JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Introduction

System:

Hybrid 4-Passenger Vehicle

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Scope:

The purpose of this report is to demonstrate key systems engineering concepts utilized in the product development lifecycle. These concepts are utilized to architect the system model of a 4-passenger hybrid vehicle.

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System Need:

Vehicles have improved fuel efficiency dramatically since their inception. However, improvements to internal combustion engines have incrementally decreased in progress over the last few years. There is demand for hybrid cars to reduced dependency on fossil fuels and meet strict low emission requirements. In summary, hybrid cars are needed for the following:

- To reduce the amount of harmful gas released.
- To repurpose energy lost from braking subsystems to provide better overall fuel efficiency to vehicles using internal combustion engines.
- To reduce dependency on fossil fuels.

Concept of Operations:

Mission A: Control Vehicle Access

Unlock Cabin/Trunk Door

The system receives wireless signals from the key (**Door Unlock Control Signal**). The system processes electromagnetic signals from the key and authenticates the signal *(internal system activity)*. The system checks state of doors as locked *(internal system activity)*. The system unlocks its driver door to provide user access *(internal system activity)*. The system receives an additional **Door Unlock Control Signal** from the key. The system processes the electromagnetic signals from the key *(internal system activity)*. The system checks state of doors *(internal system activity)*. The system verifies that first door is unlocked *(internal system activity)*. The system unlocks the remaining passenger doors *(internal system activity)*. The system receives an additional **Door Unlock Control Signal** from the key. The system processes the electromagnetic signals from the key *(internal system activity)*. The system checks state of doors as locked/unlocked *(internal system activity)*. The system verifies that all cabin doors are unlocked *(internal system activity)*. The system unlocks the rear truck *(internal system activity)*.

Lock Cabin/Trunk Door

The system receives electromagnetic signals from the key (**Door Lock Control Signal**). The system processes electromagnetic signals from the key and authenticates the signal *(internal system activity)*. The system checks state of doors as unlocked *(internal system activity)*. The system locks all cabin doors and truck *(internal system activity)*.

Mission B: Provide Vehicle Access

Open Cabin Door

The system receives a **Cabin Door Open Control Force** from the user. The system opens the cabin door selected from the user *(internal system activity).*

Open Trunk Door

A. The system receives a **Trunk Door Open Signal** from the key. The system processes the electromagnetic signal from the key and authenticates it as a truck door open signal *(internal system activity).* The system opens the trunk door *(internal system activity)*.

B. *Alternatively,* the system receives a **Trunk Door Open Control Force** from the user. The system opens the trunk door.

The system receives **Items For Storage** from the user in the trunk space.

Mission C: Control Vehicle Engine

Start Engine

The system receives **Enable Engine Start Signal** from key. The system processes electromagnetic signals from the key and authenticates the signal *(internal system activity)*. The system changes engine start state to enabled *(internal system activity)*. The system receives a **Brake Control Force** from the user. The system monitors brake state *(internal system activity)*. The system changes brake state to pressed *(internal system activity)*. The System receives **Engine Control Force** from User. The system sends engine control signal to processor *(internal system activity).* The system checks state of engine as off *(internal system activity).* The System checks brake state as pressed *(internal system activity)*. The System checks state of engine start as enabled *(internal system activity)*. The system checks state of transmission is in parking *(internal system activity)*. The system begins engine start procedures *(internal system activity)*. The system uses the energy to turn on accessory functions *(internal system activity).*

Stop Engine

The System receives **Engine Control Force** from User. The system sends engine control signal to processor *(internal system activity).* The system checks state of engine as on *(internal system activity)*. The system checks state of vehicle transmission mode *(internal system activity)*.

A. Vehicle transmission state is in drive mode. The vehicle checks engine control signal is pressed for at least 2 seconds. The vehicle cuts power to the engine.

B. *Alternatively,* Vehicle transmission state is in parking mode. The vehicle cuts power to the engine.

Mission D: Manage Vehicle Power

Accelerate Vehicle

The vehicle receives **Fuel** from fuel station. The vehicle stores Fuel for later use *(internal system activity).* The system receives **Power Control Force** from user. The system monitors amplitude of power control force *(internal system activity).* The system monitors vehicle acceleration data *(internal system activity)*. The system monitors vehicle speed data *(internal system activity)*. The system monitors crank shaft position. The system processes vehicle speed data, acceleration data, crankshaft position data, and power control force data *(internal system activity).* The system injects fuel spray into internal combustion engine *(internal system activity)*. The system outputs ignition signals to engine cylinders *(internal system activity)*.

Manage Combustion

The system **intakes air**. The system utilizes air for fuel combustion *(internal system activity).* The system **exhausts fumes**. The system pumps engine coolant to engine subsystem *(internal system activity)*. The system dissipates heat from engine coolant to radiator subsystem *(internal system activity)*. The system **dissipates heat** to the driving environment.

Decelerate Vehicle

The system receives a **Brake Control Force** from User. The system monitors amplitude of braking control force *(internal system activity)*. The system monitors driving speed *(internal system activity).* The system multiplies pedal force as hydraulic force to Brake Pads *(internal system activity).* The system receives torque from brake pads to decelerate *(internal system activity)*.

Perform Regenerative Braking

The system receives a **Brake Control Force** from User. The system monitors amplitude of braking control force *(internal system activity)*. The system receives decelerating torque from the electric generator. The system delivers electric energy to the Traction Battery Pack *(internal system activity).*

Mission E: Provide Vehicle Control

Manage Vehicle Handling

The system receives **Vehicle Steering Control Forces** from user. The system amplifies vehicle steering control force through power steering subsystem *(internal system activity)*. The system increases torque received from engine subsystem with drive train subsystem *(internal system activity)*. The system transfers power from drive train subsystem to wheels *(internal system activity).* The system outputs **Road Traction Control Forces** to the driving environment**.** The system receives **Aerodynamic Drag.**

Manage Drivetrain State

The system receives **Drivetrain Control Force** from User. The system receives drivetrain mode selection from driveshaft subsystem *(internal system activity)*. The system provides drivetrain mode to power management subsystem *(internal system activity)*.

Mission F: Provide System Status

Monitor Powertrain Status

The system displays Internal Combustion Engine (ICE) Revolutions Per Minute (RPM), **ICE RPM Data.** The system displays **Traction Motor status Data,** whether the Traction Motors are being used for auxiliary wheel torque or regenerative braking. The system monitors Engine *(internal system activity).* The system displays **Engine Warning Signal** if engine has an issue. The system monitors Engine Oil *(internal system activity).* The system displays **Oil Warning Signal** if engine has low oil.

Monitor Drivetrain Status

The system monitors angular speed of drive shaft *(internal system activity).* The system processes total revolutions and outputs updates to Odometer tally *(internal system activity).* The system displays **Odometer Data** to the user. The system monitors angular speed of drive shaft *(internal system activity)*. The system provides **Vehicle Speed** to user**.** The system monitors Tire pressure *(internal system activity)*. The system provides **Tire Pressure Data** to the User. The system provides **Tire Pressure Warning Signal** to user if pressure falls below a certain threshold.

Monitor Crash Safety

The system receives **User Body Weight** from passenger seating. The system monitors seatbelt engagement *(internal system activity)*. The system sets/checks Airbag deployment state *(internal system activity).* The system provides **Airbag Warning Signal** if necessary.

