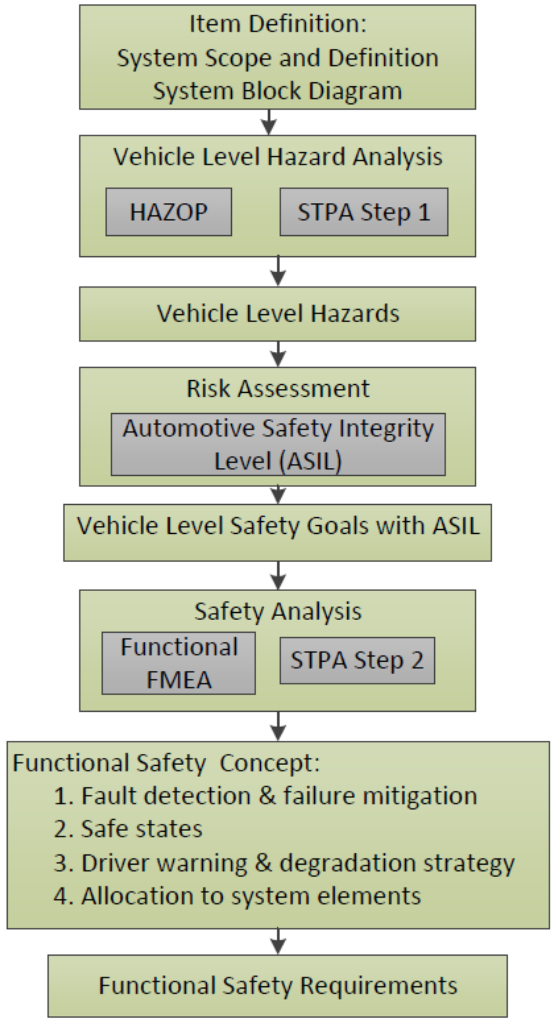
2 ANALYSIS APPROACH

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 process 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 identified automotive safety integrity level of the item under consideration. While this study does not go into implementation strategies to achieve these ASILs, the ISO 26262 process provides a flexible framework and explicit guidance for manufacturers to pursue different methods and approaches to do so. Based on their ASIL decompositions, manufacturers may employ a variety of techniques, such as driver warnings, fault detection mechanisms, plausibility checks, redundancies, etc. to achieve the necessary ASILs that effectively mitigate the underlying safety risks.

Figure 1 illustrates the hazard and 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 ISO 26262 in a previous study.[5]

[5] Brewer, J., Nasser, A., Hommes, Q. V. E., Najm, W., Pollard, J., & Jackson, C. (in press). *Safety management of automotive rechargeable energy storage systems: The application of functional safety principles to generic rechargeable energy storage systems*. Washington, DC: National Highway Traffic Safety Administration.



HAZOP: Hazard and Operability study
STPA: System 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 A-1. Hazard and 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 analyst in the rest of the process.
2. Carry out hazard analysis using both the HAZOP [3] and STPA [4] methods. 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 goals.
5. Perform safety analyses on the relevant system components and interactions as defined in the first step of this process. This project uses both a functional FMEA [5] and STPA to complete the safety analysis.
6. Follow the ISO 26262 process to develop a functional safety concept and functional safety requirements at both the ACS/ETC system level and component level. The functional safety concept and functional safety requirements are based on results from the functional FMEA and STPA, 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.[6] These methods are described in this section.[7]

2.2.1 Hazard and Operability Study

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

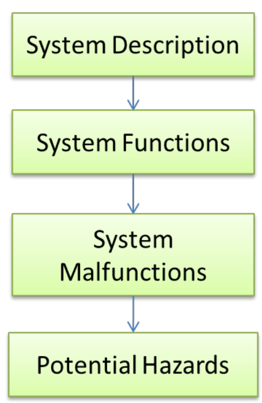


Figure A-1. HAZOP Process

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

[6] 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.

[7] 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 descriptions to better explain how the analysis is performed.

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 the functions that the system components are designed to perform. This step is also accomplished in the first step of the overall project (Figure 1).
3. For each of the identified functions, apply a set of guidewords that describe the various ways in which the function may deviate from its design intent. IEC 61882[8] lists 11 suggested guidewords, but notes that the guidewords can be tailored to the particular system being analyzed [3]. The HAZOP approach 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.

2.2.2 Functional Failure Modes 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 lead to the vehicle-level hazards. The failure modes identified by the functional FMEA are used to derive the safety requirements.

Standard J1739 by SAE International provides guidance on applying the functional FMEA method [5]. The analysis includes the following steps:

1. List each function of the item on an 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.

[8] 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 gives guidance on application of the technique and on the HAZOP procedure, including definition, preparation, examination sessions, and resulting documentation.

This study applies the first four steps listed above for the functional FMEA. Since this study is implemented at the concept phase and is not based on a specific design, the FMEA does not assume controls or mitigation measures are present; there are no 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 System Theoretic Process Analysis

STPA is a top-down systems engineering approach to system safety [4]. 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.

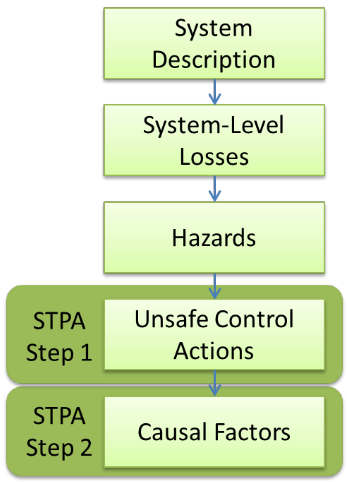


Figure A-1. STPA Process

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 (controller, sensors, actuators, controlled process, and communications links). This control structure is a generic representation of the functions for the 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 losses 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. [4]. For this project, the loss is defined as the occurrence of a vehicle crash.
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 [4]. 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 potential UCAs issued by each of the system controllers that could lead to hazardous states for the system. Four sub-steps are involved:
    a. For each controller within the scope of the system, list all control actions it can issue.
    b. For each control action, develop a set of context variables[9]. 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 in which a control action may be issued. This approach is based on a recent enhancement to the STPA method [6] that enumerates the process variable states in the first step of STPA. Process 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 variables.
    c. Apply the UCA guidewords to each control action. The original STPA literature includes four such guidewords [4]. This study uses a set of six guidewords for the identification of UCAs as illustrated in Figure 4.

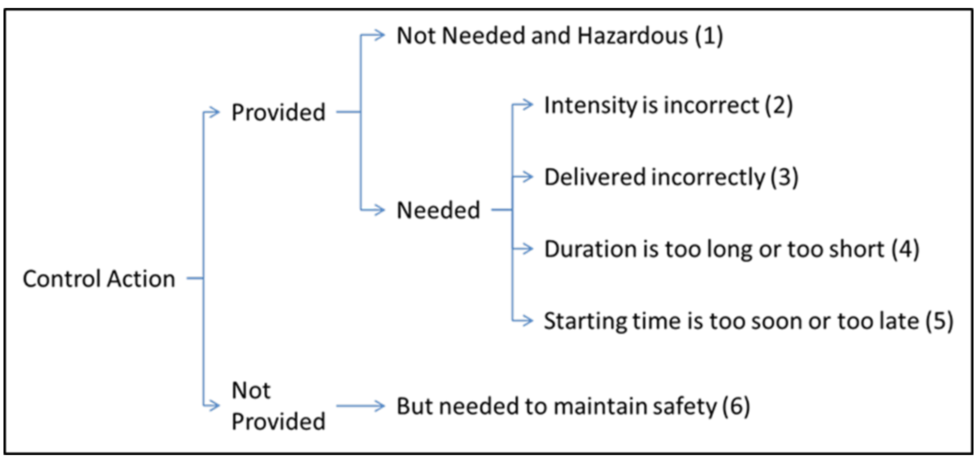


Figure A-2. Guidewords for UCAs

    For each control action, assess each of the six guidewords against each of the context variable combinations to determine if it could lead to the vehicle-level hazards. If new hazards are identified, add it 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 [7] to reduce the number of UCA statements.

[9] The context variables describe the context in which the control commands act in. For example, the control command "increase throttle opening" may operate in the context of the "driver increasing the angular position of the accelerator pedal" and "other vehicle systems requesting a torque reduction."

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 connection in the control structure representation of the system is analyzed to determine if the component or the connection may contribute to one of the UCAs identified in STPA Step 1. STPA literature provides 17 guidewords to assist the analyst in identifying CFs [4]. This project uses 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.

Please note 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".*

For the diesel ICE, the combustion element "throttled" in response to the driver-operated control is the fuel supply to the engine. Therefore, in this report ETC refers to fuel throttling in response to the driver-operated control. In literature the diesel ETC is also referred to as electronic diesel control.

Furthermore, the components and connections in the ACS mean:

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

In addition, this analysis also considers incoming torque requests from other vehicle systems such as cruise control (CC) or the traction control system. However, this analysis assumes that the incoming torque requests from other vehicle systems are correct; failures in other vehicle systems that could result in incorrect engine torque requests are out of scope for this study.

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

1. All components leading from the driver-operated control to the fuel-metering device on the engine, including the following:
    - Accelerator pedal
    - Accelerator pedal position sensor
    - Engine control module, including the fuel quantity control function
    - Fuel rail
    - Fuel rail pressure control valve
    - Fuel rail pressure sensor
    - Fuel injectors
2. All connections between the components listed above, including:
    - Wired connections
    - Communication over the vehicle bus (e.g., controller area network)
3. Brake throttle override function
4. Incoming torque requests from other vehicle systems
5. Interfacing sensors, including
    - Vehicle speed data
    - Brake pedal position sensor
    - Engine sensors
    - Fuel temperature sensor
    - Air charging system sensors

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

- Torque and power delivery downstream of generation, including failures in the transmission system
- Hazards not related to vehicle acceleration or deceleration, such as fire hazards
- Malfunctions in the air charging system or engine combustion
- Malfunctions in the low-pressure fuel delivery system (i.e., from the fuel tank to the fuel rail)
- Brake system malfunctions that may lead to acceleration- or deceleration-related hazards
- Malfunctions in other vehicle systems leading to incorrect engine torque requests
- Notifications from the ACS/ETC to the driver, such as malfunction indicator lights.
- Driver errors, such as incorrect pedal application.
- 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 diesel ICE 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 diesel ICE configuration considered in this study is the common rail[10] diesel system, which is the configuration typically found in light vehicles [9].
  - *Designs based on other diesel system architectures, such as Hydraulically Actuated Electronically Controlled Unit Injectors, may require additional analysis to identify requirements related to the safe functioning of the system.*
- The fuel pressure in the fuel rail is actively controlled by the ECM through the FPCV. Instead of an FPCV, some architectures may use a passive pressure relief valve that only prevents the fuel rail pressure from exceeding the maximum permissible pressure.
  - *A subset of the requirements related to the FPCV may still apply to systems with passive pressure relief valves.*
  - The vehicle speed is primarily provided to the EV PCM by a dedicated sensor in the drivetrain, with secondary sources of speed provided by the brake/stability[11] 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 ECM.*
- The boost pressure sensor and intake air temperature sensor provide the ECM with the necessary information regarding the air intake characteristics to develop the fuel injection

[10] The common rail system consists of a common, pressurized fuel rail that feeds all the fuel injectors. Common rail systems decouple accumulation of fuel pressure and fuel injection, allowing for more precise control of injection events and greater emissions control [13].

profile. Some system architectures may use other sensors to provide this information to the ECM.
    - *Requirements related to the air intake characteristics would apply to whichever components are responsible for providing this information to the ECM.*
- 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 [10]. 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 unintentionally press the pedals. It also does not examine other sources of unintentional pedal input such as pedal interference or entrapment by objects inside the vehicle.
    - *Requirements related to other types of driver-operated controls for acceleration and braking will need additional analysis. Additional analysis is also needed to understand why the driver may incorrectly or non-intuitively apply the AP or the BP.*
- Key interfaces with other vehicle systems considered in this analysis are limited to torque requests, fuel supply, and air supply.
    - *Other interfaces that affect the operation of the ACS/ETC may require additional analysis.*
- Safety strategies, such as redundant sensors, are not considered in the hazard analysis or safety analysis stages. They are only considered as part of the functional safety concept and are reflected in the safety requirements
    - *Once specific design strategies have been adopted, additional hazard and safety analyses should be performed.*

3.3 Key Differences between the Gasoline and Diesel ICE ACS/ETC

This study covers two different ICE architectures – the gasoline ICE and the diesel ICE. In the context of the ACS/ETC system, the key differences between these two architectures include:

- Combustion element controlled by driver:
    - In the gasoline ICE, the throttle valve regulates the air intake into the engine in response to the driver's input via the AP.
    - In the diesel ICE, the ECM regulates the quantity of fuel injected into the engine in response to the driver's input via the AP.
- Other combustion elements:
    - In the gasoline ICE, the ECM computes the amount of fuel required for combustion based on the amount of air supplied to the engine via the throttle valve. The ECM attempts to keep the air-to-fuel ratio near the stoichiometric ratio if 14.7:1. The ECM also controls the start of combustion by regulating the spark timing.
    - In the diesel ICE, air is provided to the engine from the air charging system, as described in Section 3.5.7. The air supply is not directly linked to the injected fuel quantity as in the gasoline ICE; diesel ICEs tend to operate lean (air-to-fuel ratios

above the stoichiometric ratio). In diesel ICEs, there is no external spark plug and combustion occurs because of the high temperatures of the compressed air.

- Feedback mechanism for the combustion element controlled by the driver:
  - In the gasoline ICE, a throttle position sensor directly measures the throttle valve position and provides this information to the ECM.
  - In the diesel ICE, engine speed - measured by the engine rotational speed sensor - provides feedback to the ECM.
- Additional functions of the ACS/ETC:
  - In the gasoline ICE, the ACS/ETC only controls the throttle valve position.
  - In the diesel ICE, the ACS/ETC is responsible for controlling the mean pressure in the fuel rail, in addition to controlling the injected fuel quantity.

3.4 System Block Diagram

The diesel ICE regulates the amount of fuel delivered to the engine to control the engine power output in response to changes in the driver-operated control. In mechanically controlled diesel ICEs, a mechanical governor regulates the fuel delivered to the engine as the driver presses the AP. The governor also regulates fuel injection at idle speed and establishes the maximum allowable engine speed.[9]

In modern ACS/ETC systems, the fuel injection is controlled by an electronic signal from the ECM. The signal from the ECM opens the fuel injector, for example by energizing a solenoid, allowing pressurized fuel to flow from the fuel rail into the cylinder.

Figure 5 shows a block diagram representation of the ACS/ETC system considered in this study. The dashed line indicates the system boundary for the ACS/ETC. Other vehicle systems, shown in gray, are treated as black boxes with respect to the ACS/ETC. Interfaces between these systems and the ACS/ETC system are shown as lines that cross the ACS/ETC system boundary.

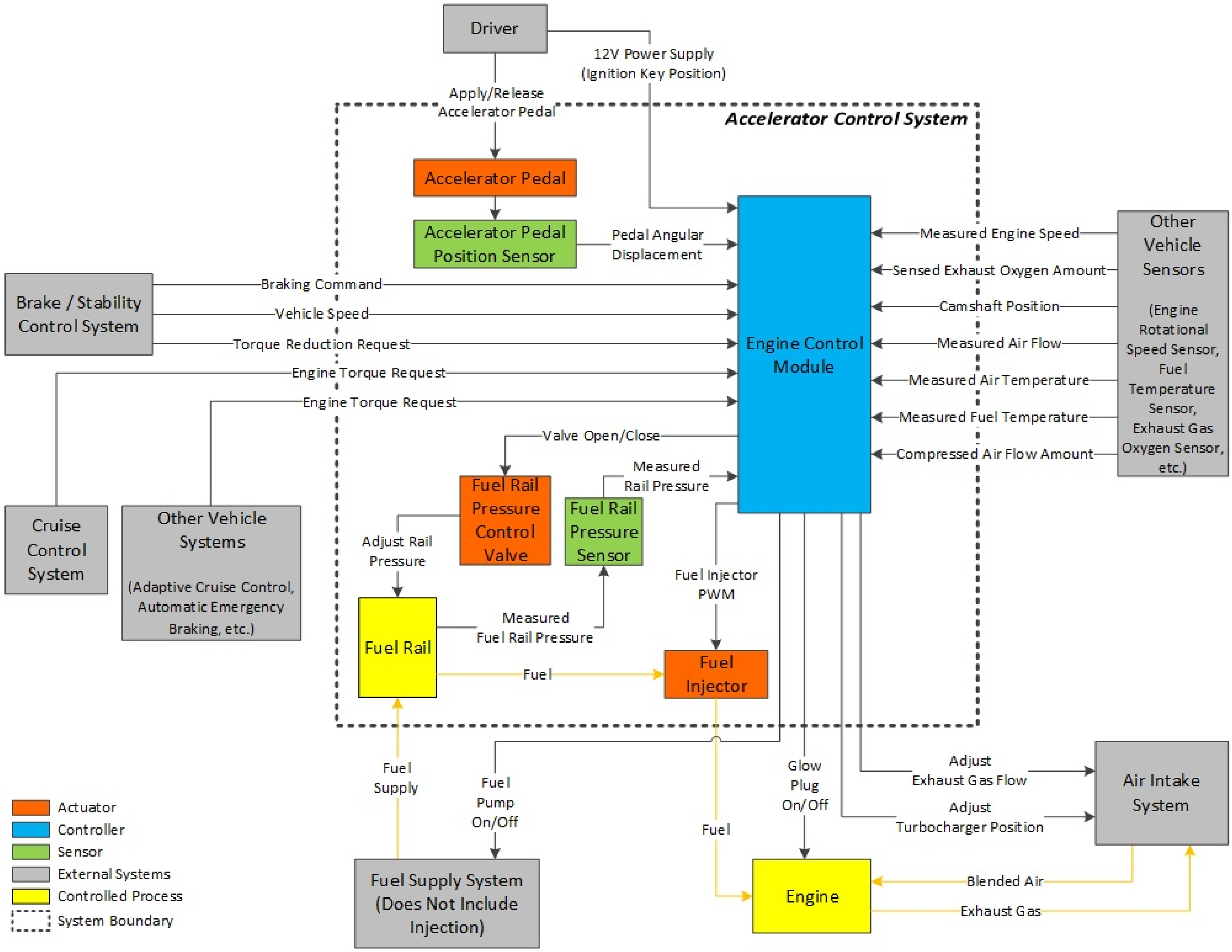


Figure A-1. Block Diagram of ACS/ETC in Diesel Internal Combustion Engine Vehicles

3.5 System Description

The following description outlines the functions of a common rail diesel ICE ACS/ETC system [9] [11] [12] [13] [14].

3.5.1 Driver-Operated Control and Other Torque Requests

The AP assembly provides the driver with an interface for the ACS/ETC. When the driver presses the AP, the APPS measures the angular position of the AP. The APPS converts the angular position of the AP to a voltage signal, which is transmitted to the ECM. The signal may be transmitted via a direct analog input or a vehicle communication bus such as the CAN bus. Depending on whether the ECM algorithms are written in the torque domain or fuel domain, the ECM uses calibration maps to convert the voltage signal from the APPS to either a desired engine torque or a desired fuel injection quantity.

- In the torque domain, the driver's request via the AP is first converted to a desired torque, which is reconciled with torque requests from other vehicle systems and internal torque requirements of the ECM (e.g., emissions control). The resulting torque is then converted into the required fuel injection quantity.

- In the fuel domain, the driver's request via the AP is converted directly to a desired fuel injection quantity. Incoming torque requests from other vehicle systems are also converted to desired fuel injection quantities, which are then reconciled with the driver's request and internal requirements of the ECM (e.g., emissions control). The final result is the required fuel injection quantity.

Regardless of which domain the ECM operates in, the ECM is responsible for reconciling the driver's request with torque requests from other vehicle systems and internal functions based on measurements from other vehicle sensors. These systems and sensors vary depending on the vehicle design, but typically include:

- Engine speed reduction requests from the traction control system
- Torque increase and reduction requests from the CC system
- Engine speed adjustment requests from the transmission control system
- Injected fuel quantity adjustments based on emissions and exhaust gas quality

3.5.2 Fuel Injection

The ECM computes the quantity of fuel required by the engine to achieve the torque necessary to meet the driver's request and other vehicle demands. To deliver the required quantity of fuel, the ECM implements a fuel delivery strategy that consists of two parts:

- The ECM computes a target mean fuel rail pressure based on the engine's current operating point and other vehicle parameters, such as engine load. The FRPS provides the ECM with the current fuel pressure in the fuel rail. Based on the difference between the actual and target fuel rail pressure, the ECM will adjust the FPCV to either increase or decrease the mean pressure in the fuel rail.
  In addition to maintaining the mean fuel rail pressure, the FPCV and fuel rail act as dampers to mitigate the impact of high frequency pressure fluctuations and pressure drops during individual injection events.

- The ECM determines a multi-phase injection strategy (i.e., fuel injection profile) to deliver the appropriate quantity of fuel to the engine cylinders. The fuel injection profile includes determining the start of fuel injection, the number of injections, and the duration of each injection pulse. The fuel injection profile is developed to meet targets such as engine torque output, emissions, and performance and drivability (e.g., noise). The ECM may also consider factors such as exhaust quality, engine temperature, and fuel temperature when determining the quantity of fuel to inject into the engine cylinders.
  The individual injectors are controlled by a signal from the ECM (e.g., pulse width modulation). The quantity of fuel delivered to the cylinders is a function of the current fuel rail pressure, the time the injector is open, and the injector orifice size. The ECM stores individual calibration data for each fuel injector to allow precise control over the quantity of fuel delivered.

The engine rotational speed is measured in rpm by the engine rotational speed sensor, which is also known as the engine rpm sensor. The ECM uses the engine rotational speed as the primary feedback mechanism to adjust the fuel delivery. This includes compensating for sudden changes in torque output (e.g., surge damping) and variations in torque output from individual cylinders (e.g., smooth running control).

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 position. When the AP is in the idle position, the ECM implements idle speed control. The ECM determines the quantity of fuel required by the engine to maintain the idle engine speed based on several parameters, including:

- Engine temperature,
- Fuel temperature,
- Engine loads, such as air conditioning, and
- Emissions and exhaust quality.

Using feedback from the engine rotational speed sensor, the ECM adjusts the injected fuel quantity to maintain the engine at idle speed.

3.5.4 Brake Throttle Override Function

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

In BTO mode, the ECM will override the torque request from the driver via the AP and reduce the injected fuel quantity to the idle fuel quantity or a pre-set injected fuel quantity for BTO mode. The ECM will maintain the injected fuel quantity at this level until BTO mode is disengaged. The ECM should not exit BTO mode while a conflict between the AP and BP still exists.

3.5.5 Fault Detection

In addition to regulating the throttle valve position, the ECM is also responsible for monitoring the ACS/ETC electronic system components to determine if faults are present. If the ECM detects a fault in the system, the ECM may log a diagnostic trouble code and may force the ACS/ETC into a safe state, such as the "limp-home mode." The ECM may also turn on the malfunction indicator light on the vehicle's instrument display panel. Some examples of system faults include:

- APPS voltage signals exceeding the calibration range,
- A short in the fuel injector circuit,
- Low fuel pressure in the fuel rail, and
- Internal software or hardware faults in the ECM.

3.5.6 Related System: Low-Pressure Fuel Delivery System

The diesel ICE ACS/ETC uses the fuel rail and FPCV to regulate the high fuel pressures required for injection. However, diesel ICEs also contain a low-pressure fuel delivery system which interfaces with the ACS/ETC. The low-pressure fuel circuit pumps diesel fuel out of the fuel tank. The fuel then passes through one or more filters to remove particulates and other contaminants. A high-pressure pump increases the fuel pressure and delivers high-pressure fuel to the fuel rail. To maintain the target mean fuel rail pressure, the FPCV may divert high-pressure fuel back to the low-pressure fuel system. The low-pressure fuel system may cool the fuel from the fuel rail to reduce the temperature before it returns to the fuel tank.

3.5.7 Related System: Air Charging System

While the air charging system is not considered part of the diesel ICE ACS/ETC, it is a closely related system and is essential for achieving the desired engine torque output. The air charging system consists of the system components responsible for delivering air to the engine cylinders. Unlike the gasoline ICE, the diesel ICE operates lean and the air-to-fuel ratio is determined based on other considerations, such as emissions. An overview of the relationship between the air charging system and the diesel ICE ACS/ETC is provided below.

Fresh air enters the air charging system through the air intake. Based on the measured exhaust quality, the ECM diverts a portion of the engine exhaust gas into the air intake stream by adjusting the exhaust gas recirculation valve. Introducing exhaust gas into the air intake reduces the volume of air available for combustion, but also reduces the concentration of nitrogen oxides in the exhaust stream. EGR can reach up to 50 percent of the air intake.

In turbocharged diesel engines, the exhaust gas stream also drives a turbine connected to a compressor in the air intake stream (turbocharger device). The compressor increases the density of combustible air entering the engine cylinders. In addition to increasing the quantity of air available for combustion, turbocharging improves the engine torque output by allowing the compressed air to expand in the cylinder during the power stroke. The boost pressure sensor provides the ECM with the air pressure following compression in the turbocharger.

4 VEHICLE-LEVEL HAZARD ANALYSIS

This study performs two types of hazard analyses - HAZOP 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 and STPA.

4.1 Vehicle-Level Hazards

The HAZOP and STPA methods identify similar vehicle-level hazards for the diesel ICE ACS/ETC. These hazards were synthesized to produce a consistent list. Table 1 shows the vehicle-level hazards and their definitions.

Table A-1. Vehicle-Level Hazards and Definitions

<table>
<tr><th></th><th>Driver Action</th><th>Vehicle Response</th><th>Hazards</th></tr>
<tr><td rowspan="2">Acceleration-Related</td><td>Does not command vehicle acceleration or commands less than the provided acceleration</td><td>Accelerates in direction chosen by driver (forward or reverse)</td><td>H1: Potential Uncontrolled Vehicle Propulsion - is analogous with Unintended Acceleration, defined as “any vehicle acceleration that the driver did not purposely cause to occur”.
H1.a: Potential Uncontrolled Vehicle Propulsion When the Vehicle Speed Is Zero</td></tr>
<tr><td>Commands vehicle acceleration</td><td>Does not accelerate or accelerates at a rate that is less than the specified speed increase profile</td><td>H2: Potential Insufficient Vehicle Propulsion - refers to incidents where the vehicle does not accelerate to the level commanded by the driver.</td></tr>
<tr><td rowspan="2">Deceleration-Related</td><td>Does not command vehicle deceleration or commands less than the provided deceleration</td><td>Decelerates</td><td>H3: 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. This includes vehicle deceleration resulting from conditions such as engine stalling.</td></tr>
<tr><td>Commands vehicle deceleration</td><td>Does not decelerate or decelerates at a rate that is less than the specified speed decrease profile</td><td>H4: Potential Insufficient Vehicle Deceleration - refers to incidents where the engine speed is not reduced to the level commanded by the driver when the driver reduces the angular position of the accelerator pedal.</td></tr>
<tr><td>Applicable to both Acceleration and Deceleration</td><td>Command either acceleration or deceleration</td><td>Accelerates or decelerates following driver’s command, and overrides active safety function</td><td>H5: 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 that the ACS/ETC should follow an active safety system’s torque request.[i]</td></tr>
<tr><td colspan="4">[i] This hazard may not apply in ACS/ETC systems designed to give the driver’s command priority over all active safety systems.</td></tr>
</table>

The hazard list in Table 1 is identical to the vehicle-level hazards identified in the gasoline ICE ACS/ETC analysis performed as part of this study.[11]

[11] *Functional Safety Assessment of a Generic Accelerator Control System With Electronic Throttle Control in Gasoline Internal Combustion Engine Vehicles* (Volpe Report DOT-VNTSC-NHTSA-15-06).

4.2 Hazard and Operability Study

4.2.1 System Description

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

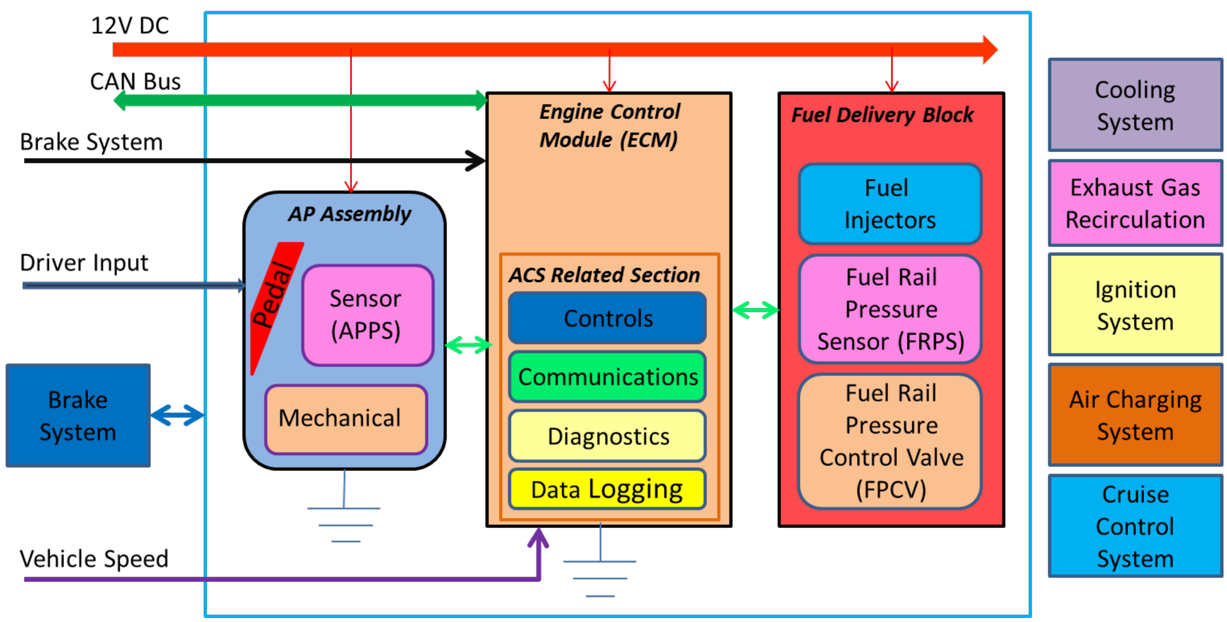


Figure A-1. Block Diagram of the ACS/ETC System for HAZOP

The light blue solid line defines the boundary of the ACS/ETC system which contains three main components.

- AP assembly
- ECM
- Fuel delivery block

The AP in the AP assembly receives the driver's input. The driver's input is communicated to the ECM, which computes the fuel injection quantity needed to meet the driver's request. The ACS/ETC also interfaces with other vehicle systems, such as:

- brake system,
- adaptive cruise control,
- automatic emergency braking, and
- traction control system.

In addition to the interfaces with other vehicle systems, the ACS/ETC is connected to the low voltage direct current power supply and communication bus (e.g., CAN bus).

4.2.2 System Functions

HAZOP identifies 16 system functions for the diesel ICE ACS/ETC.

1. Command torque from the propulsion system
2. Provide APP to the ECM
3. Return the AP to the off (un-depressed) position within a specified time

4. Provide AP request rate limiting
5. Control the fuel quantity delivered to the engine
6. Communicate the rail pressure to the ECM
7. Return injector fuel delivery to idle state
8. Establish idle fuel quantity
9. Control FPCV
10. Provide idle state control
11. Provide BTO control
12. Store the APP and engine RPM (vehicle speed) vs fuel maps
13. Communicate with internal subsystems and external vehicle systems
14. Provide diagnostics
15. Provide fault detection and failure mitigation
16. Store relevant data

Functions 15 and 16 are shown here for completeness. The HAZOP analysis concludes that malfunctions related to these two functions would not result in vehicle-level hazards.

4.2.3 System Malfunctions and Hazards

The seven HAZOP guidewords presented in Section 2.2.1 are applied to each of the sixteen ACS/ETC functions listed above. They generate a list of 112 malfunctions. These malfunctions may lead to potential vehicle-level hazards. Table 2 provides an example of how malfunctions are derived from one of the ACS/ETC functions. Table 3 shows the number of malfunctions identified for each of the ACS/ETC functions. Each of the identified malfunctions is assessed to determine if it could result in a vehicle-level hazard. Appendix B provides the complete results of HAZOP.