Monitor Energy

The system monitors Fuel Capacity Data *(internal system activity).* The system displays **Fuel Capacity Data** to user. The system monitors fuel line flow rate *(internal system activity).* The system monitors vehicle speed *(internal system activity).* The system processes distance traveled *(internal system activity).* The system processes miles per gallon of fuel *(internal system activity).* The system displays **Fuel Efficiency** data. The system monitors Traction Battery Voltage *(internal system activity).* The system monitors Traction Battery discharge *(internal system activity).* The system processes Traction Battery Capacity Data *(internal system activity).* The system displays **Traction Battery Capacity Data**.

Mission G: Handle Environmental Conditions

Handle Environmental Conditions

The system receives weather conditions from the driving environment in the form of **Rain, Snow, Sleet, Mud, Dirt, Dust,** and **UV Light, Heat**, etc.

Mission H: Receive Vehicle Maintenance

Receive Maintenance

The system provides used **Engine Oil**, Worn/Damaged **Vehicle Parts**, Dirty **Lubricant,** Old **Transmission Fluid,** Used **Engine Coolant, Power Steering Fluid, Windshield Wiper Fluid,** and **Brake Fluid** to the maintenance facility**.** The system receives new **Engine Oil**, new **Vehicle Parts**, new **Lubricant,** new **Transmission Fluid,** new **Engine Coolant, Power Steering Fluid, Windshield Wiper Fluid,** and **Brake Fluid** from the maintenance facility**.**

Context Diagram:

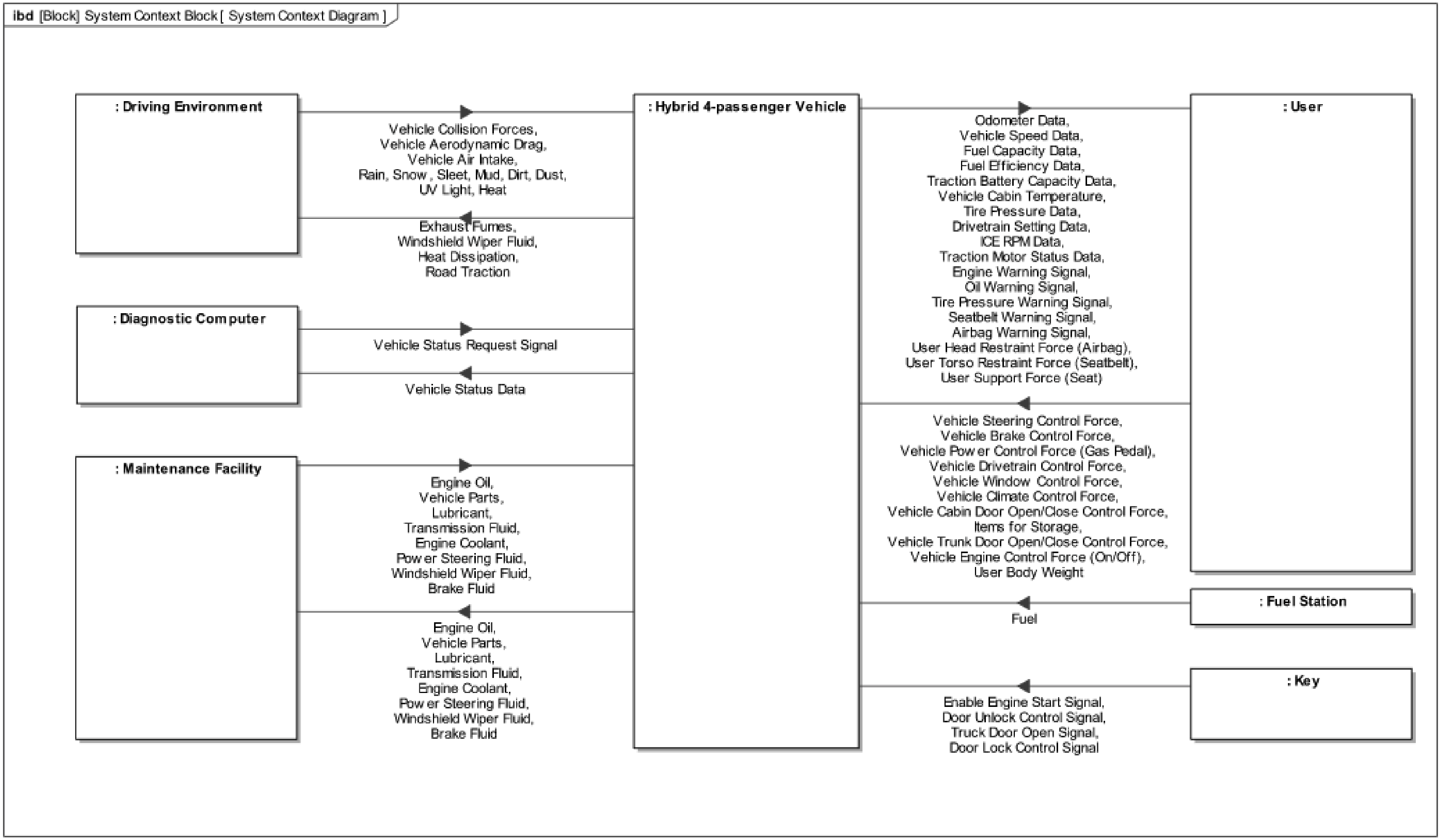

Figure 1: Context Diagram

Requirements

Capability Requirements

REQ.1.1 The hybrid car shall carry as many passengers as the conventionally powered car.

REQ.1.2 The hybrid car shall have the ability to drive on rough surfaces.

REQ.1.3 The hybrid car shall operate in multiple weather conditions.

REQ.1.4 The hybrid car shall respond to various user commands as fast as current voice control technology.

REQ.1.5 The hybrid car shall have the ability to use multiple power sources.

REQ 1.6 The hybrid car shall recharge as fast (or faster) than the modern hybrid/electric vehicle.

REQ 1.7 The hybrid car shall provide a quick and simple user interface.

REQ 1.8 The hybrid car shall respond to various user commands as fast (or faster than) current vehicle technology.