Table A-1. Derivation of Malfunctions and Hazards using HAZOP (Example)

Function: Provide the APP to the ECM.

HAZOP Guidewords	*Malfunction*	*Operating Mode*	*Potential Vehicle Level Hazard*
Loss of function	Does not provide the APP to the ECM	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
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
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 A-2. Number of Identified Malfunctions for Each HAZOP Function

HAZOP Function	Identified Mal-functions
Commands Torque From the Propulsion System	8
Provides APP to the ECM	7
Returns AP to the Off (Undepressed) Position Within a Specified Time	9
Provides AP Request Rate Limiting	7
Controls the Fuel Quantity Delivered to the Engine	6
Communicates the Rail Pressure to the ECM	7
Returns Injector Fuel Delivery to Idle State	9
Establishes Idle Fuel Quantity	7
Controls FPCV	7
Provides Idle State Control	7
Provides BTO Control	7
Stores the APP and Engine Rotational Speed Versus Fuel Quantity Maps	7
Communicates with Internal Subsystems and External Vehicle Systems	6
Provides Diagnostics	6
Provides Fault Detection and Failure Mitigation	6
Stores Relevant Data	6

4.3 System 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 ACS/ETC system (in the dashed line) and its interfacing systems and components. The low voltage 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 low voltage power supply on the system is considered in detail as part of STPA Step 2.

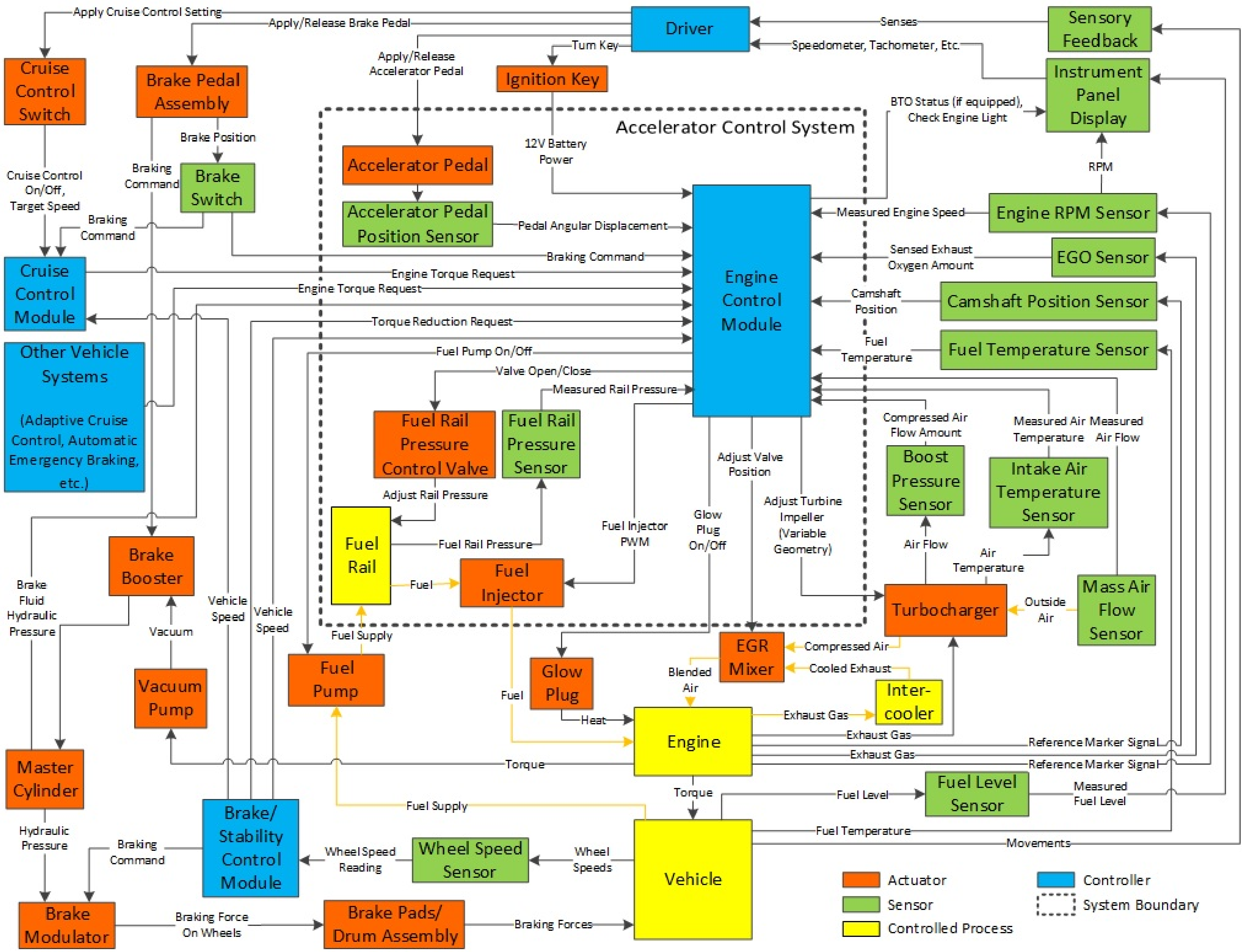


Figure A-1. Detailed Control Structure Diagram for the Diesel ICE ACS/ETC System

4.3.2 Vehicle-Level Loss and Initial Hazards

The vehicle-level loss this project seeks to prevent is a vehicle crash.

An initial list of vehicle-level hazards is generated based on literature search, engineering experience, and the vehicle-level hazards identified in the gasoline ICE analysis performed as part of this study. STPA Step 1 helps refine the initial hazard list. Section 4.3.3 and Section 4.3.4 provide the details of this process. Then, the hazards generated from both HAZOP and STPA are synthesized to produce the hazards 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 six control actions issued by the ECM related to the ACS/ETC function:

1. Two control actions relate to mode switching. These control actions are internal to the ECM and result in a change in the ECM operating state.
   i. **Enter BTO mode** – the ECM issues this control action to enter an operating state that allows the driver's request for braking to override the AP command.
   ii. **Enter normal mode** – the ECM 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. Manufacturers may elect to have lower vehicle speed threshold values.

Table A-1. STPA Context Variables for Analyzing 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 relate to fuel quantity control. These control actions are issued to the fuel injectors, which directly control the total amount of fuel injected into the engine cylinders.
   i. **Increase the injected fuel quantity** – the ECM issues this control action to increase the total amount of fuel supplied to the engine to cause an increase in engine torque.
   ii. **Decrease the injected fuel quantity** – the ECM issues this control action to decrease the total amount of fuel supplied to the engine to cause a reduction in engine torque.

The context variable states used to analyze the injected fuel quantity control actions are listed in Table 5.

Table A-2. STPA Context Variables for Analyzing the Injected Fuel Quantity Control Actions

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
ECM 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 relate to control of the mean rail pressure. The ECM issues these control actions to the FPCV to maintain the pressure in the fuel rail at the target rail pressure.
   i. **Increase mean rail pressure** – the ECM issues this control action to increase the pressure in the fuel rail (e.g., by closing the FPCV to accumulate fuel in the rail).
   ii. **Decrease mean rail pressure** – the ECM issues this control action to decrease the pressure in the fuel rail (e.g., by opening the FPCV so fuel can return to the low-pressure fuel system).

   The context variable states used to analyze the mode switching control actions are listed in Table 6.

Table A-3. STPA Context Variables for Analyzing the Mean Rail Pressure Control Actions

Context Variable	Context Variable States
Actual Rail Pressure	Below target rail pressure
	Above target rail pressure
	At target rail pressure

The process of enumerating all possible combinations of the context variable states can identify some conditions that could potentially result in a hazard that was not included in the preliminary hazard list. For example, in Table 5, this process revealed conflicting commands between the APP and torque requests from other vehicle systems, which ultimately helped identify the hazard "Potentially Allowing Driver's Command to Override Active Safety Systems" (H5).

4.3.4 Unsafe Control Actions

The six UCA guidewords (Figure 4) are applied to each combination of context variable states for the six control actions listed in the previous section. The combination of the guideword and context variable states is then assessed to determine whether the control action would result in a vehicle-level hazard. Table 7 shows how this is done for one of the control actions – "Enter BTO Mode." Appendix C contains all UCA assessment tables for the six control actions studied.

Table A-1. 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		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Not Pressed	Not Pressed	≥10 mph		H3	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		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Not Pressed	≥10 mph		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Pressed	<10 mph		H3	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	H3	H1

Vehicle-Level Hazards:

H1: Potential uncontrolled vehicle propulsion

H3: Potential propulsion power reduction/loss or vehicle stalling

Each row of Table 7 represents a UCA. For example, the last row and fourth column of the table may generate the following UCA:

- *The ECM 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 potentially result in uncontrolled vehicle propulsion.

However, writing each cell of the table into a UCA statement will create a very long list of UCAs. Many of these UCAs have overlapping logical states. Therefore, this study further applies the Quine-McCluskey minimization algorithm [7] to consolidate and reduce the number of UCA statements.

Overall, STPA Step 1 identifies a total of 57 UCAs for the generic diesel ICE ACS/ETC system studied. The breakdown of these UCAs by control action is provided in Table 8.

Table A-2. Number of Identified UCAs for Each STPA Control Action

STPA Control Action	Identified UCAs
Increase Injected Fuel Quantity	12
Decrease Injected Fuel Quantity	26
Increase Mean Rail Pressure	5
Decrease Mean Rail Pressure	4
Enter BTO Mode	6
Enter Normal Mode	4

Appendix D presents a complete list of the UCAs identified in STPA Step 1. Table 9, Table 10, and Table 11 show examples of UCAs and their associated vehicle-level hazards.

Table A-3. STPA UCA Statement for Mode Switching (Example)

Hazard	Potential propulsion power reduction/loss or vehicle stalling
UCA (Example)	The ECM issues the Enter Normal Mode command when the AP is pressed and the BP is not pressed, but the command is issued too late.

Table A-4. STPA UCA Statement for Fuel Quantity Control (Example)

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

Table A-5. STPA UCA Statement for Mean Rail Pressure Control (Example)

Hazard	Potential propulsion power reduction/loss or vehicle stalling
UCA (Example)	The ECM issues the Decrease Mean Fuel Rail Pressure command when the actual rail pressure is above the target rail pressure, but too much of a decrease in pressure is commanded.

RISK ASSESSMENT

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

4.4 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 (C) of the situation and the vehicle in the potential crash scenario.
    e. Look up the ASIL per ISO 26262 based on the E, S, and C.
3. Assign the worst-case ASIL to the hazard.

4.4.1 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 71 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.

These 71 scenarios cover 10 variables and their states as shown in Table 12. These variables and their states are identified following current industry practices.

Table A-1. Variables and States for Description of Vehicle Operational Situations

Vehicle Speed	Very high speed (V>130 kph)	**Railroad Track**	Near a railroad track
	High speed (100 kph<V≤130kph)		Over a railroad track
	Medium speed (40kph<V≤100kph)		Not near or over a railroad track
	Inside city (16kph<V≤40kph)	**Road Condition**	Slippery
	Inside city very low speed (V≤16kph)		Good
	Parking lot or driveway (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 holder feature on

4.4.2 Automotive Safety Integrity Level Assessment

ISO 26262 assesses the ASIL of identified hazards according to the S, E, and C (Part 3 in ISO 26262).

E 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 13 is directly copied from ISO 26262 Part 3 Table 2.

Table A-1. Exposure (E) Assessment

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

S 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 14 is directly quoted from ISO 26262 Part 3 Table 1.

Table A-2. 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 15 is one approach to assess severity shown in ISO 26262 (Part 3 Clause 7.4.3.2 and Annex B Table B.1), based on the Abbreviated Injury Scale. The AIS was developed to enable international comparison of severity. ISO 26262 indicates other categorizations of severity may be used, including Maximum AIS and Injury Severity Score (Part 3 Annex B).

Table A-3. AIS 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 C[12] as the "ability to avoid a specified harm or damage through the timely reactions of the persons[13] involved, possibly with support from external measures" (Part 1 Clause 1.19 in ISO 26262). Table 16 is ISO 26262's approach to assessing C (Table 3 in Part 3 in ISO 26262). Table 17 shows how ASIL is assessed based on E, S, and C (Table 4 in Part 3 of ISO 26262).

Table A-4. Controllability (C) Assessment

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

[12] The parameter C in hazard analysis and risk assessment represents the potential for controllability.
[13] Persons involved can include the driver, passengers, or persons near the vehicle's exterior.

Table A-5. 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:**
  - E = **E4** (This operational situation occurs often, > 10% 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.
  - S = **S3** (Front/rear collision or frontal impact with an object with passenger compartment deformation. More than 10% probability of AIS 5-6.)
  - C = **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, C = 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:**

- E = **E2** (Operational situation occurs about 1% of the operating time of the vehicle.)
- Crash scenario: Vehicle loses acceleration. Another vehicle runs into the vehicle from behind.
- S = **S3** (Front/rear collision with passenger compartment deformation. More than 10% probability of AIS 5-6.)
- C = **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.)

o ASIL = **B**

Appendix F contains the full ASIL assessment table.

4.5 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 five vehicle-level hazards. ISO 26262 requires the most severe ASIL be chosen for each hazard. Table 18 shows the resulting ASIL values for each hazard.

Table A-1. 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 propulsion power reduction/loss or vehicle stalling	D
H4	Potential insufficient vehicle deceleration	C[ii]
H5	Potentially allowing driver's command to override active safety systems[iv]	D[iii]

i. *For certain control system features that only operate when vehicle speed is zero, the ASIL for 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 which 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 are not readily available for the assessment of the three dimensions used to determine the ASIL--severity, exposure, and controllability.*

iii. *The effects of H5 are contained in H1, H2, H3, and H4. Therefore, H5 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.*

5 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 19. Each safety goal corresponds to the potential hazards in Table 18.

Table A-1. Safety Goals with ASIL

ID	Safety Goals	ASIL
SG 1	Potential uncontrolled vehicle propulsion resulting in vehicle acceleration greater than to-be-determined m/s^2 for a period greater than TBD s 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 propulsion power loss/reduction resulting in vehicle deceleration greater than TBD m/s^2 or vehicle stalling is to be mitigated in accordance with the identified ASIL.	D
SG 4	Potential insufficient vehicle deceleration[i] is to be mitigated in accordance with the identified ASIL.	C[ii]
SG 5	The ACS/ETC control algorithm is to choose the throttle command that has the highest priority for safety in accordance with the identified ASIL.	D

i. *Insufficient vehicle propulsion or deceleration is defined as the vehicle deviating from the correctly functioning speed increase or decrease profile, respectively, 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 accelerator pedal.*

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.*

6 SAFETY ANALYSIS

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

6.1 Functional Failure Modes and Effects Analysis

This study applied the functional FMEA for hazards H1, H1a, H2, H3, and H4 (Table 1). Because the consequences of H5 are captured in the other four hazards, no separate functional FMEA is needed for H5. Overall, the functional FMEA covers 13 systems or subsystems, including both the ACS/ETC and interfacing systems/subsystems. The systems or subsystems considered in the functional FMEA follow.

1. ECM
2. Fuel Delivery subsystem
3. BPPS
4. APPS
5. Vehicle speed sensor
6. Engine rotational speed sensor
7. Atmospheric pressure sensor
8. Vehicle Communication System (CAN Bus)
9. Air charging system
10. Exhaust air recirculation valve
11. Other (Interfacing) vehicle systems
12. AEB
13. CC/ACC

The functional FMEA identifies 30 failure modes and 91 potential causes of failures.

Table A-1. Number of Identified Faults by Failure Mode

Failure Mode	Identified Faults
AP is not returned to idle position correctly	1[i]
APP communicates with ECM incorrectly	19
APP rate limiting fault (over-limiting/under-limiting)	21
APP value interpreted lower than actual	19
BTO control fault	5
Command from ECM to exhaust air recirculation valve failure	1
Command/Request for braking from AEB to ECM failure	1
Command/Request for braking from CC/ACC to ECM failure	1
Commands incorrect fuel amount	21
Commands larger amount of fuel than required by the requested torque by the driver	21
Commands smaller amount of fuel than required by the requested torque by the driver	21
Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	1
Delivers less air than required	1[ii]
Delivers more fuel than commanded by the ECM	17
Diagnostics fault	1[iii]
Fails to maintain throttle idle position	17
Fuel delivery map corrupted	8
Incorrect signals (this may be CAN like communication or PWM or else)	2
Incorrectly establishes idle position	22
Mechanical failure prevents fuel injector movement to correct position	1[i]
Miscommunicates with external systems	7
Miscommunicates with internal subsystems	1
Misinterprets the APP	21
Misinterprets the signal from the ECM	7
Provides incorrect engine speed to ECM	1
Provides incorrect BPP input to ECM	1
Provides incorrect pressure (elevation) value to ECM	1
Provides incorrect vehicle speed to ECM	1
Provides request for incorrect (less) propulsion torque	1
Provides request for incorrect (more) propulsion torque	1

Note: Some faults may potentially result in multiple failure modes.
[i] Mechanical fault, which is considered out of scope for ISO 26262.
[ii] Fault in an interfacing system, which is considered out of scope for this study. This study assumes interfacing systems are functioning properly.
[iii] This failure mode is only considered as part of a multiple point failure analysis.

Table 21 shows a few examples from the functional FMEA. The potential causes of failures in Table 21 relate to ECM hardware and software faults that could potentially lead to the failure mode "commands a larger amount of fuel than required for the torque requested by the driver." This failure mode may result in the hazard of potential uncontrolled vehicle propulsion. Appendix G provides the complete functional FMEA results.

Table A-2. Sample Functional FMEA for H1: Potential Uncontrolled Vehicle Propulsion (Not Complete)

System/Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	DTC
ECM	Commands larger amount of fuel than required for the torque requested by the driver	ECM fault	Three-level monitoring		ECM Fault
		Hardware fault (Sensors, Integrated Circuits, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		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 Voltage	Critical messages/data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/O connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three-Level Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algorithm fault	Three-Level Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic Checks	

6.2 System 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 five 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 connection entirely within the ACS/ETC scope boundary
- Interfacing connections – defined as a connection which begins outside the ACS/ETC system boundary and terminates at an ACS/ETC system component
- Interfacing components – defined as a component where an interfacing connection 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 system is considered by analyzing the brake/stability control module and the connection between the brake/stability control module and the ECM. 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).

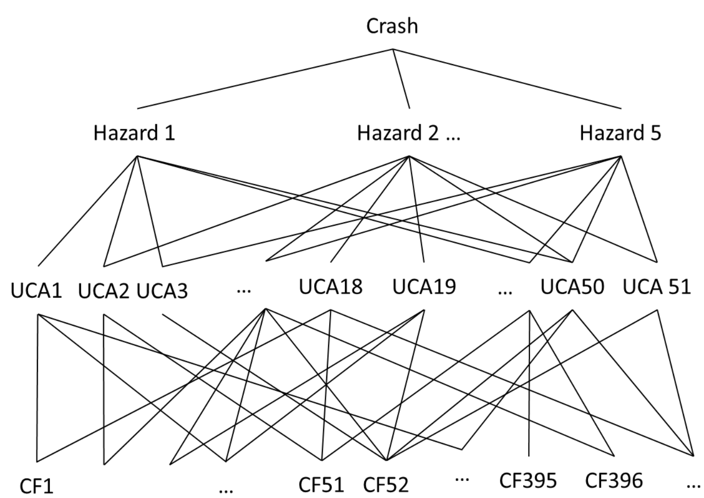


Figure A-1. Traceability in STPA Results

The STPA Step 2 analysis identifies a total of 841 CFs. Below is a breakdown of CFs by the type of UCAs they affect.

- 369 CFs may lead to UCAs related to mode switching
- 609 CFs may lead to UCAs related to fuel quantity control
- 169 CFs may lead to UCAs related to mean rail pressure control

Table A-1. Number of Identified Causal Factors by Causal Factor Category

Causal Factor Category	Identified Causal Factors
Actuation delivered incorrectly or inadequately: Hardware faulty	4
Actuation delivered incorrectly or inadequately: Incorrect connection	4
Actuator inadequate operation, change over time	24
Controlled component failure, change over time	2
Controller hardware faulty, change over time	21
Controller to actuator signal ineffective, missing, or delayed: Communication bus error	12
Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	13
Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	6
External control input or information wrong or missing	4
External disturbances	263
Hazardous interaction with other components in the rest of the vehicle	221
Input to controlled process missing or wrong	4
Power supply faulty (high, low, disturbance)	37
Process input supplier inadequate operation, change over time	3
Process model or calibration incomplete or incorrect	21
Sensor inadequate operation, change over time	36
Sensor measurement inaccurate	5
Sensor measurement incorrect or missing	5
Sensor to controller signal inadequate, missing, or delayed: Communication bus error	40
Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	48
Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	20
Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	48

As shown in Figure 8, there is a many-to-many relationship between CFs and UCAs. Multiple CFs may lead to one UCA. Similarly, one CF may lead to multiple UCAs.

Appendix H provides the complete list of CFs. Table 23 shows three examples of CFs that may result in a mode switching UCA, and the associated vehicle-level hazard:

1. The first CF example describes potentially faulty BTO software logic in the ECM. If the ECM incorporates an incorrect pedal sequence requirement in the BTO algorithm, the ECM may think the driver intended to apply both pedals. The ECM may not enter BTO mode when the driver is trying to stop the vehicle.
2. The second CF example describes a potential interaction between a vehicle component in an interfacing system and the external environment. If the contamination ingress causes the brake/stability control module to report an incorrect vehicle speed, the ECM may not enter BTO mode. This example illustrates the importance of understanding the interactions between vehicle systems.

3. The third CF example describes a case where physical interference with a connection between a sensor and the ECM may result in a lost or incorrect signal. If the BPP is not reported to the ECM, the ECM may not know that the driver is trying to apply the brakes and may not enter BTO mode.

Table A-2. Examples of Causal Factors for a Mode Switching UCA

Hazard	Potential uncontrolled vehicle propulsion	
UCA (Example)	The ECM 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.	
Potential Causal Factors (Example)	**Component**	**Potential Causal Factors**
	ECM	The sequence of pedal application is either not considered or is incorrectly considered in the software logic for entering BTO or Normal mode.
	Brake/Stability Control Module	Moisture or other fluids from other vehicle systems (e.g., air conditioning (A/C) condensation) could affect the brake/stability control module. This could affect the measurement of the vehicle speed.
	Connection between BPPS and ECM	Chafing or interference from other vehicle systems could affect the connection between the BPPS and ECM (e.g., wiring is cut). This could cause the ECM to receive no signal or an incorrect, intermittent, or delayed signal from the BPPS.

Table 24 shows three examples of CFs for a fuel quantity control-related UCA:

- The first CF example describes a potential hardware failure in the engine rotational speed sensor, potentially causing the ECM to have the wrong engine speed information. The ECM may interpret the reduction in engine speed as a need to increase engine torque output (e.g., when maintaining the engine at idle speed).
- The second CF example describes a potential software algorithm error in the ECM that affects the calculation of the engine load. If the ECM incorrectly calculates the engine load from vehicle accessories, the ECM may increase the engine torque output by too much.
- The third CF example describes a potential hardware failure in the connection between the APPS and the ECM. If the connection develops a short circuit, the ECM may have an incorrect understanding of the driver's torque request.

Table A-3. Examples of Causal Factors for a Fuel Quantity Control UCA

<table>
<tr><td>Hazard</td><td colspan="2">Potential uncontrolled vehicle propulsion</td></tr>
<tr><td>UCA (Example)</td><td colspan="2">The ECM issues the Increase Injected Fuel Quantity command when:
• the driver reduces or maintains the angular position of the AP, or is not pressing the AP.</td></tr>
<tr><td rowspan="4">Potential Causal Factors (Examples)</td><td>Component</td><td>Potential Causal Factor</td></tr>
<tr><td>Engine Rotational Speed Sensor</td><td>The engine rotational speed sensor may have an internal hardware failure.</td></tr>
<tr><td>ECM</td><td>A programming error or faulty software logic may cause the ECM to incorrectly calculate the engine load (e.g., from accessories such as A/C). If the ECM thinks the engine load increased, the ECM may increase the throttle opening or may not decrease the throttle opening enough.</td></tr>
<tr><td>Connection between APPS and ECM</td><td>The connection between the APPS and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness.</td></tr>
</table>

Table 25 shows three examples of CFs for a rail pressure control-related UCA:

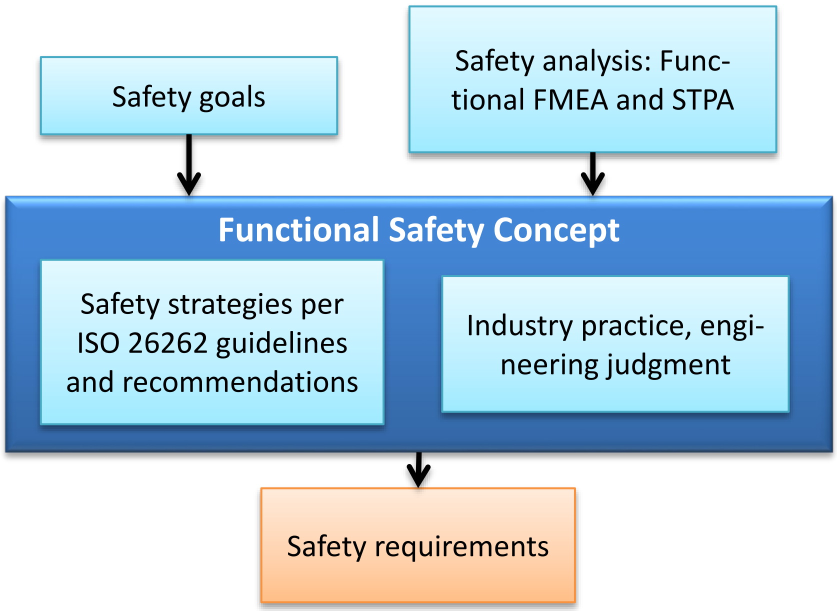
- The first CF example describes a potential interaction between the FRPS and the external environment that may result in the ECM receiving an inaccurate measurement of the rail pressure. If the ECM has an inaccurate rail pressure reading, it may adjust the rail pressure by too much.
- The second CF example describes a potential calibration error in the ECM where the stored critical parameters for the fuel rail are incorrect. If the model stored in the ECM is for a larger fuel rail, the ECM command may cause a larger change in rail pressure than expected.
- The third CF example describes interference from the external environment potentially affecting the connection between the FRPS and ECM. If the ECM thinks the fuel rail pressure is higher than it actually is, the ECM may reduce the rail pressure by too much.

Table A-4. Examples of Causal Factors for a Fuel Quantity Control UCA

<table>
<tr><td>Hazard</td><td colspan="2">Potential propulsion power reduction/loss or vehicle stalling
Insufficient vehicle propulsion</td></tr>
<tr><td>UCA (Example)</td><td colspan="2">The ECM issues the Decrease Mean Fuel Rail Pressure command when:
• the actual rail pressure is above the target rail pressure,
but too much of a decrease in the mean fuel rail pressure is commanded.</td></tr>
<tr><td rowspan="4">Potential Causal Factors (Examples)</td><td>Component</td><td>Potential Causal Factor</td></tr>
<tr><td>FRPS</td><td>Vibration or shock impact could affect the positioning of the fuel rail pressure sensor.</td></tr>
<tr><td>ECM</td><td>The control algorithm for adjusting the mean rail pressure may have an incorrect model of the fuel rail (e.g., different volume).</td></tr>
<tr><td>Connection between FRPS and ECM</td><td>Electrical noise, in addition to electromagnetic interference or electrostatic discharge, could affect the signal from the fuel rail pressure sensor to the ECM.</td></tr>
</table>

7 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.



7.1 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 which 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[14] the health of the main controller (using an auxiliary processor).

[14] "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.

4. Ensure the validity and correctness[15] 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[16]).
6. Validate the correctness of the fuel quantity delivered.
7. Ensure the health and sanity of the injectors' control algorithm.
8. Ensure the health and sanity of the BTO control algorithm.
9. Ensure that low-voltage power is available until the safe state is reached under all safety hazards conditions.
10. Mitigate the safety hazards when an unsafe condition is detected.
11. Ensure that the safe state is reached on time when a hazard is detected.
12. Ensure driver warnings are delivered when an unsafe condition is detected.
13. Ensure the correctness and timeliness of the arbitration strategy.

7.2 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 ACS/ETC are either full operation (full torque availability), degraded operation (available torque is limited at a level between zero and full torque), or switched off mode (zero torque). The degraded operation may include different levels depending on the potential failure mode.

The safety analysis at the system level, the hardware level, and the software level may identify potential failure modes with the APPS, the BPPS, the ECM, the fuel delivery block, and other interfacing systems. In cases where a good but not confirmed APPS signal is available, the safe state may allow full torque but at a ramp rate slower than normal to give the driver more reaction time in case of unintended vehicle behavior. In case the APPS signal is completely unreliable, or if the ECM faults, but the vehicle can still be controlled by the brakes and the fuel delivery block, the vehicle may be allowed a torque level higher than creep torque. In case of APPS and BPPS malfunctions, the vehicle may be limited to creep torque. If the failure mode may result in uncontrolled torque production, then the system torque may be disabled completely.

Safe states may include the following 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)

[15] "Correctness" means that the value of a parameter is the correct one from the valid set.
[16] 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 State 4: Torque produced without AP input; speed limited to TBD mph, which is greater than the creep speed (e.g., two APPS faults; an ECM fault with the fuel delivery block operating properly)
- Safe State 5: Torque produced at zero AP input value of the fuel delivery 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).

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 the identified hazards H2 through H4, 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 are not 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 hazards H2 through H4 manifest.

7.3 Example Driver Warning Strategies

Here are examples of driver warning strategies commonly seen in the automotive industry.

- Amber Light: Potential violation of a safety goal is detected, but probability 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; probability is high (e.g., AP to fuel map corruption, AP or BP communication/data transfer fault), or
  - 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 at least with the red light driver warning. The messages include instructions to the driver in case exiting or staying away from the vehicle is required.
- Haptic warning: Haptic warning 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 while the system is attempting to reach a safe state and enter a degraded operating mode.

8 APPLICATION OF THE FUNCTIONAL SAFETY CONCEPT

This study uses the example safety goals identified for the generic diesel ICE 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 204 illustrative safety-related engineering requirements for the concept ACS/ETC system and its components.[17]

These include 106 ACS/ETC system and component functional safety requirements identified by following the Concept Phase in ISO 26262, Part 3. Section 9.1 and 9.2 present these findings.

Furthermore, this study identifies an additional 98 safety requirements related to the generic ACS/ETC system and components based on the use of STPA as well as the additional safety strategies suggested in MIL-STD-882E [2]. These 98 requirements are outside the scope of the functional Safety Concept in ISO 26262, Part 3. 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 98 requirements.

8.1 Example Vehicle-Level Safety Requirements (Safety Goals)

Vehicle-level safety requirements for the generic ACS/ETC system correspond to the example safety goals presented in Table 19. 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 by more than TBD sigma when the driver increases the angular position of the accelerator pedal under any operating conditions.

SG 3: Potential propulsion power loss/reduction resulting in vehicle deceleration exceeding the driver's intent by TBD m/s^2 or vehicle stalling is to be mitigated in accordance with ASIL D classification.

SG 4: Potential insufficient vehicle deceleration is to be mitigated in accordance with ASIL C classification.

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

- Insufficient vehicle deceleration is defined as the vehicle deviating from the correctly functioning speed decrease profile by more than TBD sigma when the driver reduces the angular position of the accelerator pedal under any operating conditions.

SG 5: The ACS/ETC control algorithm is to choose the torque request that has the highest priority for safety in accordance with ASIL D 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 the vehicle-level hazards that the safety goal intends 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 be appropriate for the specific failure.
- If a failure that could lead to the vehicle-level hazards occurs, a warning is to be sent to the driver, and when necessary, the actions required by the driver are to be communicated to them.

8.2 Diesel ICE ACS/ETC System and Components Functional Safety Requirements

Following the Concept Phase in ISO 26262, Part 3, this study identifies 106 example functional safety requirements for the generic ACS/ETC system and its components. The distributions of these requirements are as follows.

1. General ACS/ETC System – 11 requirements
2. AP Assembly – 8 requirements
3. ECM – 49 requirements
4. Fuel Delivery Subsystem – 17 requirements
5. Communication Signal – 5 requirements
6. Power Supply – 6 requirements
7. BP Assembly – 1 requirement
8. Interfacing System – 9 requirements

Table 26 shows examples of safety requirements associated with the ECM, how they are developed, and how the vehicle-level safety goal (SG 1) is allocated to one of the components in the system—the ECM. The safety analysis identifies many ECM failure modes and CFs that could potentially lead to the violation of SG 1. Here, two ECM controller hardware failures are chosen as examples to illustrate the development process of safety requirements.

Table A-1. Examples of ECM 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 with the identified ASIL level.
ASIL	D
Component	ECM
Safety Analysis (Examples)	• Hardware fault (sensors, integrated circuits (ICs), etc.) • Internal connection fault (short or open)
Safety Strategy	**Potential Safety Requirements (Examples)**
Detection	All single-point and plausible dual-point ECM 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.
Fault Tolerance	
Safe State	
Warning	The ECM 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 safe state in Table 26. 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 they can maneuver the vehicle to a safe location and get the needed repair service to the vehicle. Therefore, a potential additional requirement associated with issuing a warning could be the one described in Table 26. The rest of this section lists the 106 ACS/ETC functional safety requirements derived by following the ISO 26262 Concept Phase 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 between the implementation solutions can be demonstrated (Part 9 Clause 5.2 of ISO 26262).

8.2.1 General ACS/ETC System-Level Functional Safety Requirements

There are 11 general system-level functional safety requirements derived for the generic ACS/ETC system examined in this study, corresponding 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 C/D**).
    a. Critical parameters include those that are used to calculate the magnitude of the propulsion torque, the low voltage power, the vehicle speed, the engine rotational speed, and the vehicle direction (forward or reverse).
    b. Other critical parameters may include calculation and comparison results that confirm the proper operation of the system.
    c. The pedal position – torque / fuel 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
        - Fuel injectors
        - FRPS
        - FPCV
        - Communications/data channels between the APPS and the ECM, between the ECM and the FRPS, between the ECM and the FPCV, and between the ECM and the air charging system.
    e. The sanity and health of the ECM is to be confirmed via an acceptable strategy before any propulsion torque command is issued by the ACS/ETC.
        - Sanity checks may include quizzer, or seed-and-key strategies[18]
        - State-of-health checks may include:
            - RAM/ ROM/ EEPROM tests,
            - Analog-to-digital converter test, and
            - Shutdown test.
    f. The frequency of the periodic tests is to be selected based on the FTTI, and the fault reaction time interval.
    g. In case a failure is detected during the periodic self-tests, the ACS/ETC is to transition to the appropriate 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 C/D**).

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[18] 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 correctly, then its health is confirmed. If controller B responds incorrectly, then a mitigation strategy is executed by controller A.

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 potential violation of a safety goal, and appropriate DTCs are to be set (**ASIL QM/A/B**). The diagnostics approach is to cover:
   - Hardware: APPS, ECM, injectors, FRPS, FPCV, and communication hardware.
   - Software Functions: APP calculations, torque command determination, fuel quantity determination (if APP vs fuel quantity maps are not used), injector control, FPCV control, and BTO.
7. DTCs are to be set every time a safety goal may be violated (**ASIL QM**).
8. Diagnostics covering the safety-related functionality of the ACS/ETC system components and connections (including the ECM, APPS, FRPS, FPCV, injectors, 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 to comply with the hardware architectural metrics targets (**ASIL QM/A/B**).
9. Diagnostics covering the following failure modes are to be implemented (**ASIL QM/A/B**).
   a. APPS:
      - Integrated circuit faults
      - Open/short I/Os
      - Stuck on the same reading
      - Out of range
      - Offset
      - State of health
   b. FRPS:
      - Integrated circuit faults
      - Open/short I/Os
      - Stuck on the same reading
      - Out of range
      - Offset
   c. Injectors:
      - Input voltage
      - Input current
   d. FPCV:
      - Status (Open/Close)
   e. Harnesses and Connectors:
      - Open/short circuits
      - Changes in contact resistance
      - Shorting between pins
10. The ACS/ETC is to log and retain data that can be used to reconstruct the vehicle operating scenario prior to any faults that leads to a violation of a safety goal. The recording period is TBD seconds before and TBD seconds after the safety goal violation event. The

data may include sensor data, HMI data, communication signals, and values of some critical parameters used in the propulsion torque calculations. The following data may be considered (**ASIL QM**).

- Ignition switch status
- PRNDL 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 state
    - ABS
    - TCS
    - ESC
- System low voltage value
- Driver actions regarding vehicle systems capable of initiating and or commanding changes to propulsion torque, including Driver override decisions of vehicle systems capable of initiating and or commanding changes to propulsion torque
- Arbitration logic decisions by the ECM
- ECM fuel quantity request
- ECM received torque request from ACC
- ECM torque request received from AEB
- Steering torque sensor value
- Vehicle yaw rate

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 C/D**).

8.2.2 Accelerator Pedal Assembly Functional Safety Requirements

There are eight AP assembly functional safety requirements derived for the generic ACS/ETC system studied in this project, corresponding to all established safety goals.

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**).
3. The APP value is to be measured and the measured 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. The value of the APP is to be communicated to the ECM (**ASIL B/C/D**):
    - The communication message or data transfer is to be qualified for validity (sent and received signals are the same), correctness (within range), and rationality (does not contradict with previous or other related signals/messages).
    - The updated value of the APP is to be received within TBD seconds. This time is to be specified to support the timely update of the fuel injection quantity to prevent the potential violation of any safety goal.
6. In case of a fault that violates a safety goal, the APPS is to communicate the fault to the ECM (**ASIL B/C/D**). Causes of 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
    - 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, organic growth, and other environmental conditions (**ASIL A/B**).
8. All single point and plausible dual-point[19] 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.

8.2.3 Engine Control Module Functional Safety Requirements

There are 49 ECM functional safety requirements that derived in this project. Many of these requirements correspond to all established safety goals. In the writing below, these requirements do not have safety goals specifically stated in them. 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 ECM controller are to be ensured (**ASIL C/D**).
    - Power-on self-tests are to be implemented to check the health of the controller. These tests may include:
        - CPU and Register Tests to check the internal working of the CPU. All CPU registers associated with the propulsion torque and throttle position control functions are to be checked as part of this test.
        - Interrupt and Exception Tests to check the interrupt and exception processing of the controller.
        - EEPROM Checksum Test to check the EEPROM health.
        - Device Tests to check the peripheral devices connected to the controller.
2. The ECM's I/O pins are to be monitored for shorts or ground (**ASIL B/C/D**).

[19] ISO 26262 states that the intention is not to analyze every possible combination of two hardware faults. An example of a plausible dual-point fault may be one fault that affects a safety-related element and second fault that affects the safety mechanism intended to achieve or maintain a safe state (ISO 26262, Section 5, Clause 7.4.3.2).

3. The ECM is to have diagnostics for potential safety relevant failures caused by EMI/EMC, ESD, contamination, organic growths, single event effects, and other environmental conditions (**ASIL B/C/D**).
4. All single point and plausible dual-point ECM 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 ECM is to arbitrate between multiple requests for propulsion torque modifications from interfacing vehicle systems and the driver (**ASIL B/C/D**).
6. The ECM arbitration logic strategy and algorithm are to be checked for health and sanity periodically based on the FTTI (**ASIL D**).
    - In case of a failure in the arbitration strategy, the ACS/ETC system is to transition into Safe State 1 within a FTTI of TBD seconds and an Amber Light driver warning is to be issued.
7. The output of the ECM arbitration logic is to be qualified for validity and correctness (**ASIL D**).
8. 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**).
9. The ECM is to calculate the fuel quantity 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**).
10. The ECM FQC algorithm is to include a speed increase/decrease profile. The FQC algorithm is to specify the parameters that form the basis for the ramp rate profile (e.g., vehicle speed) (**ASIL C/D**). **Safety Goals: 2 and 4.**
11. The time duration required to update the fuel quantity command is not to result in violation of a safety goal (**ASIL B/C/D**).
    - This time duration is to be reflected in the relevant software function's execution time.
12. Critical communications and data transfer between the ECM and other vehicle systems and components are to be qualified for validity and correctness (plausibility and rationality). This includes the transmission range sensors (**ASIL D**), vehicle directional sensor (**QM**), and all other inputs that are used by the ECM in the propulsion torque control algorithm.
13. All other critical parameters used by the propulsion torque control algorithm are to be checked periodically based on the FTTI requirements (**ASIL B/C/D**).
14. The ECM is to correctly adjust the propulsion torque when it receives a communication of a braking action from the brake/stability control system (**ASIL B/C/D**).
15. The ECM is to access the metrics that clearly define the limits of vehicle stability from the appropriate vehicle system (**ASIL D**). **Safety Goals: 1 and 3**.
16. The ECM is to qualify the input for stability metrics for validity and correctness (plausibility and rationality) (**ASIL D**). **Safety Goals: 1 and 3**.
17. The fuel quantity computed by the FQC algorithm is to be validated against the vehicle stability metrics before any fuel injection command is issued (**ASIL D**). **Safety Goals: 1 and 3**.

- If the calculated propulsion 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 Light driver warning is to be issued.
- Appropriate driver notifications from affected interfacing systems are to be issued.

18. The ECM is to correctly adjust the propulsion torque in response to propulsion torque modification requests from other vehicle systems, such as AEB and ACC (**ASIL B/C/D**).
19. Critical communications and data transfer between the ECM 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 C**).
    - In case of a fault, the correct failure mode effect mitigation strategy is to be applied.
    - Critical communications and data transfer include communication signals that request propulsion torque modifications and diagnostics (failure) information of these systems.
    - This requirement also includes detecting erroneous torque commands issued by malicious intruders or aftermarket components.
20. The fuel injectors are to be controlled and updated for the correct fuel amount, injection start timing, and injection duration within a time frame that does not result in a violation of a safety goal (failure mode in software execution or execution time) (**ASIL D**).
21. Communication and data transfer between the ECM and the APPS are to be qualified for validity and correctness (plausibility and rationality) (**ASIL B/C/D**).
    - In case of a fault, the correct failure mode effect mitigation strategy is to be applied.
    - The critical communications include the APP and the diagnostics of the APPS.
22. The ECM is to qualify the APP input for validity and correctness (plausibility and rationality) (**ASIL B/C/D**).
23. All electrical hardware and software elements associated with the delivery of the FQC function are to comply with **ASIL D** classification for SG1 and SG3, **ASIL C** classification for SG2 and SG4, and **ASIL B** classification for SG1a unless otherwise specified. If independence of the elements (Part 9 Clause 5.2 of ISO 26262) cannot be demonstrated, the higher ASIL classification is to be adopted.
24. The injected fuel quantity corresponding to the propulsion torque requested by the driver via the AP and propulsion torque modification capable systems 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**).
25. The fuel injection profile (injection start time, number of injection pulses, and duration) is to be controlled and updated based on changes in the torque demand within the correct time duration (**ASIL B/C/D**).
26. The injection starting time and duration, including the starting time and duration of individual injection pulses in the fuel injection cycle, are to be qualified for validity and correctness. The start time, number of injection pulses, and duration are to be reflected in the relevant software functions execution time, and the transient response of the injectors (**ASIL B/C/D**).
27. The ECM algorithms or methods for calculating the fuel injection profile and injected fuel quantity are to be validated (**ASIL B/C/D**).

28. The ECM FQC algorithms are to be checked periodically based on the correct FTTI to prevent potential violations of the safety goals (via an auxiliary processor or equivalent means) (**ASIL C/D**).
    - Fault tolerant strategies are to be applied. The fault tolerant techniques may include redundancy, voting logic, or other techniques.
    - Control flow monitoring strategies are to be applied for the FQC algorithm.
29. Communications between the ECM and fuel delivery block related to the fuel injection quantity are to be qualified for validity and correctness (plausibility and rationality). In case of a fault, the correct failure mode mitigation strategy is to be applied (**ASIL B/C/D**).
30. All critical parameters used by the FQC algorithm are to be checked periodically based on the FTTI requirements (**ASIL B/C/D**).
31. In case of a fault in the FQC algorithm that leads the ECM to be unable to control the fuel quantity, the ACS/ETC is to transition into Safe State 6 within TBD ms time and the red light driver warning is to be issued (**ASIL B/C/D**).
    - Some industry practices establish this TBD time at 200 ms.
    - For failures that prevent the ECM from controlling the idle fuel quantity, the FTTI may be larger than the FTTI for operating speeds above the idle engine rotational speed.
    - DTCs are to be set.
32. The data used in determining the requested propulsion torque are to be qualified for correctness and validity. This includes torque requests from the driver (via the AP) and other vehicle systems (**ASIL D**), vehicle speed (**ASIL D**), engine rotational speed (**ASIL D**), and altitude measurement (**QM**).
    - If torque maps or look up tables are used, their content is to be checked for validity and correctness at the correct frequency.
33. The data used in determining the amount of fuel required to deliver the requested propulsion torque are to be qualified for correctness and validity. This includes engine temperature (**ASIL D**), fuel temperature (**ASIL D**), fuel pressure (**ASIL D**), and exhaust air quality (**QM**).
    - If fuel maps or look up tables are used, their content is to be checked for validity and correctness at the correct frequency.
34. The APP to propulsion torque rate of change mapping is to be monitored for correctness (**ASIL C/D**). **Safety Goals: 2, 4, and 5**.
35. The ECM is to communicate the correct fuel injection quantity to the fuel delivery subsystem under all vehicle operating situations within TBD ms (**ASIL B/C/D**).
36. Critical communications and data transfer between the ECM 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**), engine rotational speed sensor (**ASIL D**), air charging system (**ASIL D**), exhaust air recirculation (**QM**) and all other inputs that are used by the FQC algorithms.
    - If the vehicle speed and engine speed are used redundantly, then the ASIL classification may be applied based on a selected ASIL decomposition strategy.
37. The ECM is to provide BTO control (**ASIL C**).
38. 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 5**.

39. The ECM BTO control is to command injection of a pre-determined BTO fuel quantity when both the AP and BP are pressed and the vehicle speed is above the pre-determined threshold value, regardless of the input from the APPS (**ASIL C**).
40. The ECM 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**).
41. The BTO control algorithm is to execute within TBD seconds (**ASIL C**).
42. The ECM BTO control algorithm is to be checked periodically based on the correct FTTI to prevent potential violation of the safety goals (**ASIL C**).
    - Fault tolerant strategies are to be applied, including redundancy, voting logic, or other techniques.
    - Control flow monitoring strategies are to be applied for the BTO.
    - 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 used in the industry for similar safety goals), and the red light driver warning is to be issued.
    - DTCs are to be set.
43. 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 C**).
44. All requests or commands for change in the propulsion torque by other vehicle systems are to be ignored when BTO is activated (**ASIL C**).
45. In the event of an ECM malfunction resulting in the loss of the BTO control function, the ACS/ETC is to be able to reduce the injected fuel quantity to the pre-determined BTO level (**ASIL A/B/C**). **Safety Goals: 2 and 5**. Recommended implementation strategies include:
    - Enter an appropriate Safe State
    - Implement a BTO control function that is subordinate to the ECM BTO control function

    The ASIL classification to this requirement depends on whether it is a part of ASIL decomposition or if it is a safety mechanism to the ECM BTO function.
46. The ECM is to have a mechanism to prevent unauthorized access to the ECM software, including propulsion torque control calculations, fuel quantity control calculations, and relevant command paths (**ASIL B/C/D**).
47. All single-point faults that result in a failure to prevent unauthorized access to the ECM are to be detected and mitigated (**ASIL B/C/D**).
    - In case of unauthorized access to the ECM, 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.
48. Diagnostics covering the failures for the following parts of the ECM are to be implemented (**ASIL 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:

- central processing unit (CPU)
- processor memory
- arithmetic logic unit
- registers
- A/D converter
- 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
  - arithmetic logic unit
  - registers
  - A/D converter
  - 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 ECM 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 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.

8.2.4 Fuel Delivery Subsystem

There are 17 functional safety requirements related to the fuel delivery subsystem for a generic diesel ICE ACS/ETC system. These safety requirements correspond to all safety goals.

1. The fuel delivery subsystem is to deliver the correct amount of fuel to the engine under all vehicle operating conditions (**ASIL B/C/D**).
2. All single point and plausible dual-point hardware faults of the fuel delivery subsystem that lead to violations of a safety goal are to be detected within the fault detection time interval and mitigated within the FTTI. In case 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.

3. The FRPS is to measure the fuel rail pressure under all vehicle operating conditions, and the results are to be qualified for validity and correctness over the usable life of the vehicle (**ASIL B/C/D**).
4. The method for converting the measured fuel pressure to an electrical signal is to be validated (**ASIL B/C/D**).
5. The health and sanity of the FRPS are to be monitored and confirmed under all operating vehicle conditions (**ASIL B/C/D**).
6. The fuel pressure readings/measurements are to be communicated to the ECM. The communication message or data transfer is to be qualified for validity (sent and received signals are the same), correctness, plausibility (within range), and rationality (does not contradict with previous or other related signals/messages) (**ASIL B/C/D**).
    - The updated value of the fuel pressure is to be received in TBD seconds time by the ECM. This time is to be specified to support the timely update of the fuel injection parameters (start time and duration) to prevent the violation of any safety goal.
7. The fuel delivery block mechanical faults that result in incorrect measurement of the fuel rail pressure are to be detected and mitigated (**QM**).
    - Incorrect measurements include deviations from the correct fuel rail pressure value, correct fuel quantity, or being stuck at the same value permanently or intermittently
8. In case of a fault that violates a safety goal, the FRPS is to communicate the fault to the ECM (**ASIL B/C/D**).
9. The FPCV is to maintain the fuel rail pressure as commanded by the ECM (**ASIL B/C/D**).
10. The supply voltage to the FPCV is to be monitored (**ASIL B/C/D**).
11. In case of a failure in the FPCV that violates a safety goal, the failure is to be communicated to the ECM (**ASIL B/C/D**).
12. The fuel injectors are to initiate the delivery of the fuel within TBD ms from the time the ECM commands the delivery of the fuel (**ASIL B/C/D**).
    - Industry standards specify initiation of fuel delivery within 1.0-2.0 ms from the time the power is applied.
13. The injectors are to deliver fuel for the entire duration of each injection pulse as specified in the fuel injection profile (**ASIL B/C/D**).
14. The supply voltage to the injectors is to be monitored (**ASIL B/C/D**).
15. The health of the channel that delivers the control signal from the ECM to the injectors is to be monitored (**ASIL B/C/D**). This includes, but is not limited to, software faults, software-to-hardware interface faults, and electrical faults (e.g., short, open, etc.).
16. In case of a failure in the injectors that violates a safety goal, the failure is to be communicated to the ECM (**ASIL B/C/D**).
17. The fuel delivery subsystem is to have diagnostics for the FRPS, injectors, and FPCV for safety relevant failures including those caused by EMI/EMC, ESD, contamination, and other environmental conditions (**ASIL A/B**).

8.2.5 Communication Signals

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

The critical communication signals include the following.

- APPS signals from the APPS to ECM
- APPS fault diagnostics signal
- BPPS signal to ECM
- Communication channel “secure” signals between the ECM and fuel delivery subsystem
- Communication channel “secure" signals between the ECM and the following:
  - AEB
  - CC/ACC
  - Other systems that can request modification to the propulsion torque
- Commands/requests for propulsion torque modifications from interfacing systems to ECM
- Vehicle speed signal
- Engine rotational speed signal
- Vehicle direction signal
- Command for fuel delivery signal from the ECM to the fuel injectors
- FRPS fault diagnostics signals to the ECM
- Fuel injector diagnostics signals to the ECM
- Air charging system fault signals to the ECM
- Driver warning signals
- Low voltage power loss signal from the low voltage power system to ECM
- CAN bus failure signal from the CAN bus to the ECM

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 ECM of the fault
   - Invoke the correct failure mode effect mitigation strategy
2. The CAN bus is to support the communication of the ACS/ETC with the rest of the vehicle systems to support the safe operation of the ACS/ETC (**ASIL B/C/D**).
3. The CAN bus is to support the qualification of all critical CAN signals between the ACS/ETC and the interfacing vehicle systems (**ASIL B/C/D**).
4. The CAN bus is to prevent the corruption of the critical CAN signals during transmission between the ACS/ETC and the interfacing vehicle systems (**ASIL B/C/D**).
5. In case of malfunction of the CAN bus or CAN module, the CAN communication system is to inform the ECM (**ASIL B/C/D**).

8.2.6 Power Supply Functional Safety Requirements

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

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 D**).

2. 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**).
3. The ACS/ETC is to be notified of any malfunction or disruption in the low voltage power supply system operation (**ASIL B/C/D**).
4. All communications and data transfer sent by the low voltage power system to the ACS/ETC are to be qualified for validity and correctness (plausibility and rationality). This includes the low voltage power system diagnostics information (**ASIL C/D**).
5. The ACS/ETC is to have a redundant low voltage power supply. In case of a fault in the vehicle's low voltage power supply system, the redundant power supply is to activate within TBD ms and sustain the low voltage power supply to the ACS/ETC system for a duration greater than the longest FTTI of the ACS/ETC (**ASIL 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 a red light warning is to be issued to the driver (**ASIL B/C/D**).
7.

8.2.7 Brake Pedal Assembly Functional Safety Requirements

There is one functional safety requirement for the BP assembly. It corresponds to all safety goals. Critical communication and data transfer between the BPPS and the ECM 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**).

8.2.8 Interfacing Systems Functional Safety Requirements

There are nine functional safety requirements for the interfacing systems, corresponding to all safety goals.

1. All requests or commands for propulsion torque modifications from interfacing vehicle systems are to be sent to the ECM (**ASIL C/D**). This includes:
    - Request for torque increase or decrease from the CC/ACC system
    - Request for torque reduction from the braking system including the AEB module (directly or indirectly through the braking system module)
    - Request for torque modification from the traction control system
    - Request for torque modification from the electronic stability control system
2. Interfacing systems are to qualify for validity and correctness (plausibility and rationality) all communications and data transfer regarding requests or commands for propulsion torque modifications sent to the ECM (**ASIL C/D**).
3. All interfacing systems are to inform the ECM in case of any failure that may cause the system to transition into a degraded mode of operation (**Not Assigned**).
4. In case of a fault in the transmitted information to the ECM from the interfacing system, the correct failure mode effect mitigation strategy is to be applied (**Not Assigned**).
5. The air charging system is to supply the engine with the required air for operation (**ASIL B/C/D**).
6. The combustible air supply is to be maintained above a TBD rate under all vehicle operating conditions (**ASIL B/C/D**).

7. The ACS/ETC is to be notified of any malfunctions or disruptions in the air charging system operation (**ASIL B/C/D**).
8. All communications and data sent by the air charging system to the ACS/ETC are to be qualified for validity and correctness (plausibility and rationality) (**ASIL B/C/D**).
9. All single point and plausible dual-point faults that cause the loss of air supply are to be prevented or mitigated (**ASIL B/C/D**).
   - The ACS/ETC is to transition to Safe State 6 in case of the loss or malfunction of the vehicle's air charging system and a red light warning is to be issued to the driver.

8.3 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 [2] to ensure the generation of a comprehensive list of safety requirements.

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

This study identifies an additional 98 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 – 4 requirements
3. ECM – 45 requirements
4. Fuel Delivery Subsystem – 2 requirements
5. Communication Signal – 7 requirements
6. Power Supply – 1 requirements
7. BP Assembly – 5 requirements
8. Interfacing System – 17 requirements

8.3.1 General ACS/ETC System-Level Safety Requirements

This study identifies 17 general system-level safety requirements for ACS/ETC system outside the ISO 26262 Part 3 Functional Safety Concept. These requirements correspond to all safety goals.

1. The packaging for 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 manufacturing process is to ensure the correct calibration of the critical interfacing sensors, actuators, and other critical parameters in the ECM (**ASIL B/C/D**).
5. The calibration of the safety critical sensors, safety critical actuators, and other safety critical parameters are to be checked and verified to be correct (**ASIL B/C/D**). This includes, but is not limited to, the following:

- Safety-critical sensors:
    - FRPS
    - APPS
    - BPPS
    - Engine rotational speed sensor
    - Camshaft position sensor
    - Exhaust gas oxygen (EGO) sensor
    - Boost pressure sensor
    - Fuel temperature sensor
    - Intake air temperature sensor
- Safety critical actuators:
    - Fuel injectors
    - FPCV
- Other critical components:
    - Fuel rail
    - Relevant engine combustion parameters

6. The ACS/ETC components are to meet the reliability and functional degradation requirements (**ASIL B/C/D**).
7. The APPS and FRPS are to have TBD failure rate for 100,000 miles and under all normal vehicle operating conditions (to be specified including temperature, vibration, moisture, etc.) (**ASIL C/D**). Sensor failures may include, but are not limited to:
    - Hardware failure
    - Degradation over time
    - Internal short and increased resistance
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 ECM, corruption of critical parameters including the fuel quantity and 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 considering 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 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 active connection terminals are to be designed to prevent the ingress of moisture, corrosion, and contamination from the external environment or other systems in the vehicle (**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**).
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**).

8.3.2 Accelerator Pedal Assembly Safety Requirements

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

1. The APPS is to be able to detect the loss and abnormality (spike, intermittent failure, etc.) in its low voltage power supply, and inform the ECM that its reading may be affected (**ASIL C/D**).
2. AP assembly mechanical faults that result in incorrect measurement of the APP are to be detected and mitigated (**No ASIL—not within the scope of ISO 26262**).
    - Incorrect measurements include deviations from the correct APP value or being stuck at the same value permanently or intermittently.
3. The AP assembly critical mechanical components are to meet the life and durability requirements of TBD miles without any critical failures (**No ASIL—not within the scope of ISO 26262**).
4. 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**).

8.3.3 Engine Control Module Safety Requirements

This study identifies 45 ECM safety requirements outside the ISO 26262 Part 3 Functional Safety Concept). Many of these requirements correspond to all vehicle-level safety goals. These requirements do not have safety goals specifically stated in them. However, some of the functional safety requirements correspond to only a subset of the safety goals. These requirements have the safety goals listed at the end of the requirement.

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 ECM is to monitor the CPU temperature and is to maintain the CPU temperature within the acceptable operating range (**ASIL B/C/D**).
3. The ECM is to ensure the correct operation of signal conditioning and conversion hardware and software (**ASIL C/D**).
4. The ECM software is to be secured against all unauthorized access (**ASIL B/C/D**).
5. 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**).
6. The ECM software algorithm is to correctly write to memory (**ASIL B/C/D**).

7. The ECM is to correctly calculate the engine load (e.g., additional load from accessories, such as A/C) and the results are to be qualified for validity and correctness under all vehicle operating conditions (**ASIL B/C/D**).
8. The ECM 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 ECM enters a degraded operating state (**ASIL B/C/D**).
9. The ECM software code is to be verified for correctness, including any automatically generated code (**ASIL B/C/D**).
10. The ECM is to verify the correctness of all clock or ECM internal timing signals (**ASIL B/C/D**).
11. Any unused circuits or pins in the ECM are to be properly managed to prevent unwanted signals or other interference with the ECM function (**ASIL B/C/D**).
12. The ECM IC board and its subcomponents are to have TBD reliability over the lifetime of the vehicle and under all vehicle operating conditions (to be specified including temperature, vibration, moisture, etc.) (**ASIL C/D**).
13. The ECM is to have arbitration logic that resolves multiple input requests from other vehicle systems based on a pre-established safety strategy. The arbitration logic is not to degrade the overall system performance (e.g., introduce delays in command execution) (**ASIL B/C/D**).
14. The ECM arbitration logic is to prioritize between the driver's torque request via the AP and torque requests from other vehicle systems based on a pre-established safety strategy. The arbitration logic is not to degrade the overall system performance (e.g., introduce delays in command execution) (**ASIL B/C/D**).
15. The ECM is to command an increase in the injected fuel quantity 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 ECM is in a normal operating mode. (**ASIL B/C/D**).
16. The ECM is to command a decrease in the injected fuel quantity 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 ECM is in a normal operating mode. (**ASIL B/C/D**).
17. The ECM is to have an FQC algorithm for all engine speeds (**ASIL B/C/D**).
18. The ECM is to determine the fuel quantity required to maintain the engine at idle speed, based on the vehicle's current operating conditions. The idle fuel quantity is to be qualified for validity and correctness, and checked for plausibility (**ASIL B/C/D**).
19. The ECM is not to reduce the injected fuel quantity below the idle fuel quantity or other pre-set BTO fuel quantity while in BTO mode or when transitioning out of BTO mode (**ASIL C**).
20. The ECM 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 D**).
21. The ECM is to be able to detect when the fuel delivery subsystem does not respond properly to the ECM's command to enter or exit BTO mode. If the fuel delivery subsystem is not responding properly, the ACS/ETC is to still can reduce the injected fuel quantity to the pre-determined BTO level (**ASIL C**).

22. If an activation delay time is incorporated into the control algorithms for entering or exiting BTO mode, the ECM is to have a specific activation delay time and is to monitor the activation delay timing (**ASIL C**).
23. In case of a fault in entering BTO mode or entering normal mode, the ECM is to invoke the proper fault mitigation strategy, including transition to a Safe State, if required, and alerting the driver (**ASIL C**).
24. The ECM BTO control algorithm is to have a specified vehicle speed threshold for entering BTO mode and the ECM is to monitor the vehicle speed (**ASIL C**).
25. The ECM is not to enter BTO mode when the BP is in the at-rest position (i.e., not pressed) (**ASIL C**).
26. The ECM is to remain in BTO mode while both the AP and BP are still pressed (**ASIL C**).
27. The ECM BTO control model design is to be verified and validated for correctness, including pedals sequencing, critical process parameters, and timing (**ASIL C**).
28. When entering normal mode, the ECM is to resume responding to the driver's torque request via the AP (**ASIL B/C/D**).
29. The ECM is not to command an increase in the injected fuel quantity above the pre-established BTO fuel quantity while in BTO mode or while transitioning into BTO mode (**ASIL C**).
30. The ECM is not to command an increase in the injected fuel quantity 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**).
31. Other vehicle systems are not to have the authority to command the ECM to exit BTO mode (**ASIL C**).
32. When both the AP and BP are pressed, the ECM is to detect when the driver's intention is to stop the vehicle. If the BTO algorithm considers additional variables beyond the APP, BPP, and vehicle speed, it is not to prevent the ECM from detecting when the driver's intention is to stop the vehicle (**ASIL C/D**).
33. When in BTO mode, the ECM is to can detect when the driver's intention is to resume accelerating the vehicle. If the BTO algorithm considers additional variables beyond the APP, BPP, and vehicle speed, it is not to prevent the ECM from detecting when the driver's intention is to resume acceleration (**ASIL C**).
34. The ECM is to supply the correct reference voltage to the ACS/ETC sensors (**ASIL B/C/D**).
35. The ECM 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 if a safety goal is violated (**ASIL A/B**).
36. The ECM is to qualify any changes to the idle speed set-point, including stored changes to the "learned" idle set-point, for validity and correctness (plausibility and rationality) (**ASIL QM**).
37. The ECM is to detect if combustible fluids (e.g., engine oil) enter the combustion chamber by means other than via the fuel injectors (e.g., leaks or air intake stream) at a level that violates a safety goal. The ECM is to notify the driver and enter the appropriate Safe State (**ASIL B/C/D**).

38. Other ECM algorithms or features that affect the injected fuel quantity (e.g., for meeting emissions or performance requirements) are to be qualified for validity and correctness (**ASIL B/C/D**). Example ECM features that can adjust the injected fuel quantity include:
    - Torque limiting function
    - Smoke limiting function
    - Surge damping
39. The ECM is to detect if a fuel injector does not close at the end of its injection cycle (**ASIL C/D**).
40. The ECM algorithm is to specify a target fuel rail pressure based on the vehicle's operating point for all engine speeds (**QM**).
41. The ECM is to control the fuel pressure in the fuel rail to achieve the specified fuel rail pressure (**ASIL C**).
42. The ECM is to have diagnostics to detect when the fuel rail does not achieve the specified fuel rail pressure within TBD seconds (**ASIL B**).
43. The ECM algorithm for adjusting the fuel rail pressure is to account for transient disturbances, such as individual injection events (**QM**).
44. The ECM FQC algorithm is to account for any deactivated cylinders (e.g., for torque or emissions control) (**ASIL B/C/D**).
45. The ECM is to have diagnostics for safety relevant failures in the fuel pump, including supplying the wrong quantity of fuel to the fuel rail (**ASIL A**).