Requirements Hierarchy

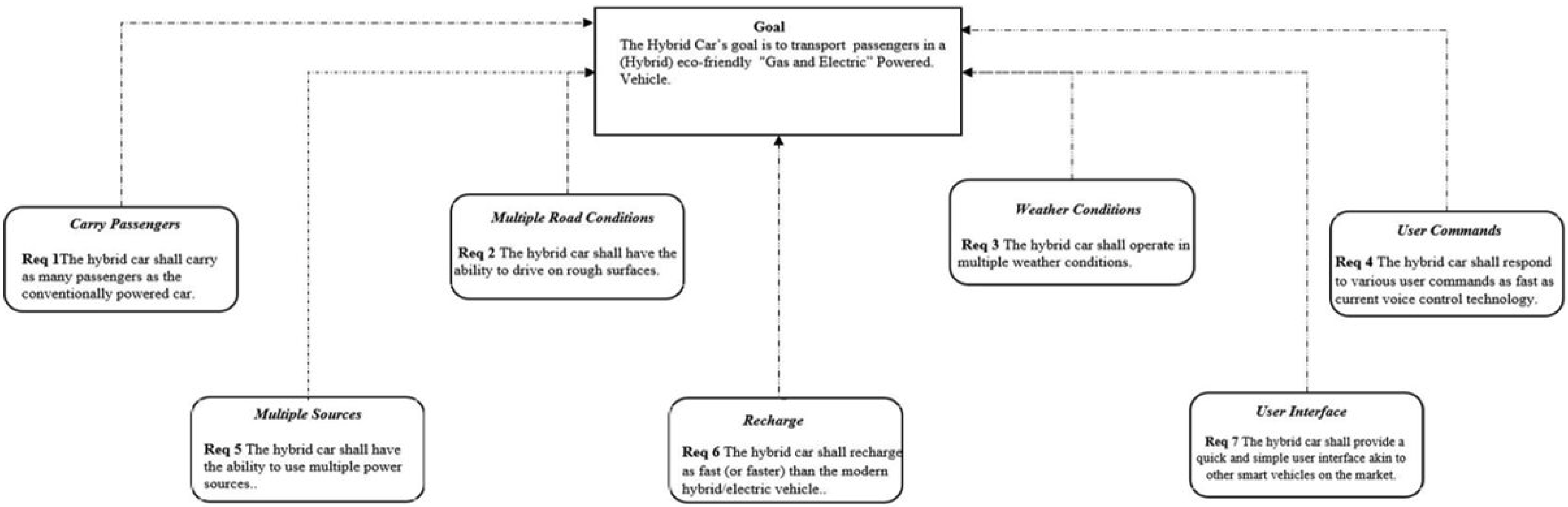

Figure 2: Requirements Hierarchy

Requirement Traceability Matrix:

Table 1: Requirement Traceability Matrix

Name	Text	Derived	Derived From	Validated By	Verified By
REQ.1 Goals		REQ.1.1 Carry Passengers REQ.1.2 Drive on Multiple Surfaces REQ.1.3 Operate in Multiple WX conditions REQ.1.4 Respond to User Voice Commands REQ.1.5 Use Multiple Power Sources REQ.1.6 Recharge REQ.1.7 User Interface			
REQ.1.1 Carry Passengers	The hybrid car shall carry as many passengers as the conventionally powered car. 4 (T), 5 (O)		REQ.1 Goals	Inspection	

REQ.1.2 Drive on Multiple Surfaces	The hybrid car shall have the ability to drive on rough surfaces. International Roughness Index (IRI) of 170 in/mile (T), 200 in/mile (O)		REQ.1 Goals		Simulation, Prototyping (Fatigue Testing)
REQ.1.3 Operate in Multiple WX conditions	The hybrid car shall operate in multiple weather conditions.	REQ.1.3.1 Hot REQ.1.3.2 Cold REQ.1.3.3 Snow REQ.1.3.4 Rain REQ.1.3.5 Hail	REQ.1 Goals	Test	
REQ.1.3.1 Hot	The hybrid car's engine shall continuously operate at temperatures as high as 195ºF(T), 220ºF(O) over a 30-day period.		REQ.1.3 Operate in Multiple WX conditions		Simulation, Prototyping (Environmental Testing)
REQ.1.3.2 Cold	The hybrid car shall continuously operate at temperatures as low as 32ºF (T), -40ºF (O) over a 30-day period.		REQ.1.3 Operate in Multiple WX conditions		Simulation, Prototyping (Environmental Testing)
REQ.1.3.3 Snow	The hybrid car's tire shall operate in up to 4" (T), 8" (O) of snow over a 7-day period.		REQ.1.3 Operate in Multiple WX conditions		Simulation, Prototyping (Environmental Testing)
REQ.1.3.4 Rain	The hybrid car shall operate in up to 4" (T), 6" (O) of rain over a 7-day period.		REQ.1.3 Operate in Multiple WX conditions		Simulation, Prototyping (Environmental Testing)

REQ.1.3.5 Hail	The hybrid car shall endure hails stones up to 0.31” (T), 0.96” (O) in diameter over the duration of a ride.		REQ.1.3 Operate in Multiple WX conditions		Simulation, Prototyping (Environmental Testing)
REQ.1.4 Respond to User Voice Commands	The hybrid car shall respond to various user commands as fast as current voice control technology.	REQ.1.4.1 Call REQ.1.4.2 Play Music REQ.1.4.3 Navigate Home REQ.1.4.4 Optimize Temp REQ.1.4.5 Voice Memo	REQ.1 Goals	Test & Analysis	
REQ.1.4.1 Call	The hybrid car shall respond to call (blank) commands in 5.5 seconds (T), 3.5 seconds (O).		REQ.1.4 Respond to User Voice Commands		Prototyping (Performance analysis & Testing)
REQ.1.4.2 Play Music	The hybrid car shall respond to play music commands 5.5 seconds (T), 3.5 seconds (O).		REQ.1.4 Respond to User Voice Commands		Prototyping (Performance analysis & Testing)
REQ.1.4.3 Navigate Home	The hybrid car shall respond to navigate home 5.5 seconds (T), 3.5 seconds (O).		REQ.1.4 Respond to User Voice Commands		Prototyping (Performance analysis & Testing)
REQ.1.4.4 Optimize Temp	1.4.4 The hybrid car shall respond to optimize temp 5.5 seconds (T), 3.5 seconds (O).		REQ.1.4 Respond to User Voice Commands		Prototyping (Performance analysis & Testing)

REQ.1.4.5 Voice Memo	The hybrid car shall respond to voice memos in 5.5 seconds (T), 3.5 seconds (O).		REQ.1.4 Respond to User Voice Commands		Prototyping (Performance analysis & Testing)
REQ.1.5 Use Multiple Power Sources	The hybrid car shall have the ability to use multiple power sources.	REQ.1.5.1 Internal Combustion Engine REQ.1.5.2 Electric Battery	REQ.1 Goals	Test & Analysis	
REQ.1.5.1 Internal Combustion Engine	The hybrid car's Internal Combustion Engine (on full tank) shall take the driver 300 miles (T), 350 miles (O).		REQ.1.5 Use Multiple Power Sources		Prototyping (Performance analysis & Testing)
REQ.1.5.2 Electric Battery	The hybrid car's electric battery (on full charge) shall take the driver 30 miles (T), 50 miles (O).		REQ.1.5 Use Multiple Power Sources		Prototyping (Performance analysis & Testing)
REQ.1.6 Recharge	The hybrid car shall recharge as fast (or faster) than the modern hybrid/electric vehicle.	REQ.1.6.3 Recharge w/ Fast Charing	REQ.1 Goals	Test & Analysis	
REQ.1.6.1 Recharge w/ 240V	The hybrid car shall recharge (on average) in 1.5 hours (T), 1 hour using a 240V charging station.				Simulation, Prototyping (Performance analysis & Testing)
REQ.1.6.2 Recharge w/ 120V	The hybrid car shall recharge (on average) in 3 hours (T), 2.5 hours (O) using a 120V charging station.				Simulation, Prototyping (Performance analysis & Testing)