8.3.4 Fuel Delivery Subsystem Requirements

This study identifies two fuel delivery subsystem safety requirements outside the ISO 26262 Part 3 Functional Safety Concept). These requirements correspond to Safety Goals 3 and 4.

1. The fuel rail is to maintain sufficient rail pressure for TBD injection events at maximum torque output (**ASIL C/D**).
2. The FPCV is to respond to changes in the ECM's specified fuel rail pressure within TBD seconds (**ASIL C/D**).

8.3.5 Communication Signal Requirements

This study identifies seven safety requirements for critical communication signals outside the Functional Safety Concept scope Part 3. These requirements trace back to all safety goals.

1. The ECM is to detect intermittent communication signals in the ACS/ETC system (**QM, ASIL B/C/D**). This includes the following connections:
    - APPS and ECM
    - FRPS and ECM
    - ECM and fuel injectors
    - ECM and FPCV
2. Interfacing vehicle systems are to detect and inform the ECM of intermittent communication signals between safety critical sensors and the ACS/ETC system (**QM, ASIL C/D**). This includes the following connections:
    - BPPS and ECM
    - Engine rotational speed sensor and ECM
    - Boost pressure sensor and ECM
    - Intake air temperature sensor and ECM
    - Vehicle speed sensor and ECM
    - Camshaft position sensor and ECM

3. The communication bus is to be secured against all unauthorized access (**ASIL B/C/D**).
4. Malicious intrusion into the communication bus is to be detected. The communication bus and ACS/ETC are to be protected from further harm (**ASIL B/C/D**).
5. The communication bus is to be designed to avoid overload (**ASIL B/C/D**).
6. The communication bus signal prioritization strategy is to allow the TBD reporting frequency for interfacing systems so that the safety critical data is updated sufficiently (**QM**).
    - Safety critical interfacing sensors include:
        - Engine rotational speed sensor
        - Camshaft position sensor
        - EGO sensor
        - Boost pressure sensor
        - Fuel temperature sensor
        - Air intake temperature sensor
    - Safety critical interfacing actuators include:
        - Fuel injectors
        - FPCV
7. If the value of the APP is communicated to ECM through data bus, the APPS data is to have the highest level of signal priority (**ASIL B/C/D**).

8.3.6 Power Supply Safety Requirements

This study identifies one safety requirement for the vehicle power supply outside the ISO 26262 Part 3 Functional Safety Concept. This requirement traces back to all safety goals.

1. The supply voltage and current to safety critical interfacing sensors are 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 (**ASIL B/C/D**). Typical safety critical interfacing sensors include:
    - BPPS
    - EGO sensor
    - Engine rotational speed sensor
    - Camshaft position sensor
    - Boost pressure sensor
    - Fuel temperature sensor
    - Intake air temperature sensor

8.3.7 Brake Pedal Assembly Safety Requirements

This study identifies five safety requirements for the BP assembly outside the ISO 26262 Part 3 Functional Safety Concept. These requirements trace back to all safety goals.

1. The BPP value is to be measured, and the value is to be valid and correct (**ASIL B/C/D**).
2. The BPPS is to have TBD reporting frequency so that the BPP is updated sufficiently (**ASIL B/C/D**).
3. The BP assembly foot well is to allow for free pedal movement and operation of the BPPS in the presence of reasonable everyday objects (**No ASIL—not within the scope of ISO 26262**).

4. 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**).
5. 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**).
    - Incorrect measurements include deviations from the correct BPP value or being stuck at the same value permanently or intermittently.

8.3.8 Interfacing Systems Safety Requirements

This study identifies 17 safety requirements for interfacing vehicle systems that are outside the ISO 26262 Part 3 Functional Safety Concept). These requirements correspond to all safety goals.

1. Interfacing vehicle systems are to correctly identify themselves (according to the ECM prioritization strategy) when issuing torque requests to the ECM (**ASIL B/C/D**).
2. The interfacing system components are to meet the reliability and functional degradation requirements (**ASIL B/C/D**).
3. The packaging for interfacing system components and connections are to meet the standards for packaging clearances (**ASIL B/C/D**).
4. The interfacing system components and connections are to be protected from physical interference from foreign objects (e.g., road debris) (**ASIL B/C/D**).
5. The design and packaging for the interfacing system's components and connections are to consider the effect of the surrounding heat generation (**ASIL B/C/D**).
    - The temperatures of the interfacing system's critical sensors (e.g., engine rotational speed, vehicle speed, camshaft, boost pressure, EGO, intake air temperature, etc.) are to be monitored.
6. The interfacing system assemblies are to be free from 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**).
7. The interfacing vehicle systems are to meet the standards for EMI/EMC with the environment and the vehicle (**ASIL B/C/D**).
8. The interfacing system 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**).
9. The interfacing system components and connections 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 meet the ambient temperature requirements considering the packaging location in the vehicle. The temperature of the components is to be monitored (**ASIL B/C/D**).
11. The interfacing system components and connections are to be designed to prevent organic growth from the external environment that affects the safe functioning of the ACS/ETC (**ASIL B/C/D**).
12. The interfacing system components are to mitigate the effects of magnetic interference from other vehicle components, as well as the external environment (**ASIL B/C/D**).
13. Interfacing vehicle sensors are to have the correct reference voltage supply (**ASIL B/C/D**).

14. Interfacing systems are to inform the ECM of any disruptions to the reference voltage supplied to safety critical sensors (e.g., too high, too low, missing, etc.) (**ASIL B/C/D**).
15. The fuel pump is to provide the fuel to the fuel rail at a sufficient quantity and pressure, and of suitable quality (e.g., free of contaminants and debris) to meet the ECM's fuel rail pressure set point (**QM, ASIL D**).
16. Safety critical interfacing sensors are to have TBD failure rate for 100,000 miles and under all normal (TBD) vehicle operating conditions (temperature, vibration, moisture, etc.) (**QM**).
    - Sensor failures may include, but are not limited to the following.
        - Hardware failure
        - Degradation over time
        - Internal short and increased resistance
    - Typical safety critical interfacing sensors include:
        - BPPS
        - EGO sensor
        - Engine rotational speed sensor
        - Camshaft position sensor
        - Fuel temperature sensor
        - Intake air temperature sensor
        - Boost pressure sensor
17. Interfacing sensors are to have TBD reporting frequency so that the safety critical data is updated sufficiently (**ASIL B/C/D**). Typical safety critical interfacing sensors include the following.
    - BPPS
    - EGO sensor
    - Engine rotational speed sensor
    - Camshaft position sensor
    - Fuel temperature sensor
    - Intake air temperature sensor
    - Boost pressure sensor

9 OBSERVATIONS

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

9.1 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 subsystem that may not be used in all the 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 S at the lower speed (this assumes the vehicle does not reach high speeds, which may have higher severity). Consequently, H1.a has an ASIL B, while H1 has an ASIL D (Table 18).

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.

9.2 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 12 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 12, 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 [15]. 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:

- 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 S and E.

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.

9.3 Variations in the Automotive Safety Integrity Level Assessment

During this study, not all safety analysts on the project team agreed to the same assessment for exposure and controllability. This is because objective data typically do not exist to support the assessment, and expert opinions are often used. This observation corroborates previous assessments of ISO 26262 [16] [17].

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 [18]. 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 [16] [17].

In addition, ISO 26262 assesses controllability based on the 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.

10 POTENTIAL USE OF STUDY RESULTS

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

- This study derives 204 potential safety requirements for the ACS/ETC system following the Concept Phase process Part 3 of ISO 26262. These requirements may serve as an illustration of the process for 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 ACS/ETC system.
- This study applies three hazard and safety analysis methods - HAZOP, Functional FMEA, and STPA. While the automotive industry is familiar with HAZOP 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.

11 CONCLUSIONS

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

1. Identified five 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 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 propulsion power loss/reduction resulting in vehicle deceleration greater than TBD m/s^2 or vehicle stalling is to be mitigated in accordance with the identified ASIL.	D
SG 4	Potential insufficient vehicle deceleration[i] is to be mitigated in accordance with the identified ASIL.	C[ii]
SG 5	The ACS/ETC control algorithm is to choose the throttle command that has the highest priority for safety in accordance with the identified ASIL.	D

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 accelerator pedal.*

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 4 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 publicly available data are available to support assessment of controllability.

2. Developed the functional safety concept and identified 106 illustrative functional safety requirements by following the Concept Phase of 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 ACS/ETC System – 11 requirements
   - AP Assembly – 8 requirements
   - ECM – 49 requirements
   - Fuel Delivery Subsystem – 17 requirements
   - Communication Signals – 5 requirements
   - Power Supply – 6 requirements

- BP Assembly – 1 requirement
- Interfacing Systems – 9 requirements

3. Identified an additional 98 illustrative safety requirements based on the comprehensive results of the safety analyses (Functional FMEA and STPA), and by following the additional safety strategy in the military standard MIL-STD-882E [2]. The breakdown of the number of requirements is as follows:
    - General ACS/ETC System – 17 requirements
    - AP Assembly – 4 requirements
    - ECM – 45 requirements
    - Fuel Delivery Subsystem – 2 requirements
    - Communication Signals – 7 requirements
    - Power Supply – 1 requirement
    - BP Assembly – 5 requirements
    - Interfacing Systems – 17 requirements

    These 98 requirements are out of the scope of the Functional Safety Concept phase in ISO 26262 Part 3). 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 98 requirements.

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Appendix A: STPA Causal Factor Guidewords and Guideword Subcategories

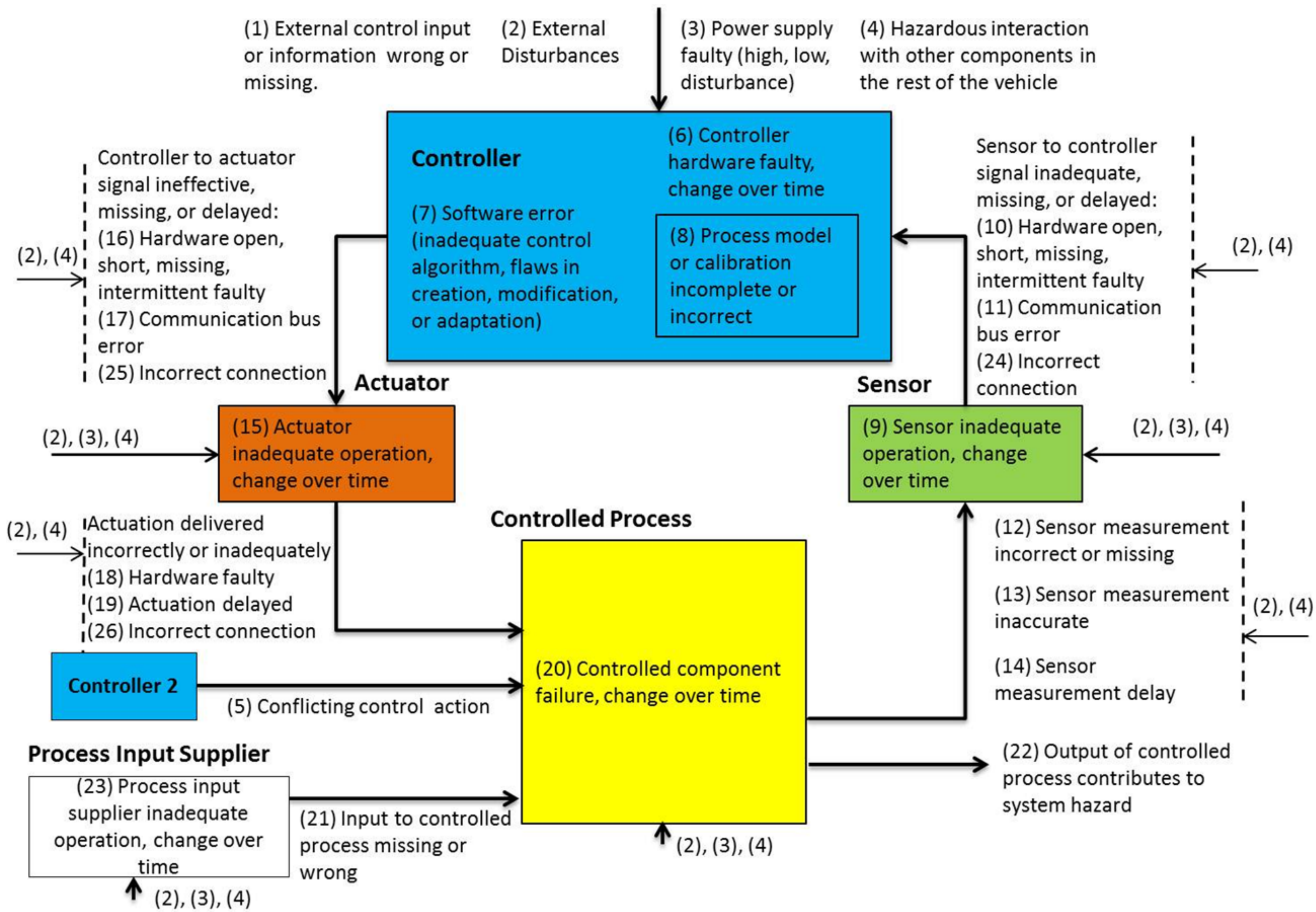

Figure A-1: Causal Factor Categories for Automotive Electronic Control Systems

Table A-1: Causal Factor Sub-categories for Automotive Electronic Control Systems

The numbering in the table below corresponds to those in Figure A-1.

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)

Controller	**(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

Process Input Supplier to Controlled Process	**(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, and 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

<table>
<tr><td>Sensor to Controller, and Controller to Actuator</td><td>(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</td></tr>
<tr><td rowspan="5">Actuator to Controlled Process</td><td>(18) Actuation delivered incorrectly or inadequately: Hardware faulty</td></tr>
<tr><td>(19) Actuation delayed</td></tr>
<tr><td>(20) Actuator to controlled process incorrect connection</td></tr>
<tr><td>(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</td></tr>
<tr><td>(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</td></tr>
</table>

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 Propulsion System

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F1-1	Does not command torque	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F1-2	Commands more torque than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F1-3	Commands less torque than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling
F1-4	Commands torque in the wrong direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	Not applicable.
F1-5	Commands torque intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F1-6	Commands torque when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F1-7	Does not update commanded torque Upward (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling
F1-8	Does not update commanded torque downward (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration

Table B-2. Function 2: Provide Accelerator Pedal Position to the Engine Control Module

I.D.	*Malfunction*	*Operating Mode*	*Potential Vehicle Level Hazard*
F2-1	Does not provide the AP position to the ECM	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F2-2	Provides larger AP travel position than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F2-3	Provides smaller AP travel position than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion
F2-4	Provides AP position intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F2-5	Provides AP travel position in the wrong direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling
F2-6	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 correct information.
F2-7	Does not update AP travel position (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-3. Function 3: Return Accelerator Pedal to the Off (Undepressed) Position Within a Specified Time

(Note: ignore this section per ISO 26262 if the function is performed through mechanical means.)

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F3-1	Does not return AP to Off position within specified time	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F3-2	Returns AP to Off position too fast	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F3-3	Returns AP to Off position within too long time	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F3-4	Returns AP past the OFF position	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	Unknown
F3-5	Returns AP "short" of the Off position	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion
F3-6	Returns AP to Off position intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion
F3-7	Moves the AP when released in the opposite direction of the OFF position	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion
F3-8	Moves the AP when released to the Off position when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	Not a possible failure scenario
F3-9	Does not move AP from its position when un-depressed	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion

Table B-4. Function 4: Provide Accelerator Pedal Request Rate Limiting

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F4-1	Does not limit the AP request rate	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F4-2	Over-limits the AP request rate	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H4: Insufficient vehicle deceleration
F4-3	Under limits the AP request rate	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F4-4	Limits the AP request rate intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F4-5	Limits the AP request rate in the opposite direction (+ vs. -)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H4: Insufficient vehicle deceleration
F4-6	Limits the AP request rate when not required	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H4: Insufficient vehicle deceleration
F4-7	Limits the AP request rate using the same limit profile	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None

Table B-5. Function 5: Control the Fuel Quantity Delivered to the Engine

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Hazards***
F5-1	Does not control fuel quantity	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F5-2	Allows more fuel than requested	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H4: Insufficient vehicle deceleration
F5-3	Allows less fuel than requested	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling H2: Insufficient vehicle propulsion
F5-4	Control fuel intermit-tently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F5-5	Allows fuel at the wrong time	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F5-6	Allows the same quantity of fuel all time (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-6. Function 6: Communicate the Rail Pressure to the Engine Control Module

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Hazards***
F6-1	Does not communicate the rail pressure	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F6-2	Over communicates	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F6-3	Under communicates	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F6-4	Communicates intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F6-5	Communicates in the wrong direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F6-6	Communicates when not required	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F6-7	Communicates the same message (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-7. Function 7: Return Injector Fuel Delivery to Idle State

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Hazards***
F7-1	Does not return injectors to idle state	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F7-2	Takes too long to return injectors to idle state	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F7-3	Return injectors to above idle state (in fuel quantity)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F7-4	Returns injectors to idle state too fast	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F7-5	Return injectors to lower than idle state (in fuel quantity)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F7-6	Returns injectors to idle state intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H4: Insufficient vehicle deceleration
F7-7	Instead of closing the fuel injector valve, further opens the valve.	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F7-8	Returns injectors to idle state when not requested	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F7-9	Keeps injectors at the same state (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-8. Function 8: Establish Idle Fuel Quantity

I.D.	*Malfunction*	*Operating Mode*	*Potential Vehicle Hazards*
F8-1	Does not establish idle fuel quantity	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F8-2	Establishes idle fuel quantity too high	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F8-3	Establishes idle fuel quantity too low	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling
F8-4	Establishes idle fuel quantity intermit-tently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F8-5	When updating the idle quantity, estab-lish it in the opposite direction of needed change (too low or too high).	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F8-6	Does not update the idle fuel quantity	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F8-7	Does not provide idle fuel quantity up-date	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None

Table B-9. Function 9: Control Fuel Rail Pressure Control Valve

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Hazards***
F9-1	Does not control rail pressure valve	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F9-2	Sets rail pressure too high	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H4: Insufficient vehicle deceleration
F9-3	Sets rail pressure too low	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F9-4	Controls rail pressure intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F9-5	Sets rail pressure in the opposite direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F9-6	Changes valve setting when not required	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F9-7	Keeps valve setting the same all the time (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-10. Function 10: Provide Idle State Control

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F10-1	Does not control the idle state	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F10-2	Provides excessive control of the idle state	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None.
F10-3	Provides in-sufficient control of the idle state	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F10-4	Provides idle state control intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F10-5	Provides idle state control in the opposite of the correct direction	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F10-6	Provides control of the idle state when not required	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None.
F10-7	Maintains the idle state at the same position (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling

Table B-11. Function 11. Provide Brake-Throttle Override Control

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F11-1	Does not provide BTO control	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F11-2	Provides excessive control of the BTO - Within a "grace time" period (very short overlap of AP and brake pedal (BP) at high speed)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	None.
F11-3	Provides in-sufficient control of the BTO	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F11-4	Provides control in the opposite of the correct direction of the BTO	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling
F11-5	Provides BTO control intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero
F11-6	Provides BTO control when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H3: Propulsion power reduction/loss or vehicle stalling
F11-7	Does not update the BTO control state (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped 5) ON; D or R: Moving <10 mph	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H3: Propulsion power reduction/loss or vehicle stalling

Table B-12. Function 12. Store the AP Position and Engine Rotational Speed (Vehicle Speed) Versus Fuel Quantity Maps

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Hazards***
F12-1	Does not store the APP vs fuel maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F12-2	Stores values higher than the intended values of the maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion
F12-3	Stores values lower than the intended values in the maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling
F12-4	Stores values in the maps intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F12-5	Stores values opposite in values than the intended values in the maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F12-6	Stores values when no values are intended in the maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	N/A
F12-7	Stores the same values in all locations of the maps	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-13. Function 13: Communicate With Internal Subsystems and External Vehicle Systems

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F13-1	Does not communicate with interfacing sub-systems and systems	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F13-2	Over communicates with interfacing sub-systems and systems	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F13-3	Under communicates with interfacing sub-systems and systems	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F13-4	Communicates intermittently with interfacing sub-systems and systems	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F13-5	Communicates with interfacing sub-systems and systems when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F13-6	Communicates the same message with interfacing sub-systems and systems	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-14. Function 14: Provide Diagnostics

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F14-1	Does not provide diagnostics	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H1a: Uncontrolled vehicle propulsion when the vehicle speed is zero H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F14-2	Provides diagnostics more than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F14-3	Provides diagnostics less than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F14-4	Provides diagnostics intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration
F14-5	Provides diagnostics when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F14-6	Provides the same diagnostics (stuck)	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	H1: Uncontrolled vehicle propulsion H2: Insufficient vehicle propulsion H3: Propulsion power reduction/loss or vehicle stalling H4: Insufficient vehicle deceleration

Table B-15. Function 15: Provide Fault Detection and Failure Mitigation

I.D.	*Malfunction*	*Operating Mode*	*Potential Vehicle Level Hazard*
F15-1	Does not provide fault detection and failure mitigation		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.
F15-2	Provides fault detection and failure mitigation more than intended		Not applicable
F15-3	Provides fault detection and failure mitigation less than intended		Not applicable
F15-4	Provides fault detection and failure mitigation intermittently		Not applicable
F15-5	Provides fault detection and failure mitigation when not intended		Not applicable
F15-6	Provides the same fault detection and failure mitigation at all times		Not applicable

Table B-16. Function 16: Store Relevant Data

I.D.	***Malfunction***	***Operating Mode***	***Potential Vehicle Level Hazard***
F16-1	Does not store relevant data	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F16-2	Store more relevant data than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F16-3	Stores less relevant data than intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F16-4	stores relevant data intermittently	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F16-5	Stores relevant data when not intended	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None
F16-6	Stores the same relevant data at all times	1) ON; D; Moving 2) ON; R; Moving 3) ON; D; Stopped 4) ON; R; Stopped	None

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		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Not Pressed	Not Pressed	≥ 10 mph		H3	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		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Not Pressed	≥ 10 mph		H3	N/A	N/A	N/A	N/A	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided
Pressed	Pressed	< 10 mph		H3	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	H3	H1

Vehicle Level Hazards:

- H1: Potential Uncontrolled Vehicle Propulsion
- H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

* Vehicle speed values are based on the maximum vehicle speed threshold for activating BTO mode. 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 in-correctly	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, H3		N/A	N/A	N/A	N/A	H3	N/A	H3
Pressed	Not Pressed	≥ 10 mph	H2, H3		N/A	N/A	N/A	N/A	H3	N/A	H3
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: Potential Uncontrolled Vehicle Propulsion
- H2: Potential Insufficient Vehicle Propulsion
- H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

* Vehicle speed values are based on the maximum vehicle speed threshold for activating BTO mode. Manufacturers may elect to have an activation speed less than 10 mph.

Table C-3: UCA Assessment for the "Increase Injected Fuel Quantity" Control Action

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
None	Not Pressed	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Not Pressed	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Not Pressed	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Not Pressed	BTO Switching to Normal		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Maintained	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
None	Angular Position is Maintained	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Maintained	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Maintained	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	Normal Mode	H2		H1	H2	H1	H2	H1, H2, H3	N/A	H2
None	Angular Position is Increased	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	BTO Switching to Normal	H2		H1	H2	H1	H2	H1, H2, H3	N/A	H2
Reduce	Not Pressed	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Not Pressed	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce	Not Pressed	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Not Pressed	BTO Switching to Normal		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Maintained	Normal Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Maintained	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Maintained	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce	Angular Position is Maintained	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	Normal Mode	H2	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	BTO Switching to Normal	H2	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	Normal Mode	H2	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Increase	Angular Position is Reduced	Normal Mode	H5	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Reduced	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Reduced	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Reduced	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	Normal Mode	H5	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Increased	Normal Mode	H2		H1	H2	H1	H2	H1, H2, H3	N/A	H2

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Increase	Angular Position is Increased	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Increased	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Increased	BTO Switching to Normal	H2		H1	H2	H1	H2	H1, H2, H3	N/A	H2
Reduce and In-crease	Not Pressed	Normal Mode	H2	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Not Pressed	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Not Pressed	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Not Pressed	BTO Switching to Normal		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Reduced	Normal Mode	H5	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Reduced	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce and Increase	Angular Position is Reduced	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Reduced	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Maintained	Normal Mode	H5	H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Maintained	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Maintained	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Maintained	BTO Switching to Normal		H1 *	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Increased	Normal Mode	H2	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Increased	Normal Switching BTO		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Increased	BTO Mode		H1	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Increase Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce and Increase	Angular Position is Increased	BTO Switching to Normal	H2	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Vehicle Level Hazards:

- H1: Potential Uncontrolled Vehicle Propulsion
- H2: Potential Insufficient Vehicle Propulsion
- H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling
- H5: Potential Allowing Driver's Command to Override an Active Safety System

* This analysis is based on a brake override process flow diagram published by Toyota, which requires the driver to explicitly increase the accelerator pedal angle to exit BTO mode. Other manufacturers may have different strategies for exiting BTO mode.

Table C-4: UCA Assessment for the "Decrease Injected Fuel Quantity" Control Action

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
None	Not Pressed	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Not Pressed	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
None	Not Pressed	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Not Pressed	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	Normal Mode	H4		H3	H4	H3	H4	H1, H3, H4	N/A	H4
None	Angular Position is Reduced	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
None	Angular Position is Reduced	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Reduced	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Maintained	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
None	Angular Position is Maintained	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
None	Angular Position is Maintained	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Maintained	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
None	Angular Position is Increased	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
None	Angular Position is Increased	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Not Pressed	Normal Mode	H4		H3	H4	H3	H4	H1, H3, H4	N/A	H4
Reduce	Not Pressed	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce	Not Pressed	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Not Pressed	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	Normal Mode	H4		H3	H4	H3	H4	H1, H3, H4	N/A	H4
Reduce	Angular Position is Reduced	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce	Angular Position is Reduced	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Reduced	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Maintained	Normal Mode	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Maintained	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce	Angular Position is Maintained	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce	Angular Position is Maintained	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	Normal Mode	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce	Angular Position is Increased	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce	Angular Position is Increased	BTO Switching to Normal	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Increase	Not Pressed	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Not Pressed	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Increase	Angular Position is Reduced	Normal Mode	H4	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Reduced	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Increase	Angular Position is Reduced	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Reduced	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Increase	Angular Position is Maintained	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Maintained	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Increased	Normal Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Increase	Angular Position is Increased	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Increase	Angular Position is Increased	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Increase	Angular Position is Increased	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Not Pressed	Normal Mode	H4	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Not Pressed	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce and Increase	Not Pressed	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Not Pressed	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Reduced	Normal Mode	H4	H5	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and Increase	Angular Position is Reduced	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce and In-crease	Angular Position is Reduced	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Reduced	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Maintained	Normal Mode	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Maintained	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce and In-crease	Angular Position is Maintained	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Maintained	BTO Switching to Normal		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Increased	Normal Mode	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided
Reduce and In-crease	Angular Position is Increased	Normal Switching BTO	H4		H3	H4	H3	H4	H1, H3, H4	H3	H4
Reduce and In-crease	Angular Position is Increased	BTO Mode		H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Context Variables (Decrease Injected Fuel Quantity)			Guidewords for Assessing Whether the Control Action May Be Unsafe								
Torque Request From Other Vehicle Systems	Driver action on accelerator pedal	ECM Operating Mode	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
Reduce and Increase	Angular Position is Increased	BTO Switching to Normal	H5	H3	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	Hazardous if Provided	N/A	Hazardous if Provided

Vehicle Level Hazards:

- H1: Potential Uncontrolled Vehicle Propulsion
- H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling
- H4: Potential Insufficient Vehicle Deceleration
- H5: Potential Allowing Driver's Command to Override Active Safety Systems

Table C-5: UCA Assessment for the "Increase Mean Fuel Rail Pressure" Control Action

Context Variable (Increase Mean Fuel Rail Pressure)	**Guidewords for Assessing Whether the Control Action May Be Unsafe**							
Actual Rail Pressure	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 Target Pressure	H2, H3			H2, H3		H2, H3	H2, H3	N/A	H2, H3
At Target Pressure							H2, H3	N/A	
Above Target Pressure							H2, H3	N/A	
Vehicle Level Hazards: • H2: Potential Insufficient Vehicle Propulsion • H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling								

Table C-6: UCA Assessment for the "Decrease Mean Fuel Rail Pressure" Control Action

Context Variables (Decrease Mean Fuel Rail Pressure)	**Guidewords for Assessing Whether the Control Action May Be Unsafe**							
Actual Rail Pressure	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 Target Pressure		H2, H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	H2, H3	N/A	Hazardous if pro-vided
At Target Pressure		H2, H3	Hazardous if provided	Hazardous if provided	Hazardous if provided	Hazardous if provided	H2, H3	N/A	Hazardous if pro-vided
Above Target Pressure			H2, H3		H2, H3		H2, H3	N/A	
Vehicle Level Hazards: • H2: Potential Insufficient Vehicle Propulsion • H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling									

Appendix D: STPA Step 1: UCAS and Mapping to Hazards

Table D-1: UCAs 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.
H3	The ECM issues the Enter BTO Mode command when: • the accelerator pedal is pressed, • the brake pedal is pressed, and • the vehicle speed is below 10 mph.
H3	The ECM issues the Enter BTO Mode command when: • the brake pedal is not pressed.
H3	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: Potential Uncontrolled Vehicle Propulsion
H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

Table D-2: UCAs for the “Enter Normal Mode” Control Action

Vehicle Level Hazard	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, H3	The ECM does not issue the Enter Normal Mode command when: • the accelerator pedal is pressed, and • the brake pedal is not pressed.
H3	The ECM correctly issues the Enter Normal Mode command, but the command is executed incorrectly.
H3	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: Potential Uncontrolled Vehicle Propulsion
H2: Potential Insufficient Vehicle Propulsion
H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

Table D-3: UCAs for the “Increase Injected Fuel Quantity” Control Action

Vehicle Level Hazard	Unsafe Control Action (Increase Injected Fuel Quantity)
H1	The ECM issues the Increase Injected Fuel Quantity command when: • the ECM is in BTO mode or is transitioning from normal mode into BTO mode.
H1, H2, H3	The ECM correctly issues the Increase Injected Fuel Quantity command, but the command is executed incorrectly.
H1	The ECM issues the Increase Injected Fuel Quantity command when: • the driver reduces or maintains the angular position of the accelerator pedal, or is not pressing the accelerator pedal.
H1	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems request an increase in engine torque, or are not requesting a change in engine torque, • the driver is increasing the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode, but too much of an increase in the injected fuel quantity is commanded.
H1	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems request an increase in engine torque, or are not requesting a change in engine torque, • the driver is increasing the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode, but the command is issued for too long.
H2	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, or request an increase in engine torque, • the driver increases the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode, but too little of an increase in the injected fuel quantity is commanded.
H2	The ECM does not issue the Increase Injected Fuel Quantity command when: • the driver increases the angular position of the accelerator pedal and • the ECM is in normal mode or is transitioning from BTO mode into normal mode.
H2	The ECM does not issue the Increase Injected Fuel Quantity 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 ECM is in normal mode.
H2	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, or request an increase in engine torque, • the driver increases the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode, but the command is issued for too short a period.

H2	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, or request an increase in engine torque, • the driver increases the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode, but the command is issued too late.
H5	The ECM issues the Increase Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque or both a reduction and increase in engine torque, • the driver increases the angular position of the accelerator pedal, and • the ECM is in normal mode or is transitioning from BTO mode into normal mode.
H5	The ECM does not issue the Increase Injected Fuel Quantity command when: • other vehicle systems request an increase in engine torque or both a reduction and increase in engine torque, • the driver is maintaining or reducing the angular position of the accelerator pedal, and • the ECM is in normal mode.

H1: Potential Uncontrolled Vehicle Propulsion
H2: Potential Insufficient Vehicle Propulsion
H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling
H5: Potential Allowing the Driver's Command to Override Active Safety System

Table D-4: UCAs for the "Decrease Injected Fuel Quantity" Control Action

Vehicle Level Hazard	Unsafe Control Action (Decrease Injected Fuel Quantity)
H1, H3, H4	The ECM correctly issues the Decrease Injected Fuel Quantity command, but the command is executed incorrectly.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is in BTO mode or is transitioning from BTO into normal mode.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, 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 ECM is in normal mode.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • the driver maintains or increases the angular position of the accelerator pedal, and • the ECM is in normal mode.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems don't request a change in engine torque, or request a reduction in engine torque, • the driver is reducing the angular position of the accelerator pedal, and • the ECM is in normal mode, but too much of a decrease is commanded.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but too much of a decrease in the injected fuel quantity is commanded.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems do not request a change, or request a reduction in engine torque, • the driver reduces the angular position of the accelerator pedal, and • the ECM is in normal mode, but the command is issued for too long a period.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but the command is issued for too long a period.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode, but too much of a decrease in the injected fuel quantity is commanded.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode, but the command is issued for too long a period.
H3	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but the command is issued too soon.

H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, or request a reduction in engine torque, • the driver is reducing the angular position of the accelerator pedal, and • the ECM is in normal mode, but too little of a decrease is commanded.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but too little of a decrease in the injected fuel quantity is commanded.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems do not request a change, or request a reduction in engine torque, • the driver is reducing the angular position of the accelerator pedal, and • the ECM is in normal mode, but the command is issued for too short a period.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but the command is issued for too short a period.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems do not request a change in engine torque, or request a reduction in engine torque, • the driver is reducing the angular position of the accelerator pedal, and • the ECM is in normal mode, but the command is issued too late.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal into BTO mode, but the command is issued too late.
H4	The ECM does not issue the Decrease Injected Fuel Quantity command when: • the driver reduces the angular position of the accelerator pedal, and • the ECM is in normal mode.
H4	The ECM does not issue the Decrease Injected Fuel Quantity command when: • the ECM is transitioning from normal mode into BTO mode.
H4	The ECM does not issue the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque or both an increase and reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode, but too little of a decrease in the injected fuel quantity is commanded.
H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode, but the command is issued for too short a period.

H4	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque, • the driver is not pressing the accelerator pedal, and • the ECM is in normal mode, but the command is issued too late.
H5	The ECM does not issue the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque or both an increase and reduction in engine torque, • the driver is maintaining or increasing the angular position of the accelerator pedal, and • the ECM is in normal mode.
H5	The ECM issues the Decrease Injected Fuel Quantity command when: • other vehicle systems request an increase in engine torque, or request both an increase and reduction in engine torque, • the driver is reducing the angular position of the accelerator pedal, and • the ECM is in normal mode.
H5	The ECM does not issue the Decrease Injected Fuel Quantity command when: • other vehicle systems request a reduction in engine torque or both an increase and reduction in engine torque, • the driver is increasing the angular position of the accelerator pedal, and • the ECM is transitioning from BTO to normal mode.

H1: Potential Uncontrolled Vehicle Propulsion
H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling
H4: Potential Insufficient Vehicle Deceleration
H5: Potential Allowing the Driver's Command to Override Active Safety System

Table D-5: UCAs for the “Increase Mean Rail Fuel Pressure” Control Action

Vehicle Level Hazard	Unsafe Control Actions (Increase Mean Rail Fuel Pressure)
H2, H3	The ECM issues the Increase Mean Fuel Rail Pressure command, but the command is executed incorrectly.
H2, H3	The ECM does not issue the Increase Mean Fuel Rail Pressure command when: • the actual rail pressure is below the target rail pressure.
H2, H3	The ECM issues the Increase Mean Fuel Rail Pressure command when: • the actual rail pressure is below the target rail pressure, but the duration of the command is too short.
H2, H3	The ECM issues the Increase Mean Fuel Rail Pressure command when: • the actual rail pressure is below the target rail pressure, but too little of an increase in the mean fuel rail pressure is commanded.
H2, H3	The ECM issues the Increase Mean Fuel Rail Pressure command when: • the actual rail pressure is below the target rail pressure, but the command is issued too late.

H2: Potential Insufficient Vehicle Propulsion
H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

Table D-6: UCAs for the "Decrease Mean Rail Fuel Pressure" Control Action

Vehicle Level Hazard	Unsafe Control Actions (Decrease Mean Rail Fuel Pressure)
H2, H3	The ECM issues the Decrease Mean Fuel Rail Pressure command, but the command is executed incorrectly.
H2, H3	The ECM issues the Decrease Mean Fuel Rail Pressure command when: • the actual rail pressure is at or below the target rail pressure.
H2, H3	The ECM issues the Decrease Mean Fuel Rail Pressure command when: • the actual rail pressure is above the target rail pressure, but the duration of the command is too long.
H2, H3	The ECM issues the Decrease Mean Fuel Rail Pressure command when: • the actual rail pressure is above the target rail pressure, but too much of a decrease in the mean fuel rail pressure is commanded.

H2: Potential Insufficient Vehicle Propulsion

H3: Potential Propulsion Power Reduction/Loss or Vehicle Stalling

Appendix E: Operational Situations

1. Vehicle in a parking lot or drive way and starting to move; good visibility with light pedestrian traffic.
2. Vehicle in a parking lot or drive way and starting to move; low visibility with light pedestrian traffic.
3. Vehicle in a parking lot or drive way and starting to move; good visibility with high pedestrian traffic (mall, supermarket).
4. Vehicle in a parking lot or drive way and starting to move; low visibility with high pedestrian traffic (mall, supermarket).
5. 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.
6. Driving inside the city with heavy traffic and pedestrians present; stop and go driving; good visibility; good road conditions.
7. Driving inside the city with heavy traffic and pedestrians present; stop and go driving; low visibility; slippery road conditions.
8. Driving inside the city with heavy traffic and negligible pedestrian presence; stop and go driving; good visibility; and good road conditions.
9. Driving inside the city with heavy traffic and negligible pedestrian presence; stop and go driving; bad visibility; and slippery road conditions.
10. Driving inside (< 40 kph) the city with heavy traffic and negligible pedestrian presence; good visibility; and good road conditions.
11. Driving inside the city (< 40 kph) with heavy traffic and negligible pedestrian presence; bad visibility; and slippery road conditions.
12. Driving at medium speed (40 kph < V < 100 kph); country road; heavy traffic; good visibility; and good road conditions.
13. Driving at medium speed (40 kph < V < 100 kph); country road; light traffic; good visibility; and good road conditions.
14. Driving at medium speed (40 kph < V < 100 kph); country road; heavy traffic; low visibility; and slippery road conditions.
15. Driving at medium speed (40 kph < V < 100 kph); country road; light traffic; low visibility; and slippery road conditions.
16. Overtaking another vehicle at medium speed (40 kph < V < 100 kph); country road; heavy traffic; good visibility; and good road conditions.
17. Overtaking another vehicle at medium speed (40 kph < V < 100 kph); country road; light traffic; good visibility; and good road conditions.

18. Overtaking another vehicle at medium speed (40 kph < V < 100 kph); country road; heavy traffic; low visibility; and slippery road conditions.
19. Overtaking another vehicle at medium speed (40 kph < V < 100 kph); country road; light traffic; low visibility; and slippery road conditions.
20. Overtaking another vehicle at medium speed (40 kph < V < 100 kph); country road; light/heavy traffic; low/good visibility; and good/slippery road conditions; pedestrians present.
21. Driving at high speed (100 kph < V < 130 kph); heavy traffic; good visibility; and good road conditions.
22. Driving at high speed (100 kph < V < 130 kph); light traffic; good visibility; and good road conditions.
23. Driving at high speed (100 kph < V < 130 kph); heavy traffic; low visibility; and slippery road conditions.
24. Driving at high speed (100 kph < V < 130 kph); country road; light traffic; low visibility; and slippery road conditions.
25. Overtaking another vehicle at high speed (100 kph < V < 130 kph); country road; heavy traffic; good visibility; and good road conditions.
26. Overtaking another vehicle at high speed (100 kph < V < 130 kph); country road; light traffic; good visibility; and good road conditions.
27. Overtaking another vehicle at high speed (100 kph < V < 130 kph); country road; heavy traffic; low visibility; and slippery road conditions.
28. Overtaking another vehicle at high speed (100 kph < V < 130 kph); country road; light traffic; low visibility; and slippery road conditions.
29. Driving at very high speed (V > 130 kph); heavy traffic; good visibility; and good road conditions.
30. Driving at very high speed (V > 130 kph); light traffic; good visibility; and good road conditions.
31. Driving at very high speed (V > 130 kph); heavy traffic; low visibility; and slippery road conditions.
32. Driving at very high speed (V > 130 kph); light traffic; low visibility; and slippery road conditions.
33. Overtaking another vehicle at very high speed (V > 130 kph); heavy traffic; good visibility; and good road conditions.
34. Overtaking another vehicle at very high speed (V > 130 kph); light traffic; good visibility; and good road conditions.
35. Overtaking another vehicle at very high speed (V > 130 kph); heavy traffic; low visibility; and slippery road conditions.
36. Overtaking another vehicle at very high speed (V > 130 kph); light traffic; low visibility; and slippery road conditions.

37. Driving at high speed (100 kph < V < 130 kph); light traffic; low visibility; and slippery road conditions.
38. Overtaking another vehicle at high speed (100 kph < V < 130 kph); heavy traffic; good visibility; and good road conditions.
39. Overtaking another vehicle at high speed (100 kph < V < 130 kph); light traffic; good visibility; and good road conditions.
40. Overtaking another vehicle at high speed (100 kph < V < 130 kph); heavy traffic; low visibility; and slippery road conditions.
41. Overtaking another vehicle at high speed (100 kph < V < 130 kph); light traffic; low visibility; and slippery road conditions.
42. Driving at very high speed (V > 130 kph); heavy traffic; good visibility; and good road conditions.
43. Vehicle in a parking lot or drive way and starting to move; good/low visibility; good/slippery road conditions.
44. Driving inside the city with heavy traffic; stop and go driving; good visibility; good road conditions.
45. Driving inside the city with heavy traffic; stop and go driving; low visibility; slippery road conditions.
46. Driving inside the city with light traffic; stop and go driving; good visibility; good road conditions.
47. Driving inside the city with light traffic; stop and go driving; low visibility; slippery road conditions.
48. Driving near rail road track; low/good visibility; good/slippery road conditions.
49. Driving at very high speed (V > 130 kph); heavy traffic; low visibility; and slippery road conditions.
50. Vehicle in a Park or Neutral (P or N) position; good/low visibility; and low to high pedestrian traffic.
51. Vehicle in a parking lot or drive way in a drive or reverse (D or R) position; the brake is applied; good/slippery road conditions; good/low visibility; and low pedestrian traffic.
52. Vehicle in a parking lot or drive way in a drive or reverse (D or R) position; the brake is applied; good/slippery road conditions; good/low visibility; and high pedestrian traffic.
53. Vehicle in a traffic stop; the brake is applied; good/slippery road conditions; good/low visibility; and light traffic.
54. Vehicle in a traffic stop; the brake is applied; good/slippery road conditions; good/low visibility; and heavy traffic.
55. Vehicle in hill-hold in drive (D) position; and the brakes are not applied
56. Vehicle in a parking lot or drive way and starting to move; good/low visibility; good/slippery road conditions; and light/heavy pedestrian traffic.
57. Driving inside the city with heavy traffic; pedestrians present; stop and go driving; good/low visibility; good/slippery road conditions.

58. Driving inside the city (< 40 kph); heavy traffic; negligible pedestrian presence; low visibility; and slippery road conditions.
59. Driving over a rail road track; low/good visibility; and good/slippery road conditions.
60. Driving at medium speed (40 kph < V < 100 kph); country road; heavy traffic; good/low visibility; and good/slippery road conditions.
61. 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.
62. Driving at high speed (100 kph < V < 130 kph); light/heavy traffic; good/low visibility; and good/slippery road conditions.
63. 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.
64. Driving at a very high speed (V > 130 kph); light/heavy traffic; good/low visibility; and good/slippery road conditions.
65. 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.
66. Overtaking another vehicle at very high speed (V > 130 kph) heavy traffic; low visibility; and slippery road conditions.
67. Driving inside the city with heavy traffic and pedestrians present; stop and go driving above 16 kph; good visibility; and good road conditions.
68. Driving inside the city with heavy traffic and pedestrians present; stop and go driving above 16 kph; low visibility; and slippery road conditions.
69. Driving inside the city with heavy traffic and negligible pedestrians present; stop and go driving above 16 kph; good visibility; and good road conditions.
70. Driving inside the city with heavy traffic and negligible pedestrians present; stop and go driving above 16 kph; bad visibility; and slippery road conditions.
71. Driving at medium speed (40 kph < V < 100 kph); country road; heavy traffic; good visibility; and good road conditions.

Appendix F: ASIL Assessment

Table F-1: Unintended Vehicle Propulsion without Destabilization

(ASIL C)

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Vehicle in a parking lot or drive way 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 drive way 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 drive way 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 drive way 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); slip-pery/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 (Unintended Vehicle Propulsion without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	Driving inside the city with heavy traffic and pedestrians presence, stop and go driving, good visibility, 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 pedestrians 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 (Unintended Vehicle 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 (Unintended Vehicle 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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	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
	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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	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
	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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	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
	Overtaking another vehicle at a 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 a 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: Unintended Vehicle Propulsion with Destabilization

(ASIL D)

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle 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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion with Destabilization)			ASIL
			Exposure	Severity	Controllability	
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
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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Unintended Vehicle Propulsion with Destabilization)			ASIL
			Exposure	Severity	Controllability	
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
Hazard occurs with destabilization	Overtaking another vehicle at a 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 a 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: Unintended Vehicle Propulsion with Zero Starting Speed

(ASIL B)

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment Unintended Vehicle Propulsion with Zero Starting Speed			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 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.	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 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.	The vehicle moves and hits a pedestrian	E4	S2	C2	B

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment Unintended Vehicle Propulsion with Zero Starting Speed			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 light traffic.	The vehicle moves and hits another vehicle.	E4	S1	C1	QM
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-4: Insufficient Vehicle Propulsion

(ASIL 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	Vehicle in a parking lot or drive way 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, good/slippery road conditions.	None	E3		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 (< 40 kph) the city with heavy traffic and negligible pedestrian presence, good visibility, and good road conditions.	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	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, 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

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 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	QM
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
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

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, 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

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, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	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	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 another 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

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 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
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

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	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 a 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 a 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

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) 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
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-5: Propulsion Power Reduction/Loss or Vehicle Stalling without Destabilization (ASIL C)

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 drive way and starting to move; good/low visibility, 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, 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 heavy traffic, stop and go driving, low visibility, 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, 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 light traffic, stop and go driving, low visibility, 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 a rail road track, low/good visibility, good/slippery road conditions.	Vehicle stalls while stopping on rail road track and gets hit by an incoming train.	E1	S3	C3	A

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling without Destabilization)			ASIL
			Exposure	Severity	Controllability	
	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

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, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C3	B
	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

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), 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
	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

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, 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 a 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 a 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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Propulsion Power Reduction/Loss or Vehicle Stalling without Destabilization)			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, light/heavy traffic, low/good visibility, and good/slippery road conditions; pedestrian present.	The vehicle runs into a person.	E2	S3	C2	A

Table F-6: Propulsion Power Reduction/Loss or Vehicle Stalling with Destabilization (ASIL D)

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

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), heavy 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), 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 a 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

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 a 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
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-7: Insufficient Vehicle Deceleration

(ASIL C)

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 drive way 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 drive way and starting to move; low visibility with light pedestrian traffic.	The vehicle runs into a pedestrian at low speed.	E3	S2	C1	QM

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 drive way 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
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 drive way 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

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 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

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, 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
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

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, 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.	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

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, 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
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

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

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), 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
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

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, 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 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

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), 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.	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), 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 a 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 a 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

Assumptions	Operating Scenario Description	Potential Crash Scenario	ASIL Assessment (Insufficient Vehicle Deceleration)			ASIL
			Exposure	Severity	Controllability	
1. Under BTO condition 2. E/E part of ACS/ETC is functioning properly. 3. AP stuck due to a mechanical failure. 4. The vehicle speed is getting reduced but not at the intended rate.	ALL		Not covered by ISO 26262; however this shall be captured in the Failure Mode Analysis and assigned the appropriate severity (10 or 9 in a Design FMEA).			
1. Under BTO condition 2. E/E part of ACS/ETC is malfunctioning. 3. The vehicle speed is getting reduced but not at the intended rate.			This scenario is covered in the Unintended Vehicle Propulsion hazard. Regardless of whether BTO is functioning or not, the hazard may still occur due to failure in the ASC/ETC system. In this case BTO is a safety mechanism for ASIL D hazard and it should be developed with ASIL B classification per ISO 26262.			B

Appendix G: Functional FMEA Results

Table G-1. Functional FMEA for H1: Uncontrolled Vehicle Propulsion
(Malfunction: Commands Less Torque than Requested)

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Commands larger amount of fuel than required by the requested torque by the driver	ECM fault:	Three levels monitoring		ECM Fault
		Hardware fault (Sensors, ICs, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in ECM I/Os connections	Critical messages/ data transfer qualification	Stuck Open/ Short	I/O Fault
		Short in ECM I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/ Short	I/O Fault
		Short in ECM I/Os connections to another connection		Stuck Open/ Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
ECM	Commands larger amount of fuel than required by the requested torque by the driver	Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three Levels Monitoring		System Fault
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		EMC/EMI fault		Hardware/ Software Diagnostics	ECM Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the APP	Hardware or Software Fault (covered above)			
	Commands Incorrect Fuel amount	Hardware or Software Fault (covered above)			
	BTO Control Fault	BTO algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic checks	
		BPPS Fault			
ECM	BTO Control Fault	Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	Fuel Delivery Map Corrupted	Hardware fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal subsystems	From: APPS	Critical messages/ data transfer qualification		Communication Fault

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Incorrect signals (this may be CAN like communication, PWM, or other types of signals)	To: Fuel delivery subsystem	Critical messages/ data transfer qualification		Commu-nication Fault
	Incorrect signals (this may be CAN like communication, PWM, or other types of signals)	From: Fuel delivery subsystem	Critical messages/ data transfer qualification		Commu-nication Fault
	Miscommunicates with external systems	From: BPPS	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Vehicle Speed Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Engine Revolution per Minute (RPM) Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
ECM	Miscommunicates with external systems	From: AEB	Critical messages/ data transfer qualification		Commu-nication Fault
		From: CC/ACC	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Atmospheric Pressure Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (Fault Tree Analysis)	Out of scope for Functional Safety Concept		
Fuel Deliv-ery Subsys-tem	Delivers more fuel than commanded by the ECM	Injector fault:			ETC fault
		Fuel rail pressure sensor (FRPS) fault		Hardware diagnostics	

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Fuel Pressure Control Valve (FPCV) fault			
		Break in fuel delivery subsystem internal/external connections	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Short in fuel delivery subsystem internal/external connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Signal connector connection failure		Hardware diagnostics	
Fuel Delivery Subsystem	Delivers more fuel than commanded by the ECM	Power connector connection failure		Hardware diagnostics	
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the signal from the ECM	Fuel injector, FPS, or FPCV faults (covered above)			

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Mechanical failure prevents fuel injector or FPCV movement to correct position	Out of Scope			
BPP Sensor	Provides incorrect input to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Brake System Fault
	Other failure modes	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…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in APP sensor I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in APP sensor I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in APP sensor I/Os connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		APP calculation algorithm fault		Software diagnostics	
		Software 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

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
APP Sensor	APP value interpreted lower than actual	EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	AP Is Not Returned to Idle Position Correctly	AP-mechanical Failure-Out of Scope			
	APP Communicates with ECM Incorrectly	Hardware or Software 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 Failure Modes	Out of Scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			
Atmospheric Pressure Sensor	Provides incorrect pressure (elevation) value to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Uncontrolled Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Out of Scope			
	Other Failure Modes	Out of Scope			
Air Charging System	None (only potential issue is with this system is reduced/loss of air intake; this does not affect this failure hazard)	Communication Faults			
	Other Failure Modes	Out of Scope			
Exhaust Air Recirculation Valve	None				
	Other Failure Modes	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 Failure Modes	Out of Scope			
AEB	Command/Request for braking from AEB to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Command/Request for braking from CC/ACC to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			

Table G-2. Functional FMEA for H1a: Unintended Vehicle Propulsion with Zero Starting Speed

(Malfunction: Commands Less Torque than Requested)

System/ Subsys-tem	Potential Failure Mode (Unintended Vehicle Pro-pulsion with Zero Start-ing Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Commands larger amount of fuel than required by the requested torque by the driver	ECM fault:	Three levels monitoring		ECM Fault
		Hardware fault (Sensors, ICs, Circuit Compo-nents, Circuit Boards…)		Hardware diagnostics	
		Internal connec-tion fault (short or open)		Hardware diagnostics	
		Break in ECM I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to an-other connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algo-rithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
ECM	Commands larger amount of fuel than required by the requested torque by the driver	Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three Levels Monitoring		System Fault
		Supply power out of range		Supply power value	Loss of Power

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	ECM Fault
		Contamination/Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the APP	Hardware or Software Fault (covered above)			
	Incorrectly Establishes Idle Position	Hardware or Software fault (covered above)			
		Atmospheric Pressure Sensor fault			
	Commands Incorrect Fuel amount	Hardware or Software Fault (covered above)			
	Fuel Delivery Map Corrupted	Hardware fault (covered above)			
ECM	Fuel Delivery Map Corrupted	Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems	From: APPS	Critical messages/ data transfer qualification		Communication Fault

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Incorrect signals (this may be CAN like communication or PWM or else)	To: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	From: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Miscommunicates with external systems	From: BPPS	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: AEB	Critical messages/data transfer qualification		Communication Fault
ECM	Miscommunicates with external systems	From: CC/ACC	Critical messages/ data transfer qualification		Communication Fault
		From: Atmospheric Pressure Sensor	Critical messages/ data transfer qualification		Communication Fault
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (Fault Tree Analysis)			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Injector fault			ETC fault
		Fuel rail pressure sensor (FRPS) fault		Hardware diagnostics	
		Fuel Pressure Control Valve (FPCV) fault			

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Break in fuel delivery subsystem internal/external connections	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Short in fuel delivery subsystem internal/ external connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Supply power out of range		Supply power value	Loss of Power
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the signal from the ECM	Fuel injector, FPS, or FPCV faults (covered above)			

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Mechanical failure prevents throttle movement to correct position	Out of Scope			
BPP Sensor	Provides incorrect input to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Brake System Fault
	Other failure modes	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…)		Hardware diagnostics	
APP Sensor	APP value interpreted lower than actual	Internal connection fault (short or open)		Hardware diagnostics	
		Break in APP sensor I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in APP sensor I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in APP sensor I/Os connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		APP calculation algorithm fault		Software diagnostics	
		Software 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

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
APP Sensor	APP value interpreted lower than actual	Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	AP Is Not Returned to Idle Position Correctly	AP-mechanical Failure-Out of Scope			
	APP Communicates with ECM Incorrectly	Hardware or Software 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 failure modes	Out of Scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
Atmospheric Pressure Sensor	Provides incorrect pressure (elevation) value to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Unintended Vehicle Propulsion with Zero Starting Speed)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Communication Faults			
	Other failure modes	Out of Scope			
Air Charging System	None (only potential issue is with this system is reduced/loss of air intake; this does not affect this failure hazard)				
	Other failure modes	Out of Scope			
Exhaust Air Recirculation Valve	None				
	Other failure modes	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 failure modes	Out of Scope			
AEB	Command/Request for braking from AEB to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
CC/ACC	Command/Request for braking from CC/ACC to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			

Table G-3. Functional FMEA for H2: Insufficient Vehicle Propulsion (Malfunction: Commands Less Torque than Requested)

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Commands smaller amount of fuel than required by the requested torque by the driver	ECM fault:	Three levels monitoring		ECM Fault
		Hardware fault (Sensors, ICs, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in ECM I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
ECM	Commands smaller amount of fuel than required by the requested torque by the driver	Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three Levels Monitoring		System Fault
		Supply power out of range		Supply power value	Loss of Power

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	ECM Fault
		Contamination/ Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/ Maintenance			
	Misinterprets the APP	Hardware or Software Fault (covered above)			
	APP Rate Limiting Fault (Over-Limiting)	Hardware or Software Fault (covered above)			
	Commands Incorrect Fuel amount	Hardware or Software Fault (covered above)			
	BTO Control Fault	BTO algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic checks	
ECM	BTO Control Fault	BPPS Fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	Fuel Delivery Map Corrupted	Hardware fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Miscommunicates with internal subsystems	From: APPS	Critical messages/ data transfer qualification		Communication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	To: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	From: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Miscommunicates with external systems	From: BPPS	Critical messages/ data transfer qualification		Communication Fault
		From: Vehicle Speed Sensor	Critical messages/ data transfer qualification		Communication Fault
ECM	Miscommunicates with external systems	From: Engine RPM Sensor	Critical messages/ data transfer qualification		Communication Fault
		From: AEB	Critical messages/ data transfer qualification		Communication Fault
		From: CC/ACC	Critical messages/ data transfer qualification		Communication Fault

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		From: Atmospheric Pressure Sensor	Critical messages/ data transfer qualification		Communication Fault
		To: Recirculation Exhaust Air Valve			
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (FTA)			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Injector fault			ETC fault
		Fuel rail pressure sensor (FRPS) fault		Hardware diagnostics	
		Fuel Pressure Control Valve (FPCV) fault			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Break in fuel delivery subsystem internal/external connections	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Short in fuel delivery subsystem internal/external connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/Corrosion			
		NVH fault			

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/Maintenance			
Fuel delivery subsystem	Misinterprets the signal from the ECM	Fuel injector, FPS, or FPCV faults (covered above)			
	Mechanical failure prevents throttle movement to correct position	Out of Scope			
BPP Sensor	Provides incorrect input to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Brake System Fault
	Other Failure Modes	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…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in APP sensor I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in APP sensor I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Short in APP sensor I/Os connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
APP Sensor	APP value interpreted lower than actual	Power connector connection failure		Hardware diagnostics	
		APP calculation algorithm fault		Software diagnostics	
		Software 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		Hardware/ Software Diagnostics	System Fault
		Contamination/Corrosion			
		NVH fault			
		Environmental temperature exposure failure			
		Aging (durability)			
		Manufacturing defect			
		Manufacturing variability			
		Service/ Maintenance			
	APP Communicates with ECM Incorrectly	Hardware or Software 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/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Other Failure Modes	Out of Scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			
Atmospheric Pressure Sensor	Provides incorrect pressure (elevation) value to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Communication Faults			
	Other Failure Modes	Out of Scope			
Air Charging System	Delivers less air than required	Air charging system failure			System Fault
Exhaust Air Recirculation Valve	Command from ECM failure	Command fault by the ECM (covered above)			
	Other Failure Modes	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 Failure Modes	Out of Scope			
AEB	Command/Request for braking from AEB to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other Failure Modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Propulsion)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
CC/ACC	Provides request for in-correct (less) propulsion torque	Communication Fault to ECM	Critical messages/ data transfer qualifica-tion		Commu-nication Fault
	Command/Request for braking from CC/ACC to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualifica-tion		Commu-nication Fault
	Other Failure Modes	Out of Scope			

Table G-4. Functional FMEA for H3: Propulsion Power Reduction/Loss or Vehicle Stalling (Malfunction: Commands Less Torque than Requested)

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Commands smaller amount of fuel than re-quired by the requested torque by the driver	ECM fault:	Three levels monitoring		ECM Fault
		Hardware fault (Sensors, ICs, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in ECM I/Os connections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault
		Short in ECM I/Os connections to another connection		Stuck Open/Short	
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algo-rithm fault	Three Levels Monitoring	Software diagnostics	System Fault
ECM	Commands smaller amount of fuel than required by the requested torque by the driver	Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three Levels Monitoring		System Fault
		Supply power out of range		Supply power value	Loss of Power

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	ECM Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the APP	Hardware or Software Fault (covered above)			
	Commands Incorrect Fuel amount	Hardware or Software Fault (covered above)			
	Incorrectly Establishes Idle Position	Hardware or Software fault (covered above)			
		Atmospheric Pressure Sensor fault			
ECM	BTO Control Fault	BTO algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic checks	
		BPPS Fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	Fuel Delivery Map Corrupted	Hardware fault (covered above)			

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Corrupted param-eters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal subsystems	From: APPS	Critical messages/ data transfer qualification		Commu-nication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	To: Fuel delivery subsystem	Critical messages/ data transfer qualification		Commu-nication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	From: Fuel deliv-ery subsystem	Critical messages/ data transfer qualification		Commu-nication Fault
	Miscommunicates with external systems	From: BPPS	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Vehicle Speed Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Engine RPM Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
ECM	Miscommunicates with external systems	From: AEB	Critical messages/ data transfer qualification		Commu-nication Fault
		From: CC/ACC	Critical messages/ data transfer qualification		Commu-nication Fault
		From: Atmos-pheric Pressure Sensor	Critical messages/ data transfer qualification		Commu-nication Fault
		To: Recirculation Exhaust Air Valve			

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (Fault Tree Analysis)			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Injector fault			ETC fault
		Fuel rail pressure sensor (FRPS) fault		Hardware diagnostics	
		Fuel Pressure Control Valve (FPCV) fault			
		Break in fuel delivery subsys-tem internal/ external connections	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
		Short in fuel delivery subsys-tem internal/ external connections to Ground or Volt-age	Critical messages/ data transfer qualification	Stuck Open/Short	System Fault
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Fails to Maintain Throttle Idle Position	Fuel injector, FPS, or FPCV faults (covered above)			
	Misinterprets the signal from the ECM	Fuel injector, FPS, or FPCV faults (covered above)			
	Mechanical failure pre-vents throttle movement to correct position	Out of Scope			
BPP Sensor	Provides incorrect input to ECM	Communication Fault to ECM	Critical mes-sages/data transfer qualification		Brake System Fault
	Other failure modes	Out of Scope			
APP Sensor	APP value interpreted lower than actual	Sensor fault:	Fault tolerant redundancy	Sensor diag-nostics	APP Sen-sor Fault
		Hardware fault (Sensors, ICs, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in APP sensor I/Os con-nections	Critical messages/ data transfer qualification	Stuck Open/Short	I/O Fault

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Short in APP sensor I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification		I/O Fault
		Short in APP sensor I/Os connections to another connection			
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		APP calculation algorithm fault		Software diagnostics	
		Software parameters corrupted		Periodic checks	
		Supply power out of range		Supply power value	Loss of Power
APP Sensor	APP value interpreted lower than actual	Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	System Fault
		Contamination/Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	AP Is Not Returned to Idle Position Correctly	AP-mechanical Failure-Out of Scope			
	APP Communicates with ECM Incorrectly	Hardware or Software 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 failure modes	Out of Scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
Atmospheric Pressure Sensor	Provides incorrect pressure (elevation) value to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Communication Faults			
	Other failure modes	Out of Scope			
Air Charging System	Delivers less air than required	Air charging system failure			System Fault
Exhaust Air Recirculation Valve	Command from ECM failure	Command fault by the ECM (covered above)			
	Other failure modes	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 failure modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Propulsion Power Reduction/Loss or Vehicle Stalling)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
AEB	Command/Request for braking from AEB to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Commu-nication Fault
	Other failure modes	Out of Scope			
CC/ACC	Provides request for incorrect (less) propulsion torque	Communication Fault to ECM	Critical messages/ data transfer qualification		Commu-nication Fault
	Command/Request for braking from CC/ACC to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Commu-nication Fault
	Other failure modes	Out of Scope			

Table G-5. Functional FMEA for H4: Insufficient Vehicle Deceleration (Malfunction: Commands Less Torque than Requested)

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Commands larger amount of fuel than re-quired by the requested torque by the driver	ECM fault:	Three levels monitoring		ECM Fault
		Hardware fault (Sensors, ICs, Circuit Components, Circuit Boards…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in ECM I/Os connections	Critical mes-sages/data transfer qualification	Stuck Open/ Short	I/O Fault
		Short in ECM I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/Shor t	I/O Fault
		Short in ECM I/Os connections to an-other connection		Stuck Open/ Short	