REQ.1.6.3 Recharge w/ Fast Charging	The hybrid car shall recharge to 80% in 20 minutes (T), 15 minutes (O) with fast charging.		REQ.1.6 Recharge		Simulation, Prototyping (Performance analysis & Testing)
REQ.1.7 User Interface	The hybrid car shall provide a quick and simple user interface.	REQ.1.7.1 Drivers Screen REQ.1.7.2 Center Console Screen	REQ.1 Goals	Test & Analysis	
REQ.1.7.1 Drivers Screen	The hybrid car shall provide an accurate and simple driver screen.	REQ.1.7.1.1 Speedometer REQ.1.7.1.2 Tachometer	REQ.1.7 User Interface		
REQ.1.7.1.1 Speedometer	The hybrid car's speedometer reading shall report 95% (T), 100% (O) accuracy.		REQ.1.7.1 Drivers Screen		Prototyping (Performance analysis & Testing)
REQ.1.7.1.2 Tachometer	The hybrid car's tachometer reading shall report 90% (T), 100% (O) accuracy.		REQ.1.7.1 Drivers Screen		Prototyping (Performance analysis & Testing)
REQ.1.7.2 Center Console Screen	The hybrid car shall provide a quick and simple center console.	REQ.1.7.2.4 Apps REQ.1.7.2.8 Car Settings REQ.1.7.2.6 Climate Controls REQ.1.7.2.2 Messaging REQ.1.7.2.7 Parking Assistant REQ.1.7.2.5	REQ.1.7 User Interface		

		Navigation REQ.1.7.2.3 Telephony REQ.1.7.2.1 Radio			
REQ.1.7.2.1 Radio	The hybrid car's radio shall have an average time to find of 10 seconds (T), 5 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.2 Messaging	The hybrid car's messaging shall have an average time to find of 30 seconds (T), 10 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.3 Telephony	The hybrid car's telephone shall have an average time to find of 20 seconds (T), 5 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.4 Apps	The hybrid car's apps shall have an average time to find of 30 seconds (T), 5 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.5 Navigation	The hybrid car's navigation shall have an average time to find of 30 seconds (T), 10 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation

REQ.1.7.2.6 Climate Controls	The hybrid car's climate controls shall have an average time to find of 10 seconds (T), 5 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.7 Parking Assistant	The hybrid car's parking assistant shall have an average time to find of 30 seconds (T), 10 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.7.2.8 Car Settings	The hybrid car's car settings shall have an average time to find of 45 seconds (T), 20 seconds (O).		REQ.1.7.2 Center Console Screen		Simulation
REQ.1.8 Respond to User Commands	The hybrid car shall respond to various user commands as fast as (or faster than) current vehicle technology.			Test & Analysis	
REQ.1.8.1 Accelerate	The hybrid car shall accelerate to 62 mph in 4.4 seconds (T) 3.4 (O) seconds.				Simulation, Prototyping (Performance analysis & Testing)
REQ.1.8.2 Brake	The hybrid car shall have an average dry braking distance from 60-0 mph of 120 ft (T), 110 ft (O)				Simulation, Prototyping (Performance analysis & Testing)
REQ.1.8.3 Directional Control	The hybrid car shall have wheel alignment accuracy of 99% (T), 100%				Simulation, Prototyping (Performance analysis & Testing)

Functional Architecture:

Tier 2: Perform Vehicle Operations

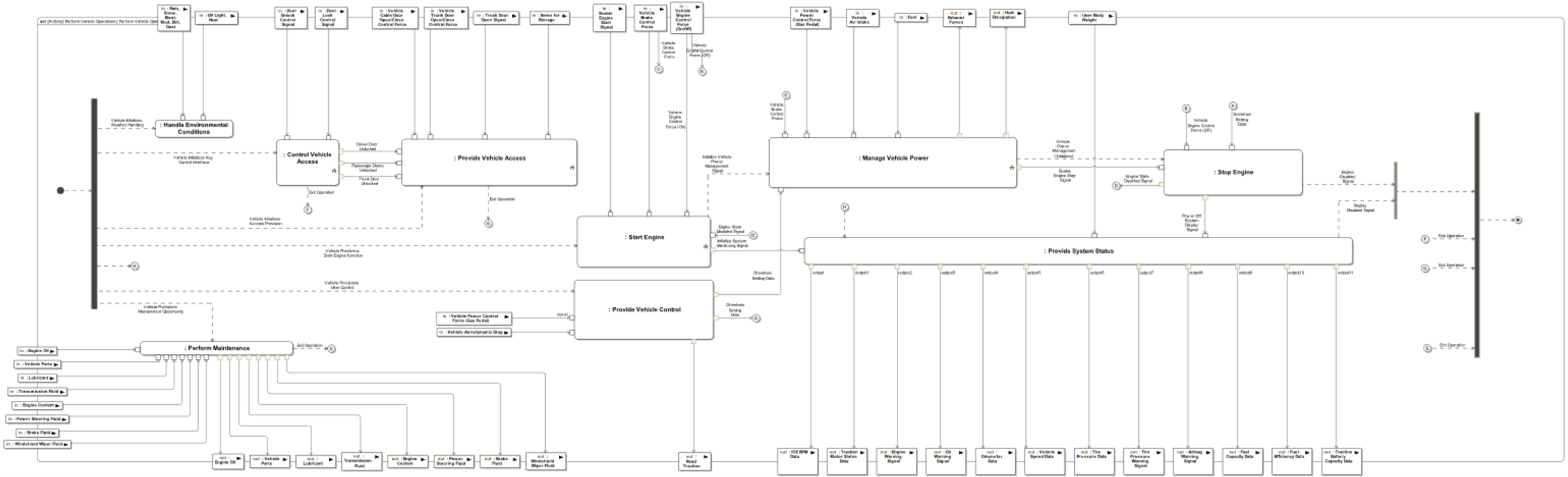

Figure 3: Hybrid 4-Passenger Vehicle Tier 2 Functional Architecture

Tier 3: Control Vehicle Access

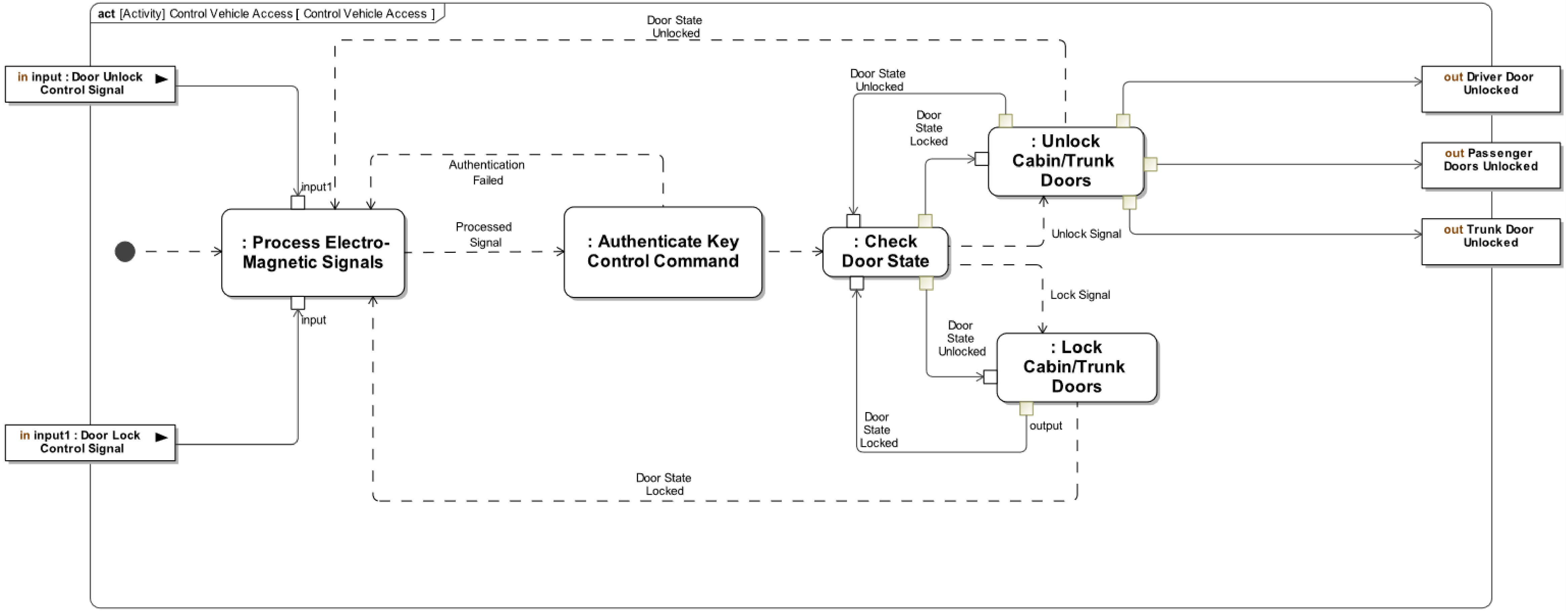

Figure 4: Control Vehicle Access Tier 3 Functional Architecture

Tier 3: Provide Vehicle Access

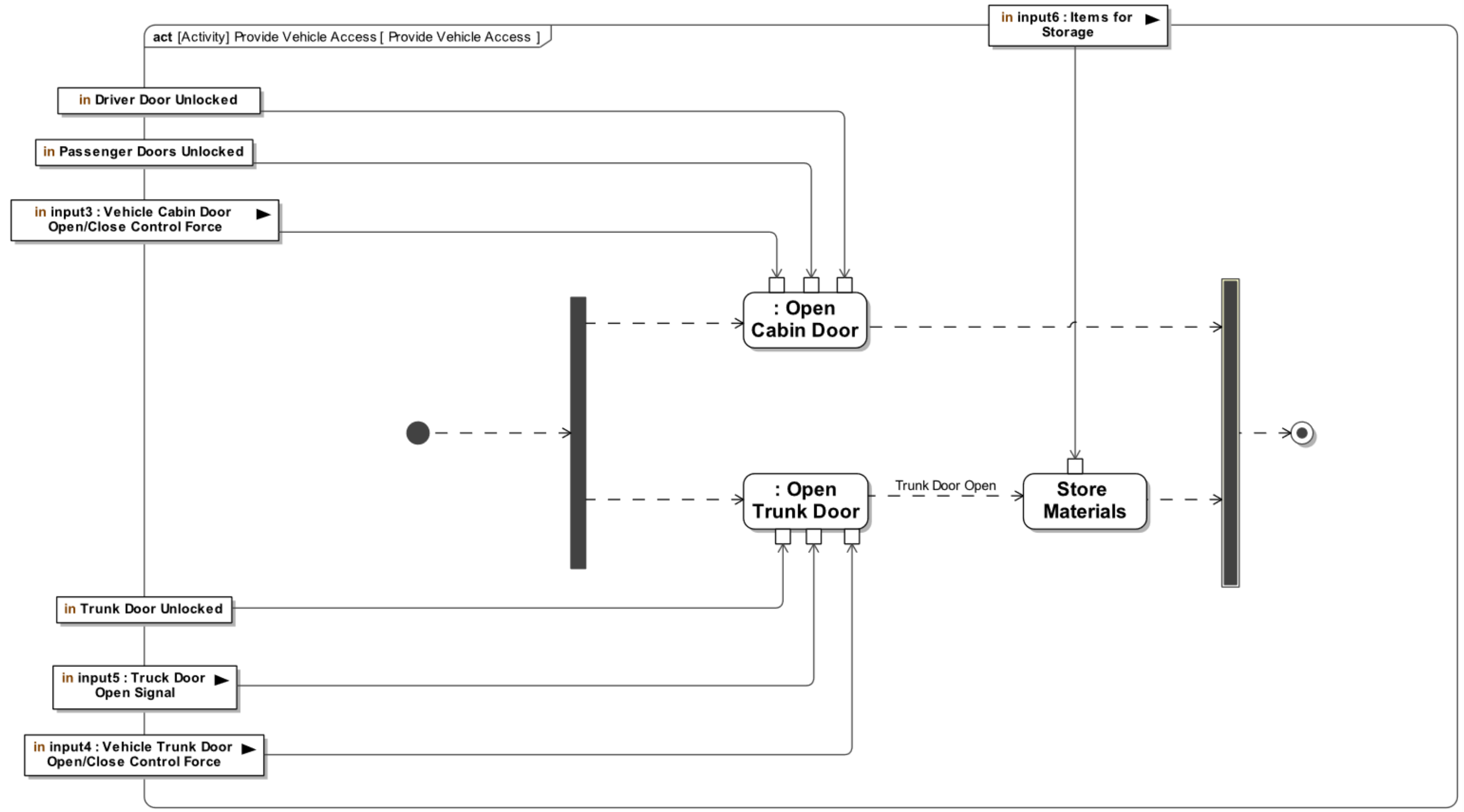

Figure 5: Provide Vehicle Access Tier 3 Functional Architecture

Tier 3: Start Vehicle Engine

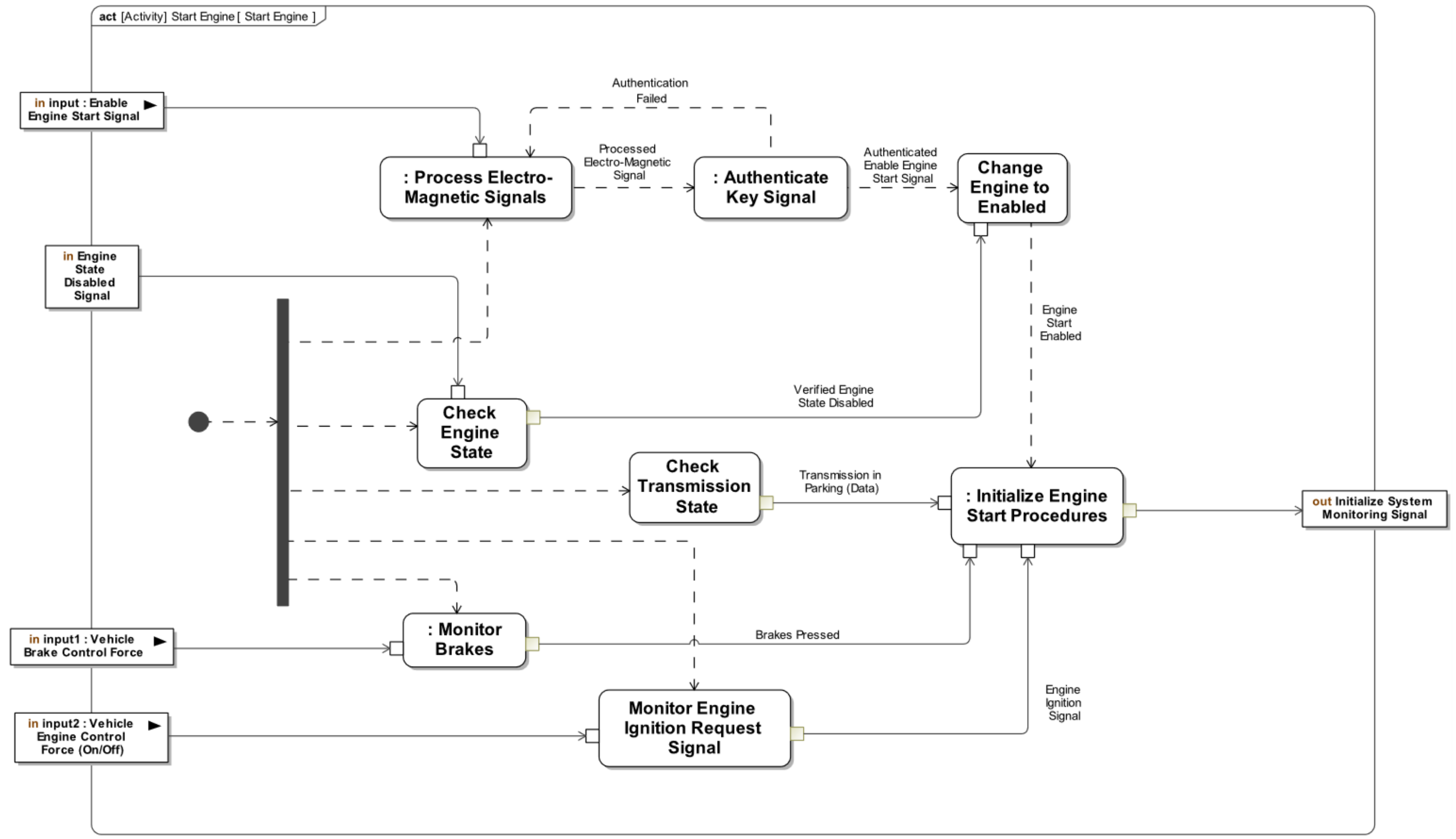

Figure 6: Start Vehicle Engine Tier 3 Functional Architecture

Tier 3: Manage Vehicle Power

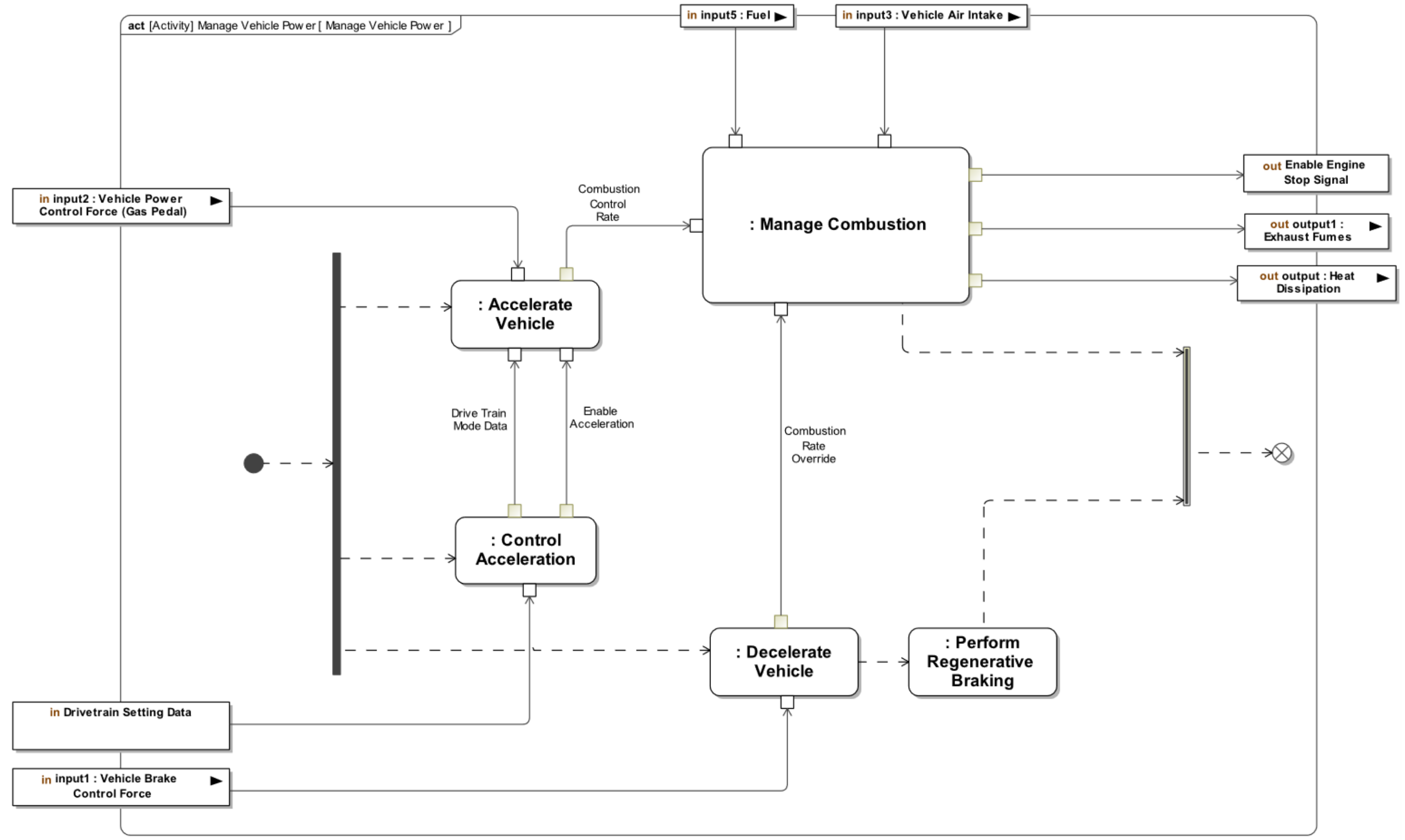

Figure 7: Manage Vehicle Power Tier 3 Functional Architecture

Tier 3: Provide Vehicle Control

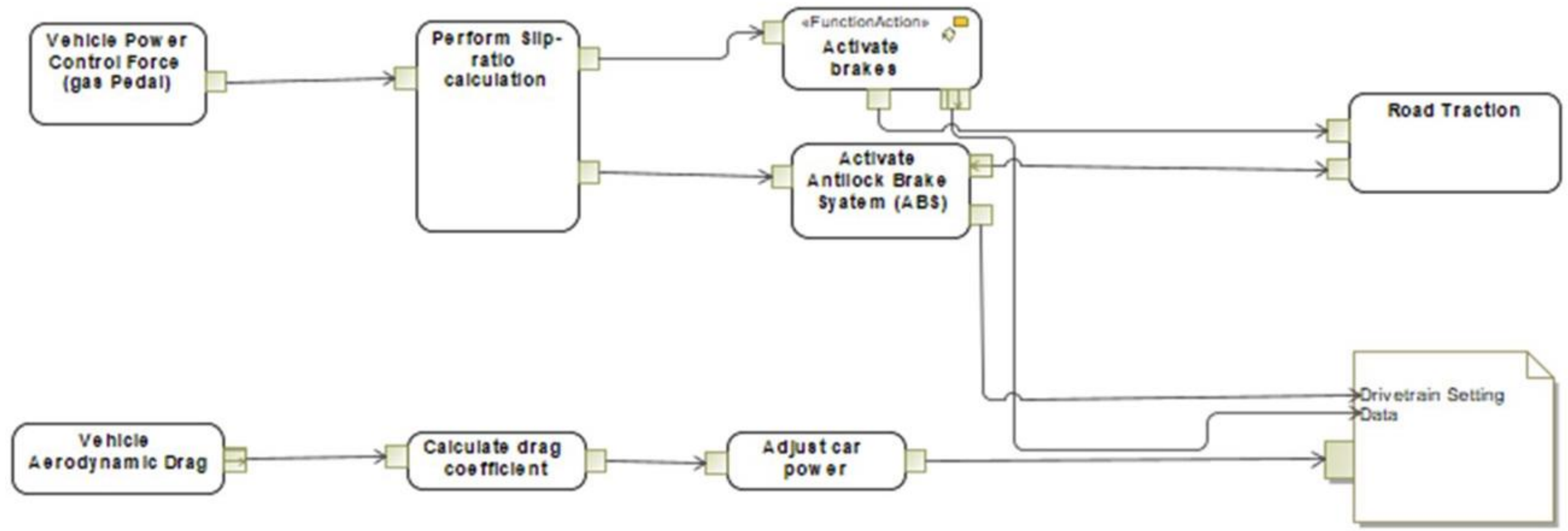