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Torque command calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Fuel amount calculation algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
ECM	Commands larger amount of fuel than required by the requested torque by the driver	Software parameters corrupted		Periodic Checks	
		Arbitration logic fault	Three Levels Monitoring		System Fault
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnostics	ECM Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Misinterprets the APP	Hardware or Software Fault (covered above)			

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
	APP Rate Limiting Fault (Over-Limiting)	Hardware or Software Fault (covered above)			
	Commands Incorrect Fuel amount	Hardware or Software Fault (covered above)			
	Incorrectly Establishes Idle Position	Hardware or Software fault (covered above)			
		Atmospheric Pressure Sensor fault			
ECM	BTO Control Fault	BTO algorithm fault	Three Levels Monitoring	Software diagnostics	System Fault
		Software parameters corrupted		Periodic checks	
		BPPS Fault			
		Vehicle speed sensor fault			
		Engine RPM speed sensor fault			
	Fuel Delivery Map Corrupted	Hardware fault (covered above)			
		Corrupted parameters (vehicle and/or environment)		Periodic checks	
	Miscommunicates with internal sub-systems	From: APPS	Critical messages/ data transfer qualification		Communication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	To: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Incorrect signals (this may be CAN like communication or PWM or else)	From: Fuel delivery subsystem	Critical messages/ data transfer qualification		Communication Fault
	Miscommunicates with external systems	From: BPPS	Critical messages/ data transfer qualification		Communication Fault

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
ECM	Miscommunicates with external systems	From: Vehicle Speed Sensor	Critical messages/ data transfer qualification		Communi-cation Fault
		From: Engine RPM Sensor	Critical messages/ data transfer qualification		Communi-cation Fault
		From: AEB	Critical messages/ data transfer qualification		Communi-cation Fault
		From: CC/ACC	Critical messages/ data transfer qualification		Communi-cation Fault
		From: Atmospheric Pressure Sensor	Critical messages/ data transfer qualification		Communi-cation Fault
		To: Recirculation Exhaust Air Valve			
	Diagnostics fault	Considered only in mitigation of multiple point failure analysis (Fault Tree Analysis)			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Injector fault			ETC fault
		Fuel rail pressure sensor (FRPS) fault		Hardware diagnostics	
		Fuel Pressure Con-trol Valve (FPCV) fault			
Fuel delivery subsystem	Delivers more fuel than commanded by the ECM	Break in fuel de-livery subsystem internal/external connections	Critical messages/ data transfer qualification	Stuck Open/ Short	System Fault
		Short in fuel deliv-ery subsystem in-ternal/external connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/ Short	System Fault

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		Signal connector connection failure		Hardware diagnostics	
		Power connector connection failure		Hardware diagnostics	
		Supply power out of range		Supply power value	Loss of Power
		Supply power quality failure		Supply power quality	Loss of Power
		EMC/EMI fault		Hardware/ Software Diagnos-tics	System Fault
		Contamination/ Corrosion	Out of scope for Functional Safety Concept		
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/ Maintenance	Out of scope for Functional Safety Concept		
	Fails to Maintain Throttle Idle Position	Fuel injector, FPS, or FPCV faults (covered above)			
Fuel delivery subsystem	Misinterprets the signal from the ECM	Fuel injector, FPS, or FPCV faults (covered above)			
	Mechanical failure pre-vents throttle movement to correct position	Out of Scope			
BPP Sensor	Provides incorrect input to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Brake System Fault
	Other failure modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
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…)		Hardware diagnostics	
		Internal connection fault (short or open)		Hardware diagnostics	
		Break in APP sensor I/Os connections	Critical messages/ data transfer qualification	Stuck Open/ Short	I/O Fault
		Short in APP sensor I/Os connections to Ground or Voltage	Critical messages/ data transfer qualification	Stuck Open/ Short	I/O Fault
		Short in APP sensor I/Os connections to another connection		Stuck Open/ Short	
		Signal connector connection failure		Hardware diagnostics	
APP Sensor	APP value interpreted lower than actual	Power connector connection failure		Hardware diagnostics	
		APP calculation algorithm fault		Software diagnostics	
		Software 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		Hardware/ Software Diagnostics	System Fault
		Contamination/Corrosion	Out of scope for Functional Safety Concept		

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
		NVH fault	Out of scope for Functional Safety Concept		
		Environmental temperature exposure failure	Out of scope for Functional Safety Concept		
		Aging (durability)	Out of scope for Functional Safety Concept		
		Manufacturing defect	Out of scope for Functional Safety Concept		
		Manufacturing variability	Out of scope for Functional Safety Concept		
		Service/Maintenance	Out of scope for Functional Safety Concept		
	AP Is Not Returned to Idle Position Correctly	AP-mechanical Failure-Out of Scope			
	APP Communicates with ECM Incorrectly	Hardware or Software 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 failure modes	Out of Scope			
Engine RPM Sensor	Provides incorrect engine speed to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
Atmospheric Pressure Sensor	Provides incorrect pressure (elevation) value to ECM	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
Vehicle Communication System (CAN Bus)	Communication messages corrupted during transfer within the ASC/ETC, and from and to the ACS/ETC and interfacing vehicle modules	Communication Faults			
	Other failure modes	Out of Scope			

System/ Subsystem	Potential Failure Mode (Insufficient Vehicle Deceleration)	Potential Cause/ Mechanism of Failure	Current Process Controls		
			Safety Mechanism	Diagnostics	Diagnostic Trouble Code
Air Charging System	None (only potential issue is with this system is reduced/loss of air intake; this does not affect this failure hazard)				System Fault
Exhaust Air Recirculation Valve	Command from ECM failure	Command fault by the ECM (covered above)			
	Other failure modes	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 failure modes	Out of Scope			
AEB	Command/Request for braking from AEB to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			
CC/ACC	Provides request for incorrect (more) propulsion torque	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Command/Request for braking from CC/ACC to ECM failure	Communication Fault to ECM	Critical messages/ data transfer qualification		Communication Fault
	Other failure modes	Out of Scope			

Appendix H: STPA Step 2: Causal Factors

Table H-1: Accelerator Pedal Mechanical Assembly

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly)
325	Actuator inadequate operation, change over time	Internal hardware failure	Failure of the accelerator pedal assembly hardware could affect the motion of the accelerator pedal (e.g., pedal comes loose from its housing, return spring failure). Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the accelerator pedal, - a delay in movement of the accelerator pedal, or - becoming stuck in a position.
326	Actuator inadequate operation, change over time	Degradation over time	The accelerator pedal assembly hardware may degrade over time (e.g., increased friction), affecting the accelerator pedal movement or position. Possible effects of this actuator failure may include: - loss of function, - incorrect or intermittent movement of the accelerator pedal, - unintended movement of the accelerator pedal, - a delay in movement of the accelerator pedal (e.g., slow return), or - becoming stuck in a position.
614	Actuator inadequate operation, change over time	Incorrectly sized actuator	Incorrectly sized return springs in the accelerator pedal assembly could affect the motion of the accelerator pedal (e.g., slow return). Possible effects of this actuator failure may include: - incorrect movement of the accelerator pedal (e.g., pedal returns at wrong rate), or - becoming stuck in a position (e.g., pedal does not return).
327	External disturbances	Physical interference (e.g., chafing)	Foreign objects in the driver's footwell could affect the accelerator pedal movement or position. Possible effects of this failure may include: - loss of function, - incorrect or intermittent movement of the accelerator pedal, - unintended movement of the accelerator pedal, or - becoming stuck in a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly)
328	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or improper assembly could affect the motion of the accelerator pedal. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittently movement of the accelerator pedal, - a delay in movement of the accelerator pedal, or - becoming stuck in a position.
352	External disturbances	Vibration or shock impact	Vibration or shock impact may cause the accelerator pedal assembly hardware to move without action by the driver (e.g., vibration of the pedal) or to become damaged. Possible effects of this failure include: - unintended movement of the accelerator pedal. 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 ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
615	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 friction). Possible effects of this actuator failure include: - incorrect or intermittent movement of the accelerator pedal, - a delay in movement of the accelerator pedal, or - becoming stuck in a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly)
896	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). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittently movement of the accelerator pedal, or - becoming stuck in a position.
329	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Other vehicle components may interfere with the accelerator pedal (e.g., floor mats), affecting the accelerator pedal movement or position. Possible effects of this failure may include: - loss of function, - incorrect or intermittent movement of the accelerator pedal, - unintended movement of the accelerator pedal, or - becoming stuck in a position.
616	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 friction). Possible effects of this actuator failure include: - incorrect or intermittent movement of the accelerator pedal, - a delay in movement of the accelerator pedal, or - becoming stuck in a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly)
897	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 without action by the driver (e.g., vibration of the pedal) or to become damaged. Possible effects of this failure include: - unintended movement of the accelerator pedal. 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 ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Table H-2: Accelerator Pedal Position Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
333	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) may affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
334	External disturbances	EMI or ESD	EMI or ESD from the external environment may affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
335	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the accelerator pedal position sensor measurement (e.g., the wiper arm makes intermittent contact in a potentiometer sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
367	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature (e.g., heat or cold) or thermal cycling may cause the accelerator pedal position sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value. In regard to mode switching: If this results in an intermittent signal to the ECM, this may cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
612	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the function of the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measurement or reporting of the accelerator pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
			- becoming stuck at a value (e.g., the accelerator pedal position measurement does not update).
655	External disturbances	Organic growth	Organisms may grow in the accelerator pedal position sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
656	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the accelerator pedal position sensor measurement (e.g., if it is a hall effect sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
904	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
337	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components may affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
338	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 accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
			- incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
354	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle components (e.g., deformation of the sensor due to inadequate clearance) may affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value. In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
657	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive temperatures from other vehicle components may affect the accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
			In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
658	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the accelerator pedal position sensor measurement (e.g., if it is a hall effect sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
659	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 accelerator pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
336	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The accelerator pedal position sensor may lose 12V power. Possible effects of this sensor failure may include: - loss of function, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
353	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12V power supply could affect the accelerator pedal position sensor. Possible effects of this failure include: - intermittent measuring or reporting of the accelerator pedal position. In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
			mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
420	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A decrease in the reference voltage to the accelerator pedal position sensor may cause the ECM to think that the accelerator pedal angular position is decreasing or is less than the actual pedal position.
428	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage to the accelerator pedal position sensor may cause the ECM to think that the accelerator pedal angular position is increasing or is greater than the actual pedal position.
168	Sensor inadequate operation, change over time	Reporting frequency too low	The accelerator pedal position sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the accelerator pedal position, or - a delay in reporting the accelerator pedal position.
330	Sensor inadequate operation, change over time	Internal hardware failure	The accelerator pedal position sensor could have a hardware failure (e.g., open circuit, stuck wiper). Possible effects of this sensor failure may include: - loss of function - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the APPS becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor)
331	Sensor inadequate operation, change over time	Degradation over time	The accelerator pedal position sensor may degrade over time (e.g., tin whiskers, change in measurement properties). Possible effects of this sensor failure may include: - loss of function - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
332	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) may cause the accelerator pedal position sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Table H-3: Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
23	Controller hardware faulty, change over time	Internal hardware failure	The ECM may be affected by a faulty electronic subcomponent or electrical connection within the ECM (e.g., a transistor is not switched off or soldering breaks).
25	Controller hardware faulty, change over time	Degradation over time	Internal subcomponents in the ECM may degrade over time, affecting the function of the ECM.
27	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	A fault during conditioning or converting a signal from a system sensor (e.g., analogue-to-digital converter, signal filters) could cause the ECM not to receive the sensor measurement, receive an incorrect or intermittent sensor measurement, or not update the sensor measurement (i.e., stuck at value).
28	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The memory block storing the current rail pressure may have a fault, or an error may occur when storing or retrieving data from memory.
143	Controller hardware faulty, change over time	Faulty memory storage or retrieval	If the brake pedal position is written to memory, the memory block in the ECM storing the brake pedal position may have a fault, or an error may occur when storing or retrieving data from memory.
144	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) may cause the ECM to overheat, affecting its function.
162	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The memory block in the ECM storing the operating mode may have a fault, or an error may occur when storing or retrieving data from memory. This could prevent the ECM from switching operating modes or may cause the ECM to incorrectly switch operating modes.
165	Controller hardware faulty, change over time	Faulty internal timing clock	If the ECM uses internal timing for determining when to issue a control action (e.g., engage BTO), faulty electronic subcomponents in the timing module could cause the control action to be issued too soon or too late.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
304	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The memory block storing the vehicle speed may have a fault, or an error may occur when storing or retrieving data from memory. This could cause the ECM to have the incorrect vehicle speed.
385	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The memory block in the ECM storing the fuel injection profile (i.e., number of injections, duration of injections, and injection timing) may have a fault, or an error may occur when storing or retrieving data from memory.
403	Controller hardware faulty, change over time	Faulty memory storage or retrieval	The memory block in the ECM storing the idle state values (e.g., fuel rail pressure, injection profile) may have a fault, or an error may occur when storing or retrieving data from memory.
617	Controller hardware faulty, change over time	Over temperature due to faulty cooling system	A hardware failure in the cooling system (e.g., damage to cooling fins) could cause the ECM to overheat, affecting its function.
916	Controller hardware faulty, change over time	Unused circuits in the controller	Unused circuits in the controller could affect the ECM (e.g., a signal may short onto an unused circuit pathway).
164	External control input or information wrong or missing	Timing related input is incorrect or missing	If the ECM requires a timing signal from an external source (e.g., a central timing module), this signal may be incorrect or missing.
376	External control input or information wrong or missing	Spurious input due to shorting or other electrical fault	The ECM may receive a signal that mimics a torque request from another vehicle system when no such request was made (e.g., a communication bus error, or a short in a wired connection to the ECM).
416	External control input or information wrong or missing	Corrupted input signal	A torque request from another vehicle system may not reach the ECM or may be corrupted before reaching the ECM (e.g., electrical noise, chafed wiring, contamination or corrosion, etc.).
620	External control input or information wrong or missing	Malicious Intruder	A malicious intruder may send a signal to the ECM that mimics a torque request from another vehicle system when no such request was made.
14	External disturbances	Moisture, corrosion, or contamination	Moisture, contamination, or corrosion from the external environment (e.g., moisture, salt corrosion) could affect the ECM, causing internal

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
			short or open circuits, or other failures of the control module.
15	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the ECM.
16	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the function of the ECM.
18	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature (e.g., heat) or thermal cycling may damage the ECM or cause the ECM to overheat, affecting its function.
138	External disturbances	Vibration or shock impact	Vibration or shock impact may affect the ECM, causing damage to internal subcomponents (e.g., soldering breaks).
621	External disturbances	Single event effects (e.g., cosmic rays, protons)	A Single Event Effect (SEE) caused by high-energy particles could affect the ECM (e.g., cause temporary faults in software logic or memory corruption).
622	External disturbances	Organic growth	Organisms may grow in the ECM (e.g., fungi), resulting in internal shorting or damage of electrical subcomponents.
909	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could affect the ECM, causing damage to electrical subcomponents or other failures of the control module.
20	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the ECM.
21	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 ECM, causing internal short or open circuits, or other failures of the control module.
22	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 ECM (e.g., damaging internal subcomponents).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
623	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 ECM (e.g., damaging internal subcomponents).
624	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 ECM (e.g., damaging internal subcomponents).
19	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A fluctuation or spike in the 12V power supply may damage the ECM, cause the ECM to erase information stored in volatile memory (e.g., sensor data or operating mode), cause the ECM to delay issuing a control action (e.g., switching operating modes), or cause the ECM to incorrectly issue a control action (e.g., incorrectly switching a transistor).
230	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the ECM loses 12V power, it will be unable to issue a required control action.
31	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The process model for adjusting the rail pressure may consider factors other than the ECM's desired operating point.
33	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The fuel rail pressure sensor calibration in the ECM may be incorrect. This could cause the ECM to misinterpret the fuel rail pressure measurement.
65	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The fuel rail pressure control valve calibration in the ECM may be incorrect. This could cause the fuel rail pressure to decrease at a different rate than expected by the ECM.
146	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The brake pedal position sensor calibration in the ECM may be incorrect. This could cause the ECM to misinterpret the travel distance of the brake pedal, or have the wrong pedal state (i.e., pressed instead of not pressed).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
167	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM process model may have an incorrect value for the BTO activation delay (e.g., 0.05 seconds instead of 0.5 seconds or vice versa).
235	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM process model may consider variables beyond the accelerator pedal position, brake pedal position, and the vehicle speed when determining whether to switch operating modes. This may make the conditions for entering BTO mode too stringent.
236	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM process model may have an incorrect value for determining the pedal application sequence.
237	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The engine RPM sensor calibration in the ECM may be incorrect. This could cause the ECM to misinterpret the engine speed information (e.g., the ECM may think the engine is already at the idle speed).
306	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the ECM process model does not consider vehicle speed or considers a vehicle speed below 10 mph, the ECM may switch into BTO mode when the driver presses both pedals and the vehicle speed is below 10 mph.
345	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM process model may consider variables beyond the accelerator pedal position and brake pedal position when determining whether to switch operating modes. This may make the conditions for entering Normal mode too stringent.
346	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The accelerator pedal position sensor calibration in the ECM may be incorrect. This could cause the ECM to have the wrong pedal position information.
360	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	If the ECM process model considers other conditions for exiting BTO mode instead of the brake and accelerator pedal positions (e.g., drive power or engine speed), then the ECM may enter Normal mode while a pedal conflict still exists.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
387	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The exhaust gas oxygen (EGO) sensor calibration in the ECM may be incorrect. If the ECM has incorrect exhaust quality data, the ECM may adjust the injected fuel quantity when an adjustment is not needed.
425	Process model or calibration incomplete or incorrect	Other	The ECM may learn an incorrect idle throttle position due to faulty inputs to the controller (e.g., the accelerator pedal position sensor shaft may have resonance with vibrations, causing the ECM to falsely recalibrate the idle position of the accelerator pedal).
470	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM process model may not account for oil or other combustible fluids that are entering the engine via pathways other than the fuel injectors (e.g., engine oil leak, oil in the air intake). This would cause more fuel to combust in the cylinder than commanded by the ECM.
471	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The fuel injector calibration in the ECM may be incorrect or the ECM may incorrectly learn an injector's injected fuel quantity (e.g., faulty smooth running control algorithm). This could cause the ECM to request the incorrect duration or amount of opening for an injector.
587	Process model or calibration incomplete or incorrect	Other	The ECM may have an improperly calibrated torque limiting function. (The torque limiting function reduces the injected fuel quantity to prevent the engine torque from exceeding mechanical limits of the engine.)
589	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The boost pressure sensor calibration in the ECM may be incorrect. This could cause the ECM to have the wrong air pressure information.
593	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The camshaft position sensor calibration in the ECM may be incorrect. If the ECM has the wrong camshaft position measurement, the injection timing may be incorrect.
613	Process model or calibration incomplete or incorrect	Other	The ECM may have an improperly calibrated smoke limiting function. The smoke limiting function prevents the engine from running rich during heavy acceleration by

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
			restricting the injected fuel quantity until the air intake increases.
619	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The intake air temperature sensor in the ECM may be incorrect or the ECM may incorrect. This could cause the ECM to have the wrong air temperature information.
918	Process model or calibration incomplete or incorrect	Model of the controlled process, including degradation characteristics	The ECM may have an incorrect model of the engine (e.g., air intake, fuel mixing in cylinders, etc.).
949	Process model or calibration incomplete or incorrect	Sensor or actuator calibration, including degradation characteristics	The fuel temperature sensor calibration in the ECM may be incorrect. This could cause the ECM to have the wrong fuel temperature information.
29	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to decrease the mean rail pressure for the wrong duration or by the wrong quantity (e.g., wrong parameter value).
30	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The control algorithm for adjusting the mean rail pressure may have an incorrect model of the fuel rail (e.g., different volume). This could cause the ECM to incorrectly adjust the rail pressure (e.g., adjusting the rail pressure by the wrong quantity or for the wrong duration).
32	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The control algorithm for adjusting the mean rail pressure does not properly consider the high-frequency rail pressure fluctuations from injection events. The ECM may adjust the mean rail pressure or injected fuel quantity in response to the high-frequency pressure fluctuations.
62	Software error (inadequate	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to decrease the mean fuel rail

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	control algorithm, flaws in creation, modification, or adaptation)		pressure when the rail pressure is already at or below the target rail pressure.
63	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to adjust the rail pressure in the wrong direction (e.g., decrease instead of increase).
145	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to switch into BTO mode when the brake pedal is not pressed.
163	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 ECM mode (e.g., writing to memory) after the ECM issues the command to switch operating modes.
166	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The timing delay before activating BTO is not considered or is incorrectly considered in the software logic for entering BTO mode.
231	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the ECM from switching into BTO mode when the driver presses both pedals and the vehicle speed is over 10 mph.
232	Software error (inadequate	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.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	control algorithm, flaws in creation, modification, or adaptation)		
233	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The ECM software algorithm does not check for consistency between the engine speed, vehicle speed, and injected fuel quantity.
277	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If the ECM does not receive updated sensor data (e.g., engine speed), it may continue to operate using the last available data, which may be outdated.
305	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to switch into BTO mode when the driver presses both pedals, but the vehicle speed is below 10 mph.
344	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the ECM from switching into Normal mode when the driver presses the accelerator pedal and releases the brake pedal.
357	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to switch into Normal mode while both the accelerator pedal and brake pedal are pressed.
358	Software error (inadequate	Inadequate control algorithm	The software algorithm allows the ECM to exit BTO mode when one pedal drops below an angular position threshold (e.g., below 25%), and

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	control algorithm, flaws in creation, modification, or adaptation)		does not require BTO mode to persist until the pedal conflict is removed (i.e., one pedal is released).
359	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 ECM to exit BTO mode while a pedal conflict still exists.
363	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The software algorithm may incorrectly incorporate a delay before exiting BTO mode.
364	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to increase the mean rail pressure for the wrong duration or by the wrong quantity (e.g., wrong parameter value).
366	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the ECM from increasing the mean fuel rail pressure when the actual rail pressure is below the target rail pressure.
368	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to decrease the injected fuel quantity when the driver increases the angular position of the accelerator pedal and the ECM is in normal mode (e.g., a flaw in the active surge damping algorithm).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
369	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The ECM may generate an incorrect injection profile (i.e., number of injections, duration of injections, or injection timing) for the commanded torque.
370	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The ECM software algorithm gives precedence to another vehicle system's request to adjust the injected fuel quantity (e.g., increase injected fuel quantity), rather than the driver's request via the accelerator pedal.
371	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to incorrectly reconcile the magnitude of multiple torque requests in opposite directions, causing the ECM not to issue a control action (i.e., inaction), to delay issuing a control action, or to issue an unsafe control action (e.g., increasing instead of decreasing the injected fuel quantity).
372	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm causes the ECM to incorrectly translate the torque requests from other vehicle systems to an injected fuel quantity command (e.g., deliver too much or too little fuel).
373	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic may cause the ECM to incorrectly calculate the engine load. If the ECM thinks the engine load decreased, the ECM may decrease the injected fuel quantity or may not increase the injected fuel quantity enough. If the ECM thinks the engine load increased, the ECM may increase the injected fuel quantity or may not decrease the injected fuel quantity enough.
374	Software error (inadequate control algorithm, flaws in	Inadequate control algorithm	A programming error or faulty software logic may cause the ECM to incorrectly enter a "limp-home" mode when other vehicle systems request a change in engine torque or when the driver changes the angular position of the accelerator

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	creation, modification, or adaptation)		pedal (e.g., if the pedal position sensor reading exceeds the calibration range).
386	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 ECM tries to reconcile the magnitude of multiple torque requests.
404	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic allows the ECM to execute another vehicle system's request to decrease or increase the engine torque when the ECM is in BTO mode or transitioning into BTO mode (e.g., a torque reduction request for traction control).
405	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	The ECM may incorrectly calculate the injected fuel quantity required to maintain the engine idle speed. The ECM might request the wrong quantity of fuel while at idle, or may allow the injected fuel quantity to drop below the idle fuel rate.
406	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 ECM decreases the injected fuel quantity when transitioning into BTO mode.
409	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic prevents the ECM from decreasing the injected fuel quantity when the driver reduces the angular position of the accelerator pedal and the ECM is in normal mode.
413	Software error (inadequate control algorithm, flaws in	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to incorrectly reconcile the magnitude of multiple torque requests in the same direction (e.g., it may add the magnitude of torque reductions).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	creation, modification, or adaptation)		
414	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to give precedence to the driver's input via the accelerator pedal instead of torque requests from other vehicle systems. This causal factor applies if the torque request comes from a vehicle system that should take precedence over the driver's input via the accelerator pedal.
415	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to not recognize that a torque reduction request is from an active safety system.
417	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic allows the ECM to decrease the injected fuel quantity when the driver reduces the angular position of the accelerator pedal when in BTO mode (e.g., the injected fuel quantity was already reduced to the idle rate upon entering BTO mode).
418	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic causes the ECM to decrease the injected fuel quantity when transitioning into normal mode (i.e., instead of increasing the injected fuel quantity).
422	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm affects how much the ECM decreases the injected fuel quantity when the driver reduces the angular position of the accelerator pedal and the ECM is in normal mode.
476	Software error (inadequate	Inadequate control algorithm	An error may occur when the ECM converts the fuel injection strategy (i.e., number of injections, duration of injections, and injection timing) to a

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	control algorithm, flaws in creation, modification, or adaptation)		pulse width modulated signal for the fuel injector.
586	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic introduces a delay when decreasing the injected fuel quantity as the ECM transitions into BTO mode.
588	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm affects how much the ECM increases the injected fuel quantity when the driver increases the angular position of the accelerator pedal and the ECM is in normal mode or is transitioning into normal mode.
595	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm causes the ECM to increase the injected fuel quantity when the driver reduces the angular position of the accelerator pedal and the ECM is in normal mode or is transitioning from BTO into normal mode (e.g., faulty surge damping control).
596	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A faulty control algorithm allows the ECM to increase the injected fuel quantity when the ECM is in BTO mode or is transitioning from normal to BTO mode (e.g., BTO does not properly override the driver's torque request).
597	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	A programming error or faulty software logic may cause the ECM to incorrectly enter a "limp-home" mode when transitioning from BTO mode to normal mode or when transitioning from normal mode into BTO mode.
598	Software error (inadequate	Inadequate control algorithm	A programming error or faulty software logic causes a delay when the ECM commands a change in the mean fuel rail pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module)
	control algorithm, flaws in creation, modification, or adaptation)		
618	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Flaws in software code creation	An error in the ECM software code may be introduced when the code is created (e.g., a flaw in automatic code generation).
919	Software error (inadequate control algorithm, flaws in creation, modification, or adaptation)	Inadequate control algorithm	If one or more cylinders have been shut off (e.g., for torque control or fuel efficiency), the algorithm for adjusting the injected fuel quantity may not account for the cylinders that have been shut off.

Table H-4: Fuel Injectors

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Injector)
472	Actuator inadequate operation, change over time	Internal hardware failure	A hardware failure could affect the fuel injector's function (e.g., failure of the spring that holds the nozzle closed). Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
473	Actuator inadequate operation, change over time	Degradation over time	The fuel injector may degrade over time (e.g., worn nozzle opening). Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
475	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
477	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, dirt) could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Injector)
			- incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
478	External disturbances	Vibration or shock impact	Vibration or shock impact may cause the fuel injector to become misaligned with the cylinder. Possible effects of this failure include: - incorrect amount of fuel delivered by the injector.
479	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
480	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperatures or thermal cycling could affect the fuel injector (e.g., seals leaking). Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect amount of fuel delivered by the injector, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
481	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Injector)
482	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference from other vehicle systems could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
483	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 fuel injector (e.g., causing a short circuit). Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
592	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components may affect the fuel injector. Possible effects of this actuator failure include: - loss of function (e.g., the injector doesn't open when commanded), - a delay in opening or closing the fuel injector, or - stuck at a position (e.g., the injector is stuck).
697	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle systems could affect the fuel injector. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in injection, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Injector)
698	Actuator inadequate operation, change over time	Relay failure modes, including: 1) does not energize, 2) does not de-energize, and 3) welded contacts	The fuel injector may not energize or de-energize when commanded by the ECM. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, or - becoming stuck at a position (e.g., the injector nozzle becomes stuck).
699	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	The power supply to the fuel injector may be too low. Possible effects of this failure include: - loss of function (e.g., the injector doesn't open when commanded), or - a delay in injection.
700	External disturbances	Magnetic interference	Magnetic interference from the external environment may affect the fuel injector. Possible effects of this actuator failure include: - loss of function (e.g., the injector doesn't open when commanded), - a delay in opening or closing the fuel injector, or - stuck at a position (e.g., the injector is stuck).
701	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components causes the fuel injector to become misaligned with the cylinder. Possible effects of this failure include: - incorrect amount of fuel delivered by the injector.
702	External disturbances	Organic growth	Organisms may grow in the fuel injector (e.g., fungi), causing internal shorting, damage to electrical subcomponents, or affecting the nozzle mechanism. Possible effects of this actuator failure include: - loss of function (e.g., the injector doesn't open when commanded), - incorrect duration of the injector opening, - incorrect amount of fuel delivered by the injector, - a delay in opening or closing the fuel injector, or - stuck at a position (e.g., the injector is stuck).

Table: H-5: Fuel Rail

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail)
79	Controlled component failure, change over time	Internal hardware failure	The fuel rail may have a hardware failure (e.g., a leaking seal). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), or - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
730	Controlled component failure, change over time	Degradation over time	The fuel rail may degrade over time (e.g., build-up in the rail). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), or - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
80	External disturbances	Extreme external temperature or thermal cycling	An extreme external temperature or thermal cycling could affect the fuel rail (e.g., causing a seal to leak). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), or - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
81	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., debris buildup in the rail) could affect fuel flow through the rail. Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), or - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
82	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the fuel rail (e.g., exceeding tolerance). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), or - accumulating or dissipating rail pressure at a different rate than expected by the ECM.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail)
910	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the fuel rail (e.g., causing a seal to leak). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
83	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 fuel rail (e.g., causing a seal to leak). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
729	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 fuel rail (e.g., causing a seal to leak). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
731	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 fuel rail (e.g., causing a seal to leak). Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
732	Hazardous interaction with other components in the rest of the vehicle	Unable to meet demands from multiple components (e.g., inadequate torque)	The fuel rail may have insufficient volume to maintain a consistent rail pressure for multiple injection events. Possible effects of this component failure include: - loss of function (i.e., unable to accumulate rail pressure), - accumulating or dissipating rail pressure at a different rate than expected by the ECM.
78	Input to controlled process	Other	The injected fuel quantity from the fuel pump to the fuel rail may be different from the rate ex-

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail)
	missing or wrong		pected by the ECM. Possible effects of this failure include: - supplying the wrong quantity of fuel to the fuel rail.

Table H-6: Fuel Rail Pressure Control Valve

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve)
67	Actuator inadequate operation, change over time	Internal hardware failure	The fuel rail pressure control valve could have an internal hardware failure (e.g., plunger sticks). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
68	Actuator inadequate operation, change over time	Degradation over time	The fuel rail pressure control valve could degrade over time (e.g., wear of a seal). . . Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
704	Actuator inadequate operation, change over time	Relay failure modes, including: 1) does not energize, 2) does not de-energize, and 3) welded contacts	The fuel rail pressure control valve may not energize or de-energize when commanded by the ECM. Possible effects of this actuator failure include: - loss of function, or - becoming stuck at a position.
70	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, dirt) could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve)
			the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
71	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
72	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., improper installation) could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
73	External disturbances	Extreme external temperature or thermal cycling	An extreme external temperature or thermal cycling could affect the fuel rail pressure control valve (e.g., causing deformation of the valve). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve)
74	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the fuel rail pressure control valve (e.g., damage internal subcomponents). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
706	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
709	External disturbances	Organic growth	Organisms may grow in the fuel rail pressure control valve (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
911	External disturbances	Physical interference (e.g., chafing)	Physical interference from the external environment could affect the fuel rail pressure control valve (e.g., causing deformation of the valve). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve)
75	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 fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
76	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
77	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 fuel rail pressure control valve (e.g., causing deformation of the valve). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
703	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 fuel rail pressure control valve (e.g., causing deformation of the valve). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve)
707	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the fuel rail pressure control valve. Possible effects of this actuator failure include: - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
708	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 fuel rail pressure control valve (e.g., damage internal subcomponents). Possible effects of this actuator failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
710	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 fuel rail pressure control valve. Possible effects of this actuator failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
705	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	The power supplied to the fuel rail pressure control valve may be too low. Possible effects of this actuator failure include: - loss of function, or - a delay in adjusting the fuel rail pressure control valve position.

Table H-7: Fuel Rail Pressure Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor)
4	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.
5	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., exceeded tolerance) could affect the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
6	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.
7	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the positioning of the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
8	External disturbances	Extreme external temperature or thermal cycling	Extreme ambient temperature (e.g., heat) or thermal cycling may affect the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor)
629	External disturbances	Organic growth	Organisms may grow in the fuel rail pressure sensor (e.g., fungi), resulting in internal shorting or damage of electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
912	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects could affect the fuel rail pressure sensor (e.g., dislodge the sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.
10	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.
11	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 fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
12	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 fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor)
625	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 fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
630	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 positioning of the fuel rail pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
9	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	If the fuel rail pressure sensor is a piezoresistive sensor, a rise in the reference voltage supplied to the fuel rail pressure sensor may cause the sensor to report too high of a fuel rail pressure.
407	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	If the fuel rail pressure sensor is a piezoresistive sensor, a drop in the reference voltage supplied to the fuel rail pressure sensor may cause the sensor to report too low of a fuel rail pressure.
628	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	The reference voltage supplied to the fuel rail pressure sensor may have a disturbance. Possible effects of this failure include: - loss of function, or - intermittent measurement of the fuel rail pressure.
913	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the fuel rail pressure sensor loses the reference voltage (e.g., because of a loss of 12-volt power), the ECM would not receive a fuel rail pressure measurement.
1	Sensor inadequate operation, change over time	Internal hardware failure	The fuel rail pressure sensor could have an internal hardware failure (e.g., damage to the piezoelectric sensing element). Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor)
2	Sensor inadequate operation, change over time	Degradation over time	The fuel rail pressure sensor could degrade over time (e.g., wear of the diaphragm in contact with the fuel). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value.
3	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The fuel rail pressure sensor could overheat from faulty subcomponents (e.g., internal shorting). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel rail pressure, or - becoming stuck at a value.
388	Sensor inadequate operation, change over time	Reporting frequency too low	The fuel rail pressure sensor reporting frequency may be too low. Possible effects of this failure include: - loss of function, - intermittent reporting of the fuel rail pressure, or - a delay in reporting the fuel rail pressure.

Table H-8: Boost Pressure Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
435	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
436	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., exceeded tolerance) could affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
437	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
			An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
438	External disturbances	Extreme external temperature or thermal cycling	Extreme ambient temperature (e.g., heat or cold) or thermal cycling may affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
644	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment (e.g., vehicle crash) could affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air pressure, or - becoming stuck at a value (e.g., reporting a constant air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
645	External disturbances	Organic growth	Organisms may grow in the boost pressure sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air pressure, or - becoming stuck at a value (e.g., reporting a constant air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
440	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
441	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 boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
			cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
646	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 boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air pressure, or - becoming stuck at a value (e.g., reporting a constant air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
647	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 boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air pressure, or - becoming stuck at a value (e.g., reporting a constant air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
648	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 boost pressure sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air pressure, or - becoming stuck at a value (e.g., reporting a constant air pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
			An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
439	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A decrease in the reference voltage could affect the boost pressure sensor measurement (e.g., if it is a piezoresistive sensor). Possible effects of this sensor failure include: - incorrect measuring of the boost air pressure (e.g., reported air pressure is too low). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
643	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage could affect the boost pressure sensor measurement (e.g., if it is a piezoresistive sensor). Possible effects of this sensor failure include: - incorrect measuring of the boost air pressure (e.g., reported air pressure is too high). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
905	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the boost pressure sensor loses the reference voltage from the ECM, it would not be able to report a measurement. Possible effects of this sensor failure include: - loss of function, or - becoming stuck at a value. An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
432	Sensor inadequate operation, change over time	Internal hardware failure	The boost pressure sensor could have an internal hardware failure (e.g., damage to the piezoelectric sensing element). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
433	Sensor inadequate operation, change over time	Degradation over time	The boost pressure sensor could degrade over time (e.g., wear of the diaphragm or sensing element). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor)
434	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The boost pressure sensor could overheat from faulty subcomponents (e.g., internal shorting). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
442	Sensor inadequate operation, change over time	Reporting frequency too low	The boost pressure sensor reporting frequency may be too low. Possible effects of this sensor failure include - loss of function, - intermittent reporting of the boost air pressure, or - a delay in reporting the boost air pressure. An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Table H-9: Brake/Vehicle Stability Assist Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
199	Controller hardware faulty, change over time	Degradation over time	Degradation of internal subcomponents could affect the Brake / VSA Control Module. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
200	Controller hardware faulty, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) may cause the Brake / VSA Control Module to overheat, affecting its function. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
201	Controller hardware faulty, change over time	Faulty signal conditioning or converting (e.g., analog-to-digital converter, signal filters)	The Brake / VSA Control Module may incorrectly process the individual wheel speed measurements (e.g., faulty analog to digital conversion). Possible effects of this failure include: - loss of function, - incorrect calculation of the vehicle speed, or - becoming stuck at a value (e.g., calculating a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
877	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, affecting its function. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
878	Controller hardware faulty, change over time	Sensor or actuator calibration, including degradation characteristics	The wheel speed sensor calibration in the Brake / VSA control module may be incorrect. Possible effects of this failure include: - loss of function, or - incorrect calculation of the vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
879	Controller hardware faulty, change over time	Faulty memory storage or retrieval	If individual wheel speeds are stored in memory, an error may occur during storage or retrieval of the wheel speed measurement. Possible effects of this failure include: - loss of function, - incorrect calculation or reporting of the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
880	Controller hardware faulty, change over time	Flaws in software code creation	An error in the Brake / VSA control module software code may be introduced when the code is created (e.g., a flaw in automatic code generation). Possible effects of this failure include: - loss of function, - incorrect calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
917	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., shorting of a signal to an unused circuit). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
202	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 (e.g., causing internal short or open circuits, or other failure of the control module). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
203	External disturbances	EMI or ESD	EMI or ESD from the external environment can affect the Brake / VSA Control Module. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
204	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects (e.g., damaged subcomponents) or assembly problems could affect the function of the Brake / VSA Control Module. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
205	External disturbances	Vibration or shock impact	Vibration or shock impact could damage internal subcomponents in the Brake / VSA Control Module (e.g., solder breaks). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
206	External disturbances	Single event effects (e.g., cosmic rays, protons)	A Single Event Effect (SEE) caused by high-energy particles could affect the Brake / VSA control module (e.g., cause temporary faults in software logic or memory corruption). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
884	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could damage the Brake / VSA control module. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
885	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the Brake / VSA control module, causing internal shorting or damage to electrical subcomponents. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
212	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. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
213	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 (e.g., causing internal short circuits). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
214	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Physical interference with other vehicle components may affect the Brake / VSA Control Module (e.g., damaging electronic subcomponents). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
882	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 Brake / VSA Control Module (e.g., damaging electronic subcomponents). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
883	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could damage internal subcomponents in the Brake / VSA Control Module (e.g., solder breaks). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
211	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The Brake / VSA Control Module may lose 12V power. Possible effects of this failure include: - loss of function, - intermittent calculation or reporting of the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
426	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A fluctuation in the 12V power supply may damage the Brake / VSA Control Module or cause the Brake / VSA Control Module to erase information stored in volatile memory (e.g., sensor data). Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
198	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 related to determining the vehicle speed. Possible effects of this failure may include: - loss of function, - incorrect or intermittent calculating or reporting of the vehicle speed,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist (VSA) Control Module)
			- a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant 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 / VSA Control Module computes an average vehicle speed from the wheel speed, and provides the average vehicle speed to the ECM. Other vehicle configurations may use other components to compute the vehicle speed.

Table H-10: Brake Pedal Mechanical Assembly

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Mechanical Assembly)
109	Actuator inadequate operation, change over time	Internal hardware failure	Failure of the brake pedal assembly hardware could affect the motion of the brake pedal (e.g., failure of the return spring). Possible effects of this failure include: - loss of function (e.g., the brake pedal does not move when pressed), - incorrect or intermittent movement of the brake pedal, - a delay in movement of the brake pedal, or - becoming stuck at a position (e.g., the brake pedal does not return when released).
110	Actuator inadequate operation, change over time	Degradation over time	The brake pedal assembly may degrade over time (e.g., increased friction). Possible effects of this actuator failure include: - loss of function (e.g., the brake pedal does not move when pressed), - incorrect or intermittent movement of the brake pedal, - a delay in movement of the brake pedal, or - becoming stuck at a position (e.g., the brake pedal does not return when released).
718	Actuator inadequate operation, change over time	Incorrectly sized actuator	Incorrectly sized return springs in the brake pedal assembly could affect the motion of the brake pedal (e.g., slow return). Possible effects of this actuator failure may include: - a delay in movement of the brake pedal, or - becoming stuck in a position (e.g., pedal does not return).
111	External disturbances	Physical interference (e.g., chafing)	Foreign objects in the driver's footwell could interfere with the brake pedal when the driver tries to change the angular position of the pedal. . . Possible effects of this actuator failure include: - loss of function (e.g., the brake pedal does not move when pressed), - incorrect movement of the brake pedal, or - becoming stuck at a position (e.g., the brake pedal does not return when released).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Mechanical Assembly)
112	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the motion of the brake pedal (e.g., exceeded tolerances, improper mounting). Possible effects of this component failure include: - loss of function (e.g., the brake pedal does not move when pressed), - incorrect or intermittent movement of the brake pedal, - a delay in movement of the brake pedal, or - becoming stuck at a position (e.g., the brake pedal does not return when released).
343	External disturbances	Vibration or shock impact	Vibration may affect the brake pedal assembly. Possible effects of this failure include: - intermittent movement of the brake pedal, or - unintended movement of the brake pedal. The ECM 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).
719	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment could affect the motion of the brake pedal (e.g., increasing friction). Possible effects of this actuator failure may include: - a delay in movement of the brake pedal, or - becoming stuck in a position (e.g., pedal does not return).
113	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 brake pedal. Possible effects of this component failure include: - loss of function (e.g., the brake pedal does not move when pressed), - incorrect movement of the brake pedal, or - becoming stuck at a position (e.g., the brake pedal does not return when released).
720	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 brake pedal (e.g., increasing friction). Possible effects of this actuator failure may include: - a delay in movement of the brake pedal, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Mechanical Assembly)
			- becoming stuck in a position (e.g., pedal does not return).
721	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration from other vehicle components may affect the brake pedal assembly. Possible effects of this failure include: - intermittent movement of the brake pedal, or - unintended movement of the brake pedal. The ECM 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-11: Brake Pedal Position Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
129	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., improper installation) could affect the brake pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
130	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, dirt, and salt corrosion) could affect the brake pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
131	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the brake pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
132	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the brake pedal position sensor (e.g., making intermittent contact). Possible effects of this sensor failure include: - intermittent measuring or reporting of the brake pedal position.
133	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature (e.g., heat or cold) or thermal cycling may affect the brake pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
			- a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
678	External disturbances	Organic growth	Organisms may grow in the brake pedal position sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
679	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects may affect the brake pedal position sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
680	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the brake pedal position sensor (e.g., a hall-effect type sensor). Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
134	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 affect the brake pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
135	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. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
136	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. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
675	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 pedal position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
681	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. Possible effects of this sensor failure include: - intermittent measuring or reporting of the brake pedal position.
682	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 (e.g., a hall-effect type sensor). Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
			- becoming stuck at a value (e.g., reporting a constant brake pedal position).
683	Hazardous interaction with other components in the rest of the vehicle	Electrical arcing from neighboring components or exposed terminals	If the brake pedal position sensor is a plunger-type switch, electrical arcing from neighboring components or across exposed terminals could affect the measurement. Possible effects of this failure include: - loss of function, - incorrect measuring of the brake pedal position.
137	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage could affect the brake pedal position sensor. Possible effects of this failure include: - incorrect measuring of the brake pedal position (e.g., incorrectly reporting the brake pedal is pressed).
226	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The brake pedal position sensor may lose the reference voltage supply. Possible effects of this failure include: - loss of function.
676	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage to the brake pedal position sensor could affect the measurement. Possible effects of this failure include: - incorrect measuring of the brake pedal position.
677	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption may occur in the reference voltage supply to the brake pedal position sensor. Possible effects of this failure include: - intermittent measuring or reporting of the brake pedal position.
126	Sensor inadequate operation, change over time	Degradation over time	The brake pedal position sensor could degrade over time (e.g., carbonization of electrical contacts). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor)
			- becoming stuck at a value (e.g., reporting a constant brake pedal position).
127	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). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
128	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) may cause the brake pedal position sensor to overheat, affecting internal subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
197	Sensor inadequate operation, change over time	Reporting frequency too low	The brake pedal position sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the brake pedal position, or - a delay in reporting the brake pedal position.

Table H-12: Camshaft Position Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
443	Sensor inadequate operation, change over time	Internal hardware failure	The camshaft position sensor may have an internal hardware failure. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
444	Sensor inadequate operation, change over time	Degradation over time	The camshaft position sensor may degrade over time. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
445	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) could cause the camshaft position sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
447	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
448	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
449	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the function of the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
450	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the camshaft position sensor (e.g., dislodge the sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
451	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature or thermal cycling could cause the camshaft position sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
453	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
455	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 camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
			of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
456	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 camshaft position sensor (e.g., dislodge the sensor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
457	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
458	Sensor inadequate operation, change over time	Reporting frequency too low	The camshaft position sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the camshaft position, or - a delay in reporting the camshaft position. If the ECM does not have the correct camshaft

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
			position, this could affect injection timing (e.g., execution of the injection profile).
668	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components (e.g., engine) could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
670	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The camshaft position sensor may lose 12-volt power. Possible effects of this sensor failure include: - loss of function, or - becoming stuck at a value.
671	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	The 12V power supply to the camshaft position sensor could be disrupted. Possible effects of this failure include: - incorrect or intermittent measuring or reporting of the camshaft position, or - delay in reporting the camshaft position.
672	External disturbances	Organic growth	Organics may grow in the camshaft position sensor (e.g., fungi), causing internal shorting or damage to electronic subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the camshaft position, or - becoming stuck at a value (e.g., reporting a constant camshaft position).
673	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the camshaft position sensor. Possible effects of this sensor failure include: - loss of function,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor)
			- incorrect measuring or reporting of the cam-shaft position, or - becoming stuck at a value (e.g., reporting a constant camshaft position).

Table H-13: Exhaust Gas Oxygen Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
380	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., improper installation) could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
381	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, dirt, and salt corrosion) could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
382	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
661	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
662	External disturbances	Extreme external temperature or thermal cycling	Temperature cycling could damage the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
663	External disturbances	Organic growth	Organisms may grow in the exhaust gas oxygen (EGO) sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
664	External disturbances	Physical interference (e.g., chafing)	Physical interference with foreign objects (e.g., road debris) could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect measuring or reporting of the exhaust quality, or - becoming stuck at a value (e.g., the exhaust quality measurement does not update). An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
383	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
384	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 exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
665	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 exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
666	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 exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
667	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components (e.g., exhaust gas) could affect the exhaust gas oxygen (EGO) sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
906	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	If the exhaust gas oxygen sensor is heated (e.g., HEGO sensor), loss of the 12-volt power supply would prevent the heating element from functioning. Possible effects of this sensor failure include: - loss of function, - incorrect measuring or reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
377	Sensor inadequate operation, change over time	Internal hardware failure	The exhaust gas oxygen (EGO) sensor could have an internal hardware failure (e.g., flawed design, plunger breaks). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor)
378	Sensor inadequate operation, change over time	Degradation over time	The exhaust gas oxygen (EGO) sensor could degrade over time (e.g., carbonization of electrical contacts). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
379	Sensor inadequate operation, change over time	Reporting frequency too low	The exhaust gas oxygen (EGO) sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the exhaust gas quality, or - a delay in reporting the exhaust gas quality. An increased injected fuel quantity may be necessary to reduce emissions. This may result in an increased engine torque if the fuel injection timing is incorrect.
660	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The exhaust gas oxygen (EGO) sensor may be affected by increased resistance or internal shorting, causing overheating. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Table H-14: Engine Rotational Speed Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor)
242	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
243	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
244	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the function of the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
245	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the engine RPM sensor (e.g., dislodge the sensor, damage internal subcomponents). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor)
246	External disturbances	Extreme external temperature or thermal cycling	An extreme ambient temperature or thermal cycling could cause the engine RPM sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
634	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measurement of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., a constant crankshaft speed measurement).
635	External disturbances	Organic growth	Organisms may grow in the engine RPM sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., reporting a constant engine crankshaft speed).
248	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor)
250	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 engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
252	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 engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
424	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measurement of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., a constant crankshaft speed measurement).
633	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 engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor)
636	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 positioning of the engine RPM sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
247	Power supply faulty (high, low, disturbance)	Loss of 12-volt power	The engine RPM sensor could lose 12V power. Possible effects of this failure include: - loss of function.
632	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	The 12V power supply to the engine RPM sensor could be disrupted. Possible effects of this failure include: - incorrect or intermittent measuring or reporting of the engine crankshaft speed, or - delay in reporting the engine crankshaft speed.
238	Sensor inadequate operation, change over time	Internal hardware failure	The engine RPM sensor may have an internal hardware failure. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
239	Sensor inadequate operation, change over time	Degradation over time	The engine RPM sensor may degrade over time. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor)
240	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	A hardware failure (e.g., increased resistance in a subcomponent, internal shorting) could cause the engine RPM sensor to overheat, affecting its function. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
430	Sensor inadequate operation, change over time	Reporting frequency too low	The engine RPM sensor reporting frequency may be too low. Possible effects of this failure include: - loss of function, - intermittent reporting of the engine crankshaft speed, or - a delay in reporting the engine crankshaft speed.

Table H-15: Fuel Pump

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
601	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
602	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
603	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects could affect the fuel pump (e.g., exceeded tolerance). Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
605	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
611	External disturbances	Other	Using an incompatible fuel type (e.g., wrong fuel or water intrusion) could affect the fuel pump. Possible effects of this failure may include: - loss of function, or - supplying the wrong quantity of fuel to the rail. This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
887	External disturbances	Extreme external temperature or thermal cycling	Extreme external temperature or thermal cycling could affect the fuel pump (e.g., deformation of the housing). Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
			- supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
892	External disturbances	Magnetic interference	Magnetic interference from the external environment could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
604	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Extreme heat from other vehicle components could affect the fuel pump (e.g., deformation of the housing). Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
886	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 fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
			This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
888	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., salt corrosion) could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
889	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
890	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 fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
891	Hazardous interaction with other components in the rest of the vehicle	Magnetic interference	Magnetic interference from other vehicle components could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
606	Power supply faulty (high, low, disturbance)	Power supply faulty (high, low, disturbance)	A disruption in the 12V power supply could affect the fuel pump. Possible effects of this failure may include: - loss of function, or - intermittent supply of fuel to the fuel rail. This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
599	Process input supplier inadequate operation, change over time	Process input supplier inadequate operation, change over time	A hardware failure can affect the fuel pump (e.g., damaged impeller). Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Pump)
			This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
600	Process input supplier inadequate operation, change over time	Process input supplier inadequate operation, change over time	The fuel pump may degrade over time (e.g., wear of bearings or seals). Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).
609	Process input supplier inadequate operation, change over time	Power supply faulty (high, low, disturbance)	Electrical noise, in addition to EMI or ESD, could affect the fuel pump. Possible effects of this failure may include: - loss of function, - intermittent supply of fuel to the fuel rail, - supplying the wrong quantity of fuel to the rail, or - becoming stuck at a value (i.e., supplying a constant amount of fuel to the fuel rail). This causal factor applies if the fuel pump can adjust amount of fuel supplied to the fuel rail in response to mean rail pressure increase or decrease requests (e.g., low-pressure side control).

Table H-16: Fuel Temperature Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
927	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
928	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., exceeded tolerance) could affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
929	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
			A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
930	External disturbances	Extreme external temperature or thermal cycling	Extreme ambient temperature (e.g., heat or cold) or thermal cycling may affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
951	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, or - becoming stuck at a value (e.g., reporting a constant fuel temperature). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
952	External disturbances	Organic growth	Organisms may grow in the fuel temperature sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, or - becoming stuck at a value (e.g., reporting a constant fuel temperature). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
921	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
922	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 fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
			combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
953	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 fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, or - becoming stuck at a value (e.g., reporting a constant fuel temperature). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
954	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 fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, or - becoming stuck at a value (e.g., reporting a constant fuel temperature). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
955	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 fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, or - becoming stuck at a value (e.g., reporting a constant fuel temperature).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
			A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
920	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage may affect the fuel temperature sensor. Possible effects of this sensor failure include - loss of function, - incorrect measuring of the fuel temperature (e.g., reporting too high of a fuel temperature), or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
950	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A decrease in the reference voltage may affect the fuel temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel temperature (e.g., reporting too low of a fuel temperature), or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
923	Sensor inadequate operation, change over time	Reporting frequency too low	The fuel temperature sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the fuel temperature, or - a delay in reporting the fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
			A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
924	Sensor inadequate operation, change over time	Internal hardware failure	The fuel temperature sensor could have an internal hardware failure (e.g., damage to a resistor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
925	Sensor inadequate operation, change over time	Degradation over time	The fuel temperature sensor could degrade over time. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.
926	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent	The fuel temperature sensor could overheat from faulty subcomponents (e.g., internal shorting). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the fuel temperature,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor)
		or internal shorting	- a delay in reporting the fuel temperature, or - becoming stuck at a value. A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual fuel temperature.

Table H-17: Ignition Key

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Ignition Key)
56	Actuator inadequate operation, change over time	Internal hardware failure	A hardware failure in the ignition key assembly (e.g., excessive switch bouncing) may cause intermittent or loss of 12V power to vehicle systems.
684	Actuator inadequate operation, change over time	Degradation over time	The ignition key assembly may degrade over time, causing intermittent or loss of 12V power to vehicle systems.
57	External disturbances	Physical interference (e.g., chafing)	Foreign objects may interfere with the ignition key assembly causing intermittent or loss of 12V power to vehicle systems (e.g., driver making contact with ignition key).
58	External disturbances	Moisture, corrosion, or contamination	Contamination or corrosion of the ignition key assembly (e.g., moisture, dirt) may cause intermittent or loss of 12V power to vehicle systems.
59	External disturbances	EMI or ESD	EMI or ESD from the external environment may interfere with the ignition key assembly (e.g., wireless key and start/stop switches) causing intermittent or loss of 12V power to vehicle systems.
685	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the ignition key assembly, causing intermittent or loss of 12V power to vehicle systems.
686	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the ignition key assembly, causing intermittent or loss of 12V power to vehicle systems.
60	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 ignition key assembly, causing intermittent or loss of 12V power to vehicle systems.
61	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components may interfere with the ignition key assembly (e.g., wireless key and start/stop switches) causing intermittent or loss of 12V power to vehicle systems.
687	Hazardous interaction with	Vibration or shock impact	Vibration or shock impact from other vehicle systems could affect the ignition key assembly, causing intermittent or loss of 12V power to vehicle systems.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Ignition Key)
	other components in the rest of the vehicle		

Table H-18: Intake Air Temperature Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
491	External disturbances	Moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
492	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., exceeded tolerance) could affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., com-

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
			bustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
493	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
494	External disturbances	Extreme external temperature or thermal cycling	Extreme ambient temperature (e.g., heat or cold) or thermal cycling may affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
650	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment could affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air temperature, or - becoming stuck at a value (e.g., reporting a constant air temperature). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
651	External disturbances	Organic growth	Organisms may grow in the intake air temperature sensor (e.g., fungi), causing internal shorting or damage to electrical subcomponents. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air temperature, or - becoming stuck at a value (e.g., reporting a constant air temperature). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
485	Hazardous interaction with other components in the rest of the vehicle	EMI or ESD	EMI or ESD from other vehicle components could affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
486	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 intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
652	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 intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air temperature, or - becoming stuck at a value (e.g., reporting a constant air temperature). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
653	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 intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air temperature, or - becoming stuck at a value (e.g., reporting a constant air temperature). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
654	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 intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the air temperature, or - becoming stuck at a value (e.g., reporting a constant air temperature). A problem with the air temperature measurement could affect the ECM's model for how

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
			combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
484	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	An increase in the reference voltage may affect the intake air temperature sensor. Possible effects of this sensor failure include - loss of function, - incorrect measuring of the intake air temperature (e.g., reporting too high of an air temperature), or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
649	Power supply faulty (high, low, disturbance)	Reference voltage incorrect (e.g., too low, too high)	A decrease in the reference voltage may affect the intake air temperature sensor. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the intake air temperature (e.g., reporting too low of an air temperature), or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
487	Sensor inadequate operation, change over time	Reporting frequency too low	The intake air temperature sensor reporting frequency may be too low. Possible effects of this sensor failure include: - loss of function, - intermittent reporting of the intake air temperature, or - a delay in reporting the intake air temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
			A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
488	Sensor inadequate operation, change over time	Internal hardware failure	The intake air temperature sensor could have an internal hardware failure (e.g., damage to a resistor). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.
489	Sensor inadequate operation, change over time	Degradation over time	The intake air temperature sensor could degrade over time. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor)
490	Sensor inadequate operation, change over time	Overheating due to increased resistance in a subcomponent or internal shorting	The intake air temperature sensor could overheat from faulty subcomponents (e.g., internal shorting). Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring or reporting of the intake air temperature, - a delay in reporting the intake air temperature, or - becoming stuck at a value. A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate a fuel injection strategy that is not suitable for the actual air composition in the cylinder.

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

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly to Accelerator Pedal Position Sensor)
349	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects (e.g., exceeded tolerance) or assembly problems could affect the connection between the accelerator pedal and accelerator pedal position sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent measurement of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
350	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. Possible effects of this failure include: - loss of function, - incorrect or intermittent measurement of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
790	External disturbances	Vibration or shock impact	Vibration or shock impact could affect the connection between the accelerator pedal and accelerator pedal position sensor (e.g., misalignment of the sensor). Possible effects of this failure include: - loss of function, - incorrect or intermittent measurement of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
351	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) could cause the accelerator pedal and accelerator pedal position sensor to become misaligned. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Mechanical Assembly to Accelerator Pedal Position Sensor)
791	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 accelerator pedal and accelerator pedal position sensor (e.g., misalignment of the sensor). Possible effects of this failure include: - loss of function, - incorrect or intermittent measurement of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
348	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The accelerator pedal and accelerator pedal position sensor could be misaligned. Possible effects of this failure include: - loss of function, - incorrect or intermittent measurement of the accelerator pedal position, or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).
347	Sensor measurement incorrect or missing	Sensor incorrectly aligned or positioned	The connection between the accelerator pedal and accelerator pedal position sensor (e.g., shaft) could become damaged or may degrade over time. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the accelerator pedal position, - a delay in measuring the accelerator pedal position (e.g., the shaft slips before engaging the potentiometer), or - becoming stuck at a value (e.g., reporting a constant accelerator pedal position).

Table H-20: Accelerator Pedal Position Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
171	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 accelerator pedal position sensor or ECM, causing shorting to other pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
173	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the accelerator pedal position sensor and ECM. Possible effects of this connection failure include: Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
175	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the accelerator pedal position sensor or ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
176	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 terminals on the wiring harness connecting the accelerator pedal position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
840	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the accelerator pedal position sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
841	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may affect the connection between the accelerator pedal position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
172	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 accelerator pedal position sensor or ECM, causing shorting to other pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
174	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 and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
177	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 terminals on the wiring harness connecting the accelerator pedal position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
178	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the accelerator pedal position sensor and ECM to develop an open connection, short to ground, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
842	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the accelerator pedal position sensor or ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
843	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 position sensor and the ECM (e.g., wiring melts). Possible effects of this failure include: - loss of function, - incorrect or reporting of the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
169	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 ECM is transmitted over the communication bus, a communication bus error or overload could affect the accelerator pedal position signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
170	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 ECM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the accelerator pedal position signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., reporting a constant accelerator pedal position). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
181	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the accelerator pedal position sensor to the ECM is transmitted over the communication bus, the accelerator pedal position signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (i.e., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
341	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the accelerator pedal position sensor to the ECM is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the accelerator pedal position. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
180	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 or ESD, could affect the signal from the accelerator pedal position sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, - a delay in reporting the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
339	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 accelerator pedal position sensor and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness (e.g., worn insulation). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
837	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing,	Connection is intermittent	The connection from the accelerator pedal position sensor to the ECM may become intermittent. Possible effects of this failure include: - loss of function, - intermittent reporting of the accelerator pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
	intermittent faulty		- a delay in reporting the accelerator pedal position. In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
838	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 terminals of the accelerator pedal position sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
839	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connector terminals of the accelerator pedal position sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.
342	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection between the accelerator pedal position sensor and ECM could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Accelerator Pedal Position Sensor to Engine Control Module)
836	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection between the accelerator pedal position sensor and ECM could be incorrectly wired (e.g., reversed wires). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the accelerator pedal position, or - becoming stuck at a value (e.g., the accelerator pedal position measurement does not update). In regard to mode switching: If the signal from the accelerator pedal position sensor becomes intermittent, this could cause the ECM to think the pedal conflict is removed and exit BTO mode; the ECM may not re-enter BTO mode because the brake pedal will appear to have been pressed first.

Table H-21: Engine Control Module to Fuel Injector

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Injector)
545	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the ECM to the fuel injectors is transmitted over the communication bus, a communication bus overload or error could affect the signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck in a position (e.g., open).
546	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the ECM to the fuel injectors is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could prevent or delay transmission of the signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck in a position (e.g., open).
547	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the ECM to the fuel injectors is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the signal from the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck in a position (e.g., open).
548	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the ECM to the fuel injectors is transmitted over the communication bus, the signal priority may not be high enough. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation.
542	Controller to actuator signal ineffective, missing, or delayed: Hardware open,	Connection is open, short to ground, short to battery, or short to other	The connection between the ECM and the fuel injectors could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Injector)
	short, missing, intermittent faulty	wires in harness	- incorrect injector operation, or - becoming stuck in a position (e.g., open).
744	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the ECM and the fuel injectors could become intermittent. Possible effects of this failure include: - intermittent injector operation, - a delay in injector operation, or - becoming stuck in a position (e.g., open).
745	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 ECM and the fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, or - becoming stuck in a position (e.g., open).
751	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance for the connection terminals of the fuel injector or ECM may be too high. Possible effects of this failure include: - loss of function, or - incorrect injector operation.
752	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the fuel injectors or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect injector operation, or - becoming stuck at a position (e.g., injector stays open).
549	Controller to actuator signal ineffective,	Incorrect wiring connection	The connections between the ECM and two or more injectors may be reversed (e.g., connected

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Injector)
	missing, or delayed: Incorrect connection		to injector 1 instead of injector 2). Possible effects of this failure include: - incorrect injector operation.
550	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection from the ECM to the fuel injector could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect injector operation, or - becoming stuck at a position (e.g., closed).
551	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection from the ECM to the fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
552	External disturbances	Active connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the connection terminals of the ECM or the fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
553	External disturbances	Unused connection terminals affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination from the external environment (e.g., moisture, salt corrosion) could affect the unused connection terminals of the wiring harness connecting the ECM and the fuel injectors, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
554	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the ECM or the fuel injectors to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Injector)
			- a delay in injector operation, or - becoming stuck at a position (e.g., closed).
746	External disturbances	Organic growth	Organisms may grow in the connection terminals of the ECM or the fuel injectors, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect injector operation, or - becoming stuck at a position (e.g., closed).
747	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the ECM and the fuel injector. Possible effects of this failure include: - loss of function, - incorrect injector operation, or - becoming stuck at a position (e.g., closed).
555	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 ECM to the fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
556	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 ECM or the fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Injector)
557	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 ECM and the fuel injectors, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
558	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the ECM and the fuel injectors to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, or - becoming stuck at a position (e.g., closed).
748	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the ECM or the fuel injectors to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).
749	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 ECM and the fuel injectors (e.g., melting the wiring harness). Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, or - becoming stuck at a position (e.g., closed).
750	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 between exposed terminals could affect the connection terminals of the ECM or fuel injectors. Possible effects of this failure include: - loss of function, - incorrect or intermittent injector operation, - a delay in injector operation, or - becoming stuck at a position (e.g., closed).