Figure 8: Provide Vehicle Control Tier 3 Functional Architecture

Tier 3: Provide System Status

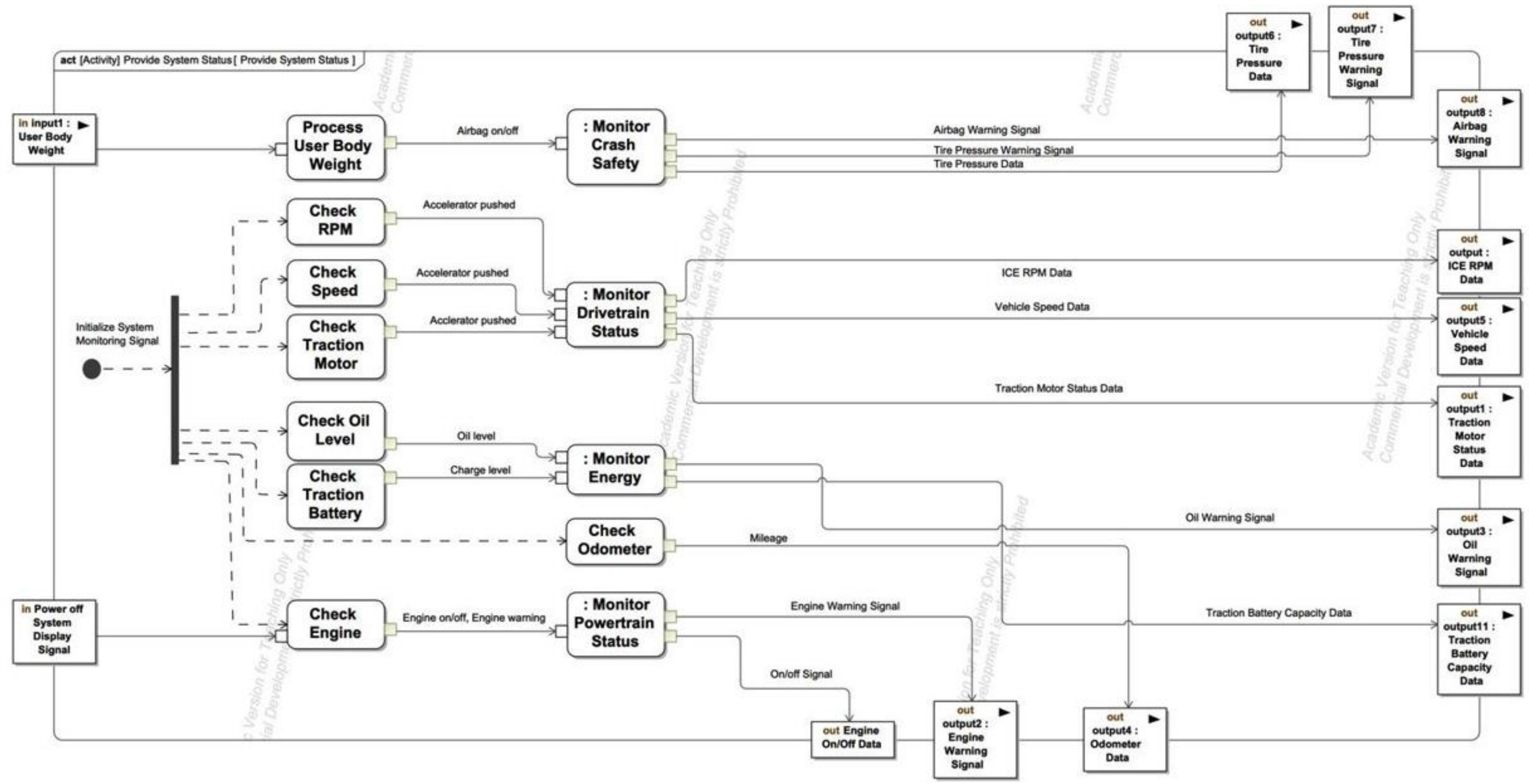

Figure 9: Provide System Status Tier 3 Functional Architecture

Physical Architecture

Tier 2: Hybrid 4-Passenger Vehicle System Physical Hierarchy

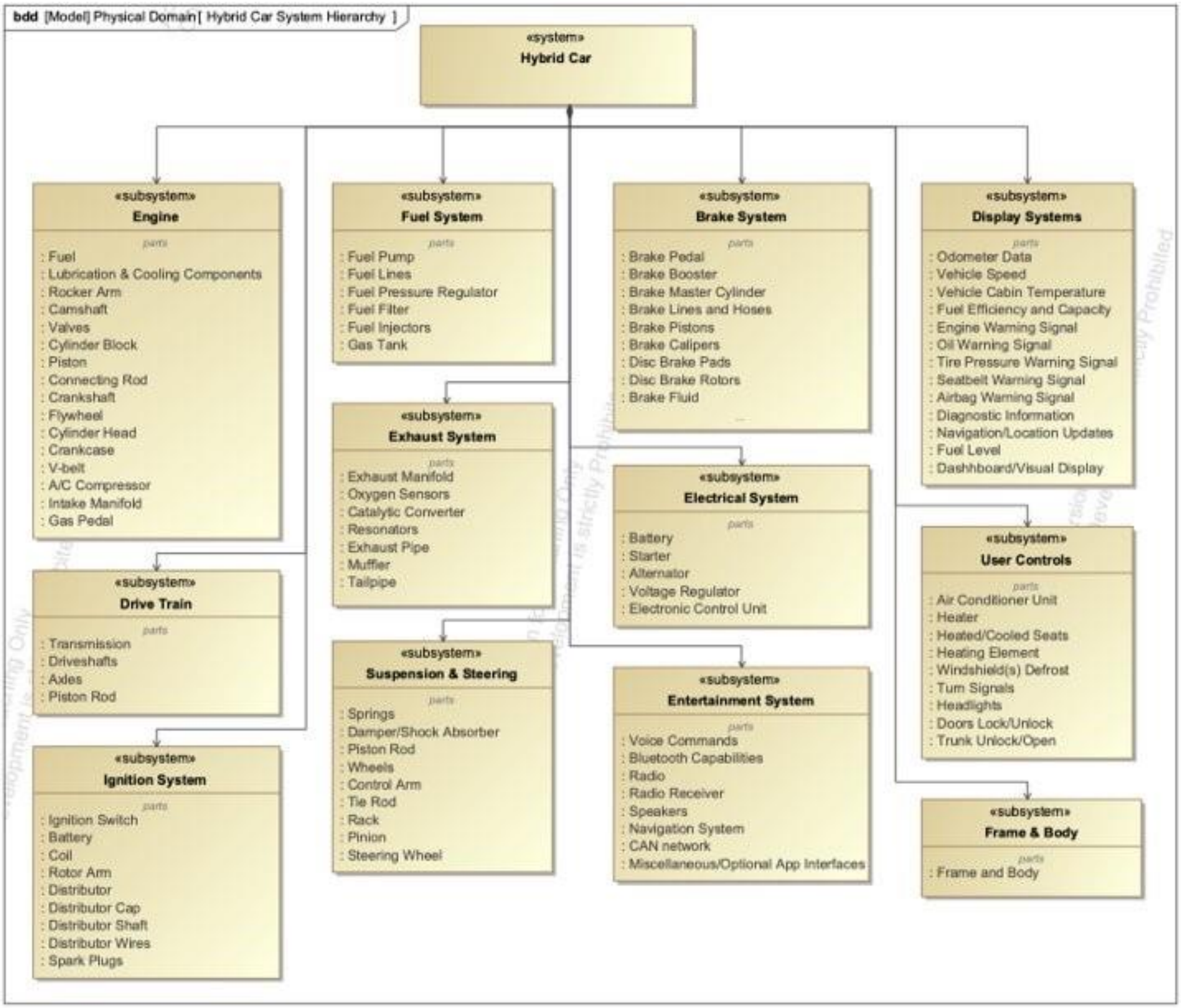

Figure 10: Hybrid 4-Passenger Vehicle Tier 2 Physical Hierarchy