Table H-22: Engine Control Module to Fuel Rail Pressure Control Valve

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
86	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the ECM to the fuel rail pressure control valve is transmitted over the communication bus, a communication bus overload or error could prevent or delay transmission of the signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
87	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the ECM to the fuel rail pressure control valve is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could prevent or delay transmission of the signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
88	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the ECM to the fuel rail pressure control valve is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the signal from the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
761	Controller to actuator signal ineffective, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the ECM to the fuel rail pressure control valve is transmitted over the communication bus, the signal priority from the ECM may be too low. Possible effects of this failure include: - loss of function, - intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
84	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 ECM and the fuel rail pressure control valve could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this connection failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
753	Controller to actuator signal ineffective, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the ECM and the fuel rail pressure control valve could become intermittent. Possible effects of this connection failure include: - intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank.
754	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 ECM and fuel rail pressure control valve. Possible effects of this connection failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
90	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection from the ECM to the fuel rail pressure control valve could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
755	Controller to actuator signal ineffective, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection from the ECM to the fuel rail pressure control valve may be incorrectly wired. Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
91	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection from the ECM to the fuel rail pressure control valve. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
92	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 ECM or the fuel rail pressure control valve. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
93	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 the unused connection terminals of the wiring harness connecting the ECM and the fuel rail pressure control valve, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
94	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the ECM or the fuel rail pressure control valve to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - becoming stuck at a position.
756	External disturbances	Organic growth	Organisms may grow in the connection terminals of the ECM or fuel rail pressure control valve (e.g., fungi), causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
757	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the ECM and the fuel rail pressure control valve. Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
95	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 ECM to the fuel rail pressure control valve. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
96	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 ECM or the fuel rail pressure control valve. Possible effects of this connection failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - a delay in the movement of the control valve, or - becoming stuck at a position.
97	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 in the wiring harness connecting the ECM and the fuel rail pressure control valve, causing shorting between pins. Possible effects of this connection failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
98	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the ECM and the fuel rail pressure control valve to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - becoming stuck at a position.
758	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the ECM or the fuel rail pressure control valve to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - becoming stuck at a position.
759	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Extreme heat from other vehicle components could affect the connection between the ECM and the fuel rail pressure control valve (e.g. melting the wiring harness). Possible effects of this failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong quantity of fuel to flow back to the fuel tank, - becoming stuck at a position.
760	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 between exposed terminals could affect the connection from the ECM to the fuel rail pressure control valve. Possible effects of this connection failure include: - loss of function, - incorrect movement of the fuel rail pressure control valve, which could allow the wrong

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Control Module to Fuel Rail Pressure Control Valve)
			quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Table H-23: Fuel Rail to Fuel Injector

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail to Fuel Injector)
563	External disturbances	Other	Fuel contamination (e.g., dirt or debris) may prevent the nozzle of the fuel injector from sealing in its seat when the ECM commands the injector to close. Possible effects of this failure include: - incorrect quantity of fuel injected into the cylinder, or - becoming stuck at a position.
893	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may affect the fuel delivery from the fuel rail to the injector. Possible effects of this failure include: - incorrect quantity of fuel injected into the cylinder, or - becoming stuck at a position.
894	External disturbances	Vibration or shock impact	Vibration or shock impact from the external environment may affect the tubing connecting the fuel rail to the fuel injector. Possible effects of this failure include: - incorrect quantity of fuel injected into the cylinder, or - becoming stuck at a position.
895	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 tubing connecting the fuel rail to the fuel injector. Possible effects of this failure include: - incorrect quantity of fuel injected into the cylinder, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail to Fuel Injector)
562	Input to controlled process missing or wrong	Other	A high fuel rail pressure may prevent the nozzle of the fuel injector from sealing in its seat when the ECM commands the injector to close. Possible effects of this failure include: - incorrect quantity of fuel injected into the cylinder, or - becoming stuck at a position.

Table H-24: Fuel Rail to Fuel Rail Pressure Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail to Fuel Rail Pressure Sensor)
52	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may cause the fuel rail pressure sensor to be incorrectly mounted on the fuel rail. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel rail pressure, - becoming stuck at a value (e.g., measuring a constant fuel rail pressure).
53	External disturbances	Vibration or shock impact	Vibration or shock impact may cause the fuel rail pressure sensor to become incorrectly mounted on the fuel rail. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel rail pressure, - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
66	External disturbances	Other	Contaminants in the fuel rail (e.g., particulates, water) may affect the pressure sensor reading or physically interfere with the fuel rail pressure sensor diaphragm. Possible effects of this sensor failure include: - loss of function, - incorrect or intermittent measuring of the fuel rail pressure, - becoming stuck at a value (e.g., reporting a constant fuel rail pressure)
55	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) may cause the fuel rail pressure sensor to become incorrectly mounted on the fuel rail. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel rail pressure, - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
789	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 fuel rail pressure sensor to become incorrectly mounted on the fuel rail. Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel rail pressure,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail to Fuel Rail Pressure Sensor)
			- becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
51	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The fuel rail pressure sensor may be mounted somewhere on the fuel rail that is not representative of the mean rail pressure (e.g., near the fuel inlet). Possible effects of this sensor failure include: - loss of function, - incorrect measuring of the fuel rail pressure, - becoming stuck at a value (e.g., measuring a constant fuel rail pressure).

Table: H-25: Fuel Rail Pressure Control Valve to Fuel Rail

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve to Fuel Rail)
100	External disturbances	Vibration or shock impact	Vibration or shock impact could affect how the fuel rail pressure control valve is mounted on the fuel rail (e.g., causing the valve to become misaligned). Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
102	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect how the fuel rail pressure control valve is mounted on the fuel rail (e.g., the valve is not seated properly). Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
762	External disturbances	Extreme external temperature or thermal cycling	Thermal cycling could affect the seal between the fuel rail pressure control valve and the fuel rail (e.g., causing leaking). Possible effects of this failure include: - loss of function, or - allowing the wrong quantity of fuel to flow out of the fuel rail.
901	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	The fuel rail pressure control valve may be affected by an incompatible fuel type in the fuel rail. Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
103	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., battery acid) could affect the connection between the fuel rail pressure control valve and fuel rail (e.g., causing a seal to leak). Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Control Valve to Fuel Rail)
104	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 fuel rail pressure control valve and fuel rail (e.g., causing the valve to become misaligned). Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.
763	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Extreme heat from other vehicle components could affect the connection between the fuel rail pressure control valve and fuel rail (e.g., damaging a seal). Possible effects of this failure include: - loss of function, or - allowing the wrong quantity of fuel to flow out of the fuel rail.
764	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 how the fuel rail pressure control valve is mounted on the fuel rail (e.g., causing the valve to become misaligned). Possible effects of this failure include: - loss of function, - allowing the wrong quantity of fuel to flow back to the fuel tank, or - becoming stuck at a position.

Table H-26: Fuel Rail Pressure Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
42	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 fuel rail pressure sensor or the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure). . .
43	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 fuel rail pressure sensor and the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
44	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the fuel rail pressure sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
45	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the fuel rail pressure sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
805	External disturbances	Organic growth	Organisms may grow in the connection terminals of the fuel rail pressure sensor or ECM (e.g., fungi), causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
806	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the fuel rail pressure sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
46	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 fuel rail pressure sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
47	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or interference from other vehicle components (e.g., wiring is cut) could cause the connection between the fuel rail pressure sensor and the ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
48	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 fuel rail pressure sensor or the ECM. . . Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
49	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 in the wiring harness connecting the fuel rail pressure sensor and the ECM, causing shorting between pins. Possible effects of this connection failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
807	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the fuel rail pressure sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
869	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 fuel rail pressure sensor and ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
37	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the fuel rail pressure sensor is connected to the ECM with the communication bus, a bus overload or error could affect the fuel rail pressure signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).
38	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the fuel rail pressure sensor is connected to the ECM with the communication bus, a failure of the message generator, transmitter, or receiver could affect the fuel rail pressure signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).
39	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the fuel rail pressure sensor is connected to the ECM with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the fuel rail pressure sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).
40	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the fuel rail pressure sensor is connected to the ECM with the communication bus, the fuel rail pressure signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (i.e., the fuel rail pressure measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
34	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 fuel rail pressure sensor and the ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
36	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 or ESD, could affect the signal from the fuel rail pressure sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, - a delay in reporting the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).
803	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the fuel rail pressure sensor and the ECM could become intermittent. Possible effects of this failure include: - intermittent reporting of the fuel rail pressure.
867	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 fuel rail pressure sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
868	Sensor to controller signal inadequate, missing, or delayed: Hardware open,	Connector shorting between neighboring pins	The connection terminals of the fuel rail pressure sensor or ECM may develop shorts between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Rail Pressure Sensor to Engine Control Module)
	short, missing, intermittent faulty		rail pressure, or - becoming stuck at a value (e.g., reporting a constant fuel rail pressure).
41	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	If the fuel rail pressure sensor or the ECM has the wrong pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).
804	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The connection from the fuel rail pressure sensor to the ECM could be wired incorrectly (e.g., reversed wires). Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel rail pressure, or - becoming stuck at a value (e.g., the fuel rail pressure measurement does not update).

Table H-27: Fuel Injector to Engine

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Injector to Engine)
561	External disturbances	Vibration or shock impact	Vibration could affect the fuel injector position relative to the engine cylinder. Possible effects of this connection failure include: - incorrect fuel delivery. The behavior of fuel in the cylinder (e.g., spray pattern, combustion rate) may differ from the ECM's expectation, which may affect the torque output.
560	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 fuel injector position relative to the engine cylinder. Possible effects of this connection failure include: - incorrect fuel delivery. The behavior of fuel in the cylinder (e.g., spray pattern, combustion rate) may differ from the ECM's expectation, which may affect the torque output.
559	Input to controlled process missing or wrong	Other	The fuel injector may be incorrectly positioned with respect to the engine cylinder as a result of manufacturing flaws or assembly problems. Possible effects of this connection failure include: - incorrect fuel delivery. The behavior of fuel in the cylinder (e.g., spray pattern, combustion rate) may differ from the ECM's expectation, which may affect the torque output.

Table H-28: Boost Pressure Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
502	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 boost pressure sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
503	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 the unused connection terminals in the wiring harness connecting the boost pressure sensor to the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
504	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the boost pressure sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
			- a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
505	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the boost pressure sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
825	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the boost pressure sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
826	External disturbances	Vibration or shock impact	Manufacturing defects or assembly problems could affect the connection from the boost pressure sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
506	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 boost pressure sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
507	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., abraded wiring) could cause the connection between the boost pressure sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
			An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
508	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 systems (e.g., A/C condensation) could affect the connection terminals of the boost pressure sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
509	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 systems (e.g., A/C condensation) could affect unused connection terminals in the wiring harness connecting the boost pressure sensor and ECM, causing shorts between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
827	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the boost pressure sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
874	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 boost pressure sensor and ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
497	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the boost pressure sensor to the ECM is transmitted over the communication bus, a communication bus overload or error could affect the signal from the boost pressure sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
498	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the boost pressure sensor to the ECM is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the boost air pressure measurement. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
499	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the boost pressure sensor to the ECM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the signal from the boost pressure sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
			air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
500	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the boost pressure sensor to the ECM is transmitted over the communication bus, the boost pressure sensor's priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the boost air pressure, or - a delay in reporting the boost air pressure. An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
495	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 boost pressure sensor and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
496	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 boost pressure sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, - a delay in reporting the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
821	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection from the boost pressure sensor to the ECM may become intermittent. Possible effects of this failure include: - loss of function, - intermittent reporting of the boost air pressure, or - a delay in reporting the boost air pressure. An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
822	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance of the connection terminals of the boost pressure sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Boost Pressure Sensor to Engine Control Module)
823	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the boost pressure sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
501	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The boost pressure sensor or ECM connection terminals could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.
824	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection from the boost pressure sensor to the ECM could be wired incorrectly. Possible effects of this failure include: - loss of function, - incorrect reporting of the boost air pressure, or - becoming stuck at a value (e.g., reporting a constant boost air pressure). An incorrect air pressure measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., spray pattern). The ECM may generate a fuel injection strategy that is not suitable for the actual air pressure.

Table H-29: Brake/Vehicle Stability Assist Control Module to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
187	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection from the Brake / VSA Control Module to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
188	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 / VSA Control Module or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
189	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 on the wiring harness connecting the Brake / VSA Control Module and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
190	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the Brake/VSA Control Module or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
811	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the Brake / VSA control module or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
812	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the Brake / VSA control module and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
191	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 ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			- a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
192	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 ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
193	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 / VSA Control Module and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
194	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the Brake / VSA Control Module and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
813	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the Brake / VSA Control Module or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
871	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 / VSA control module and the ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
184	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 ECM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the vehicle speed signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
185	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 ECM is transmitted over the communication bus, a bus overload or error could affect the vehicle speed signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
186	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 ECM is transmitted over the communication bus, the vehicle speed signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehi-

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			cle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
223	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the Brake / VSA Control Module to ECM 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. Possible effects of this failure include: - loss of function, - incorrect or intermittent calculation or reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., reporting a constant vehicle speed). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
183	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 or ESD, could affect the signal from the Brake / VSA Control Module to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, - a delay in reporting the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			Brake / VSA Control Module provides the vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
307	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 / VSA Control Module and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
808	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the Brake / VSA Control Module and ECM could become intermittent. Possible effects of this failure include: - loss of function, or - intermittent reporting of the vehicle speed. This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
870	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection between the Brake / VSA control module and ECM could develop shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
809	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The Brake / VSA Control Module or ECM may have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.
810	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The Brake / VSA Control Module or ECM may be incorrectly wired. Possible effects of this failure include: - loss of function, - incorrect reporting of the vehicle speed, or - becoming stuck at a value (e.g., the vehicle speed measurement does not update). This causal factor applies if the vehicle speed is

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake/Vehicle Stability Assist Control Module to Engine Control Module)
			used to determine whether to engage BTO or to determine the appropriate injected fuel quantity when in BTO Mode. This analysis assumes the Brake / VSA Control Module provides the average vehicle speed to the ECM; other vehicle configurations may use other components to compute the vehicle speed.

Table H-30: Engine to Camshaft Position Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine to Camshaft Position Sensor)
526	External disturbances	Vibration or shock impact	Vibration or shock impact may cause the camshaft position sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
527	External disturbances	Manufacturing defects and assembly problems	The camshaft position sensor could be incorrectly positioned relative to the engine as a result of flaws in the manufacturing process or assembly problems (e.g., improper installation). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
908	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the magnetic reading of the tone wheel attached to the engine camshaft. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the camshaft position, or - becoming stuck at a value (e.g., measuring a constant camshaft position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine to Camshaft Position Sensor)
779	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 camshaft position sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
780	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) may cause the camshaft position sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
525	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The camshaft position sensor may become incorrectly positioned relative to the engine (e.g., degradation of the sensor mounting). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Table H-31: Engine to Engine Rotational Speed Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine to Engine Speed (RPM) Sensor)
298	External disturbances	Vibration or shock impact	Vibration or shock impact may cause the engine RPM sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).
303	External disturbances	Manufacturing defects and assembly problems	The engine RPM sensor could be incorrectly positioned relative to the engine as a result of flaws in the manufacturing process or assembly problems (e.g., improper installation). Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).
907	External disturbances	Mechanical connections affected by moisture, corrosion, or contamination	Moisture, corrosion, or contamination could affect the magnetic reading of the tone wheel attached to the engine crankshaft. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).
781	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 engine RPM sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine to Engine Speed (RPM) Sensor)
782	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) may cause the engine RPM sensor to become incorrectly positioned relative to the engine. Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).
297	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	The engine RPM sensor may become incorrectly positioned relative to the engine (e.g., degradation of the sensor mounting). Possible effects of this failure include: - loss of function, - incorrect or intermittent measuring of the engine crankshaft speed, or - becoming stuck at a value (e.g., measuring a constant engine crankshaft speed).

Table H-32: Brake Pedal Mechanical Assembly to Brake Pedal Position Sensor

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Mechanical Assembly to Brake Pedal Position Sensor)
120	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. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
793	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the brake pedal and brake pedal position sensor to become misaligned. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
794	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems (e.g., exceeded tolerance) could cause the brake pedal and brake pedal position sensor to be misaligned. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
795	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 brake pedal and brake pedal position sensor to degrade. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Mechanical Assembly to Brake Pedal Position Sensor)
121	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. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
796	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the brake pedal and brake pedal position sensor to become misaligned. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
792	Sensor measurement inaccurate	Sensor incorrectly aligned or positioned	'The connection between the brake pedal and brake pedal position sensor (e.g., shaft) could become damaged or may degrade over time. Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).
119	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). Possible effects of this failure include: - loss of function (e.g., the brake pedal does not activate the pedal position sensor), - incorrect or intermittent activation of the pedal position sensor, or - the brake pedal position sensor becoming stuck at a value (e.g., in the "pressed" position).

Table H-33: Brake Pedal Position Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
150	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 ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
151	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 or ESD, could affect the signal from the brake pedal position sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
152	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the brake pedal position sensor to the ECM 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. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
154	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 ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
			- becoming stuck at a value (e.g., reporting a constant brake pedal position).
155	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 ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
156	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the brake pedal position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
157	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the brake pedal position sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
158	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 ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
159	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the brake pedal position sensor and the ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
160	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 ECM. . . Possible effects of this connection failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
161	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 ECM, causing shorts between pins. Possible effects of this connection failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
			- becoming stuck at a value (e.g., reporting a constant brake pedal position).
196	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 ECM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the sensor signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
227	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the brake pedal position sensor and ECM may become intermittent. Possible effects of this failure include: - loss of function, - intermittent reporting of the brake pedal position, or - a delay in reporting the brake pedal position.
228	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 ECM is transmitted over the communication bus, a bus overload or error could affect the sensor signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
229	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The brake pedal position sensor or ECM connection terminals could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the brake pedal position, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
			- becoming stuck at a value (e.g., the brake pedal position measurement does not update).
362	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 ECM is transmitted over the communication bus, the brake pedal position signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the brake pedal position, - a delay in reporting the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
859	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the brake pedal position sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
860	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the brake pedal position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
861	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the brake pedal position sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Brake Pedal Position Sensor to Engine Control Module)
862	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 from the brake pedal position sensor and ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., reporting a constant brake pedal position).
864	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 terminals of the brake pedal position sensor and ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
865	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the brake pedal position sensor or ECM may develop shorts between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).
866	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The brake pedal position sensor or ECM connection terminals could be wired incorrectly (e.g., wiring reversed). Possible effects of this failure include: - loss of function, - incorrect reporting of the brake pedal position, or - becoming stuck at a value (e.g., the brake pedal position measurement does not update).

Table H-34: Camshaft Position Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
517	External dis-turbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the cam-shaft position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the cam-shaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
518	External dis-turbances	Active connec-tion terminals affected by moisture, cor-rosion, or con-tamination	Moisture, corrosion, or contamination from the external environment (e.g., salt corrosion) could affect the connection terminals of the camshaft position sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the cam-shaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
519	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 camshaft position sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
520	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the camshaft position sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
857	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the camshaft position sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
858	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the camshaft position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update).
521	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 camshaft position sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
522	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the camshaft position sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
523	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 camshaft position sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
524	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 of the wiring harness connecting the camshaft position sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
855	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the camshaft position sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
856	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 from the camshaft position sensor to the ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
512	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the camshaft position sensor is connected to the ECM with the communication bus, a failure of the message generator, transmitter, or receiver could affect the signal from the camshaft position sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
513	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the camshaft position sensor is connected to the ECM with the communication bus, a bus overload or error could affect the signal from the camshaft position sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
514	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the camshaft position sensor is connected to the ECM with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the camshaft position. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
515	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the camshaft position sensor is connected to the ECM with the communication bus, the camshaft position's signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
510	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 camshaft position sensor and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
511	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 or ESD, could affect the signal from the camshaft position sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the camshaft position, - a delay in reporting the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
851	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the camshaft position sensor and ECM may become intermittent. Possible effects of this failure include: - loss of function, - intermittent reporting of the camshaft position, or - a delay in reporting the camshaft position. If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
852	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance of the connector terminals of the camshaft position sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
853	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the camshaft position sensor or ECM may develop shorting between pins. Possible effects of this failure include: - loss of function, - incorrect reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
516	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The camshaft position sensor or the ECM could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update). If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).
854	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The camshaft position sensor or the ECM could be wired incorrectly. Possible effects of this failure include: - loss of function, - incorrect reporting of the camshaft position, or - becoming stuck at a value (e.g., the camshaft position measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Camshaft Position Sensor to Engine Control Module)
			If the ECM does not have the correct camshaft position, this could affect injection timing (e.g., execution of the injection profile).

Table H-35: Exhaust Gas Oxygen Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
395	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 exhaust gas oxygen (EGO) sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
396	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 exhaust gas oxygen (EGO) sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
397	External dis-turbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the exhaust gas oxygen (EGO) sensor and ECM. Possible ef-fects of this failure include: - loss of function, - incorrect or intermittent reporting of the ex-haust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be nec-essary to reduce emissions. This may result in increased engine torque if the fuel injection tim-ing is incorrect.
398	External dis-turbances	Vibration or shock impact	Vibration or shock impact could cause the con-nection terminals of the exhaust gas oxygen (EGO) sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the ex-haust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be nec-essary to reduce emissions. This may result in increased engine torque if the fuel injection tim-ing is incorrect.
849	External dis-turbances	Organic growth	Organisms (e.g., fungi) may grow in the connec-tion terminals of the exhaust gas oxygen (EGO) sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the ex-haust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be nec-essary to reduce emissions. This may result in increased engine torque if the fuel injection tim-ing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
850	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the exhaust gas oxygen (EGO) sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
399	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 exhaust gas oxygen (EGO) sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
400	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the exhaust gas oxygen (EGO) sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
401	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 systems (e.g., A/C condensation) could affect the connection terminals of the exhaust gas oxygen (EGO) sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
402	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 systems (e.g., A/C condensation) could affect unused connection terminals on the wiring harness connecting the brake pedal position sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
847	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the exhaust gas oxygen (EGO) sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
848	Hazardous interaction with other components in the rest of the vehicle	Excessive heat from other components	Excessive heat from other vehicle components affect the connection between the exhaust gas oxygen (EGO) sensor and ECM (e.g., melt the wiring). Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
391	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the signal from the exhaust gas oxygen (EGO) sensor to ECM is transmitted over the communication bus, a bus overload or error could affect the signal from the EGO sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
392	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the signal from the exhaust gas oxygen (EGO) sensor to ECM is transmitted over the communication bus, a failure of the message generator, transmitter, or receiver could affect the signal from the EGO sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
393	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the signal from the exhaust gas oxygen (EGO) sensor to ECM is transmitted over the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the EGO sensor signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
394	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the signal from the exhaust gas oxygen (EGO) sensor to ECM is transmitted over the communication bus, the EGO sensor signal priority may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value (e.g., the exhaust gas quality measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
			An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
389	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 exhaust gas oxygen (EGO) sensor and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. . . Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
390	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 or ESD, could affect the connection between the exhaust gas oxygen (EGO) sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the exhaust gas quality, - a delay in reporting the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
844	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 terminals of the exhaust gas oxygen (EGO) sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the exhaust gas quality, or - becoming stuck at a value.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
			An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
845	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connector terminals of the exhaust gas oxygen (EGO) sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
419	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The exhaust gas oxygen (EGO) sensor or ECM connection terminals could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in increased engine torque if the fuel injection timing is incorrect.
846	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The exhaust gas oxygen (EGO) sensor or ECM connection terminals could be wired incorrectly. Possible effects of this failure include: - loss of function, - incorrect reporting of the exhaust gas quality, or - becoming stuck at a value. An increased injected fuel quantity may be necessary to reduce emissions. This may result in

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Exhaust Gas Oxygen (EGO) Sensor to Engine Control Module (ECM))
			increased engine torque if the fuel injection timing is incorrect.

Table H-36: Engine Rotational Speed Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
260	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the engine RPM sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
261	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 engine RPM sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
262	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 engine RPM sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
263	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the engine RPM sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
			- becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
799	External disturbances	Organic growth	Organisms may grow in the connection terminals of the engine RPM sensor or ECM (e.g., fungi), causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
800	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems may affect the connection between the engine RPM sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
264	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 engine RPM sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
265	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or interference from other vehicle components (e.g., wiring is cut) could cause the connection between the engine RPM sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
			crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
266	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 engine RPM sensor or ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
267	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 of the wiring harness connecting the engine RPM sensor and ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
801	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the engine RPM sensor or ECM to wear over time (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
802	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 engine RPM sensor and ECM (e.g., melt the wiring harness). Possible effects of this failure include: - loss of function, - intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
255	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the engine RPM sensor is connected to the ECM with the communication bus, a failure of the message generator, transmitter, or receiver could affect the signal from the engine RPM sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
256	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the engine RPM sensor is connected to the ECM with the communication bus, a bus overload or error could affect the signal from the engine RPM sensor. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
257	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the engine RPM sensor is connected to the ECM with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the engine speed. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
258	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the engine RPM sensor is connected to the ECM with the communication bus, the engine speed signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
253	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 engine RPM sensor and ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
254	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 or ESD, could affect the signal from the engine RPM sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, - a delay in reporting the engine crankshaft

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
			speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
797	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection between the engine RPM sensor and ECM could become intermittent. Possible effects of this failure include: - intermittent reporting of the engine crankshaft speed.
872	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 terminals of the engine RPM sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
873	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connection terminals of the engine RPM sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
259	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The engine RPM sensor or the ECM could have an incorrect pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the engine crankshaft speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).
798	Sensor to controller signal inadequate, missing, or delayed:	Incorrect wiring connection	The engine RPM sensor or the ECM could be incorrectly wired (e.g., wires are reversed). Possible effects of this failure include: - loss of function, - incorrect reporting of the engine crankshaft

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Engine Speed (RPM) Sensor to Engine Control Module
	Incorrect connection		speed, or - becoming stuck at a value (e.g., the engine crankshaft speed measurement does not update).

Table H-37: Fuel Temperature Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
931	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 fuel temperature sensor and the ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
932	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 or ESD, could affect the signal from the fuel temperature sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
933	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the fuel temperature sensor is connected to the ECM with the communication bus, a bus overload or error could affect the fuel temperature signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
			- a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
934	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the fuel temperature sensor is connected to the ECM with the communication bus, a failure of the message generator, transmitter, or receiver could affect the fuel temperature signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
935	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the fuel temperature sensor is connected to the ECM with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the fuel temperature measurement. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
			combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
936	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the fuel temperature sensor is connected to the ECM with the communication bus, the fuel temperature sensor signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function, - intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
937	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The fuel temperature sensor or ECM may have the wrong pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
938	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 fuel temperature sensor or the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
939	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 the unused connection terminals in the wiring harness connecting the fuel temperature sensor and the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
940	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the fuel temperature sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature,

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
			- a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
941	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the fuel temperature sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
942	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 fuel temperature sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
943	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the fuel temperature sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
944	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 fuel temperature sensor or the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
945	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 in the wiring harness connecting the fuel temperature sensor and the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
958	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection from the fuel temperature sensor to ECM may become intermittent. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, - a delay in reporting the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
959	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing,	Connector contact resistance is too high	The contact resistance of the connector terminals for the fuel temperature sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
	intermittent faulty		A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
960	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connector terminals for the fuel temperature sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
961	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection from the fuel temperature sensor to the ECM may be incorrectly wired. Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
962	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the fuel temperature sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
			- becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
963	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the fuel temperature sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.
964	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the fuel temperature sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Fuel Temperature Sensor to Engine Control Module)
965	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 fuel temperature sensor and the ECM (e.g., melt the wiring harness). Possible effects of this failure include: - loss of function, - incorrect reporting of the fuel temperature, or - becoming stuck at a value (e.g., the fuel temperature measurement does not update). A problem with the fuel temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the actual fuel temperature.

Table H-38: Intake Air Temperature Sensor to Engine Control Module

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
572	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 intake air temperature sensor or the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
573	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 the unused connection terminals in the wiring harness connecting the intake air temperature sensor and the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
574	External disturbances	EMI or ESD	EMI or ESD from the external environment could affect the connection between the intake air temperature sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
575	External disturbances	Vibration or shock impact	Vibration or shock impact could cause the connection terminals of the intake air temperature sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
832	External disturbances	Organic growth	Organisms (e.g., fungi) may grow in the connection terminals of the intake air temperature sensor or ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
833	External disturbances	Manufacturing defects and assembly problems	Manufacturing defects or assembly problems could affect the connection between the intake air temperature sensor and ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
576	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 intake air temperature sensor and the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
577	Hazardous interaction with other components in the rest of the vehicle	Physical interference (e.g., chafing)	Chafing or physical interference from other vehicle components (e.g., wiring is cut) could cause the connection between the intake air temperature sensor and ECM to develop an open circuit, short to ground or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
578	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 intake air temperature sensor or the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
			temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
579	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 in the wiring harness connecting the intake air temperature sensor and the ECM, causing shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
834	Hazardous interaction with other components in the rest of the vehicle	Vibration or shock impact	Vibration or shock impact from other vehicle components could cause the connection terminals of the intake air temperature sensor or the ECM to wear (e.g., fretting) or become loose. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update).

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
			A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
835	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 intake air temperature sensor and the ECM (e.g., melt the wiring harness). Possible effects of this failure include: - loss of function, - incorrect reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
567	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Bus overload or bus error	If the intake air temperature sensor is connected to the ECM with the communication bus, a bus overload or error could affect the air temperature signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

Causal Factor ID #	Causal Factor Guide Phrase	Causal Factor Subcategory	Causal Factor (Intake Air Temperature Sensor to Engine Control Module)
568	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Failure of the message generator, transmitter, or receiver	If the intake air temperature sensor is connected to the ECM with the communication bus, a failure of the message generator, transmitter, or receiver could affect the air temperature signal. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
569	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Malicious Intruder	If the intake air temperature sensor is connected to the ECM with the communication bus, a malicious intruder or aftermarket component may write a signal to the communication bus that mimics the air temperature measurement. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
570	Sensor to controller signal inadequate, missing, or delayed: Communication bus error	Signal priority too low	If the intake air temperature sensor is connected to the ECM with the communication bus, the intake air temperature sensor signal priority on the communication bus may not be high enough. Possible effects of this failure include: - loss of function,

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			- intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
564	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 intake air temperature sensor and the ECM could develop an open circuit, short to ground, short to battery, or short to other wires in the harness. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
566	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 or ESD, could affect the signal from the intake air temperature sensor to the ECM. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how

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			combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
828	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connection is intermittent	The connection from the intake air temperature sensor to ECM may become intermittent. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, - a delay in reporting the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
829	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector contact resistance is too high	The contact resistance of the connector terminals for the intake air temperature sensor or ECM may be too high. Possible effects of this failure include: - loss of function, - incorrect reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

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830	Sensor to controller signal inadequate, missing, or delayed: Hardware open, short, missing, intermittent faulty	Connector shorting between neighboring pins	The connector terminals for the intake air temperature sensor or ECM may have shorting between pins. Possible effects of this failure include: - loss of function, - incorrect or intermittent reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.
571	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect pin assignment	The intake air temperature sensor or ECM may have the wrong pin assignment. Possible effects of this failure include: - loss of function, - incorrect reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

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831	Sensor to controller signal inadequate, missing, or delayed: Incorrect connection	Incorrect wiring connection	The connection from the intake air temperature sensor to the ECM may be incorrectly wired. Possible effects of this failure include: - loss of function, - incorrect reporting of the air temperature, or - becoming stuck at a value (e.g., the air temperature measurement does not update). A problem with the air temperature measurement could affect the ECM's model for how combustion in the cylinder will occur (e.g., combustion rate). The ECM may generate an injection strategy that is not suitable for the air mixture in the cylinder.

DOT HS 812 585
October 2018

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

13638-100518-v4