Tier 2: Hybrid 4-Passenger Vehicle Tier 2 Internal Block Diagram

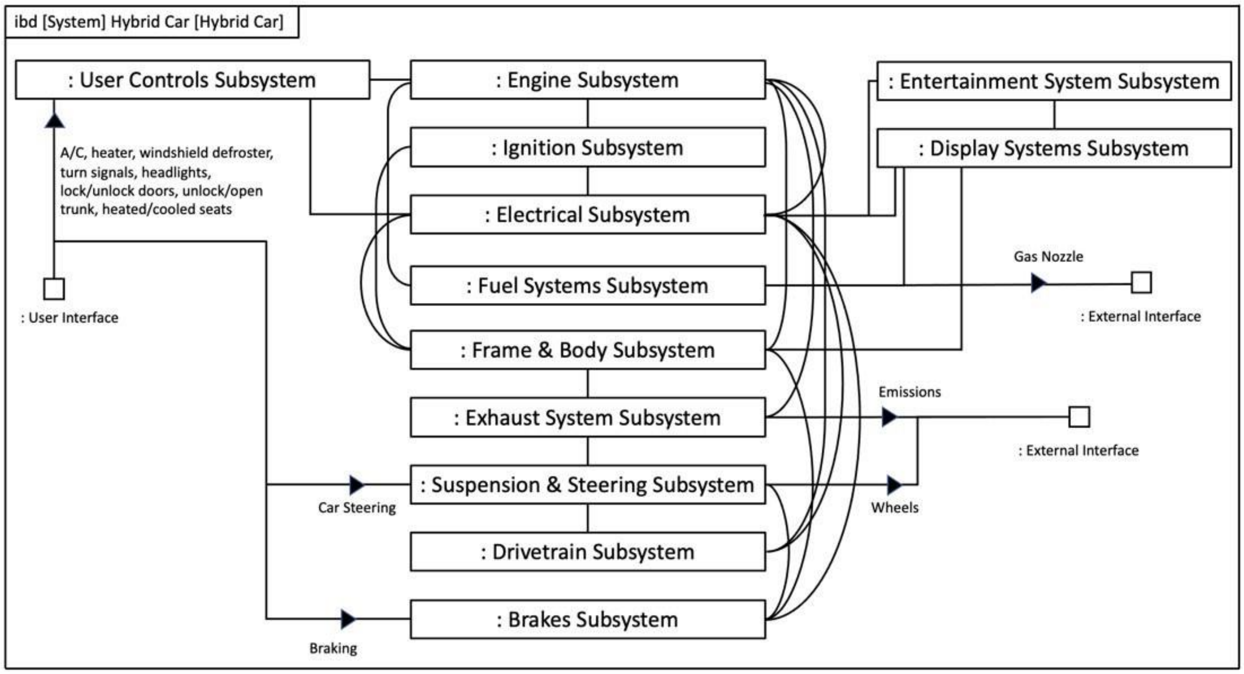

Figure 11: Hybrid 4-Passenger Vehicle Tier 2 Physical Hierarchy

Tier 3: Engine Subsystem Physical Architecture

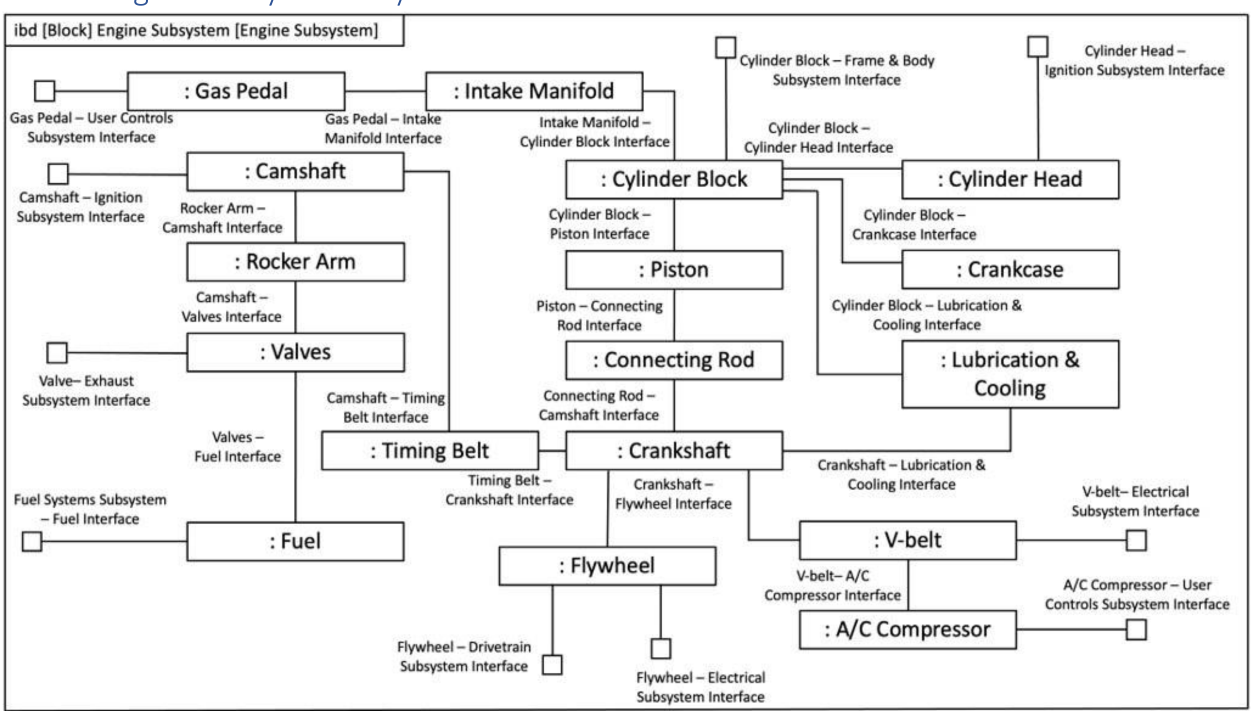

Figure 12: Engine Subsystem Tier 3 Physical Architecture

Tier 3: Drivetrain Subsystem Physical Architecture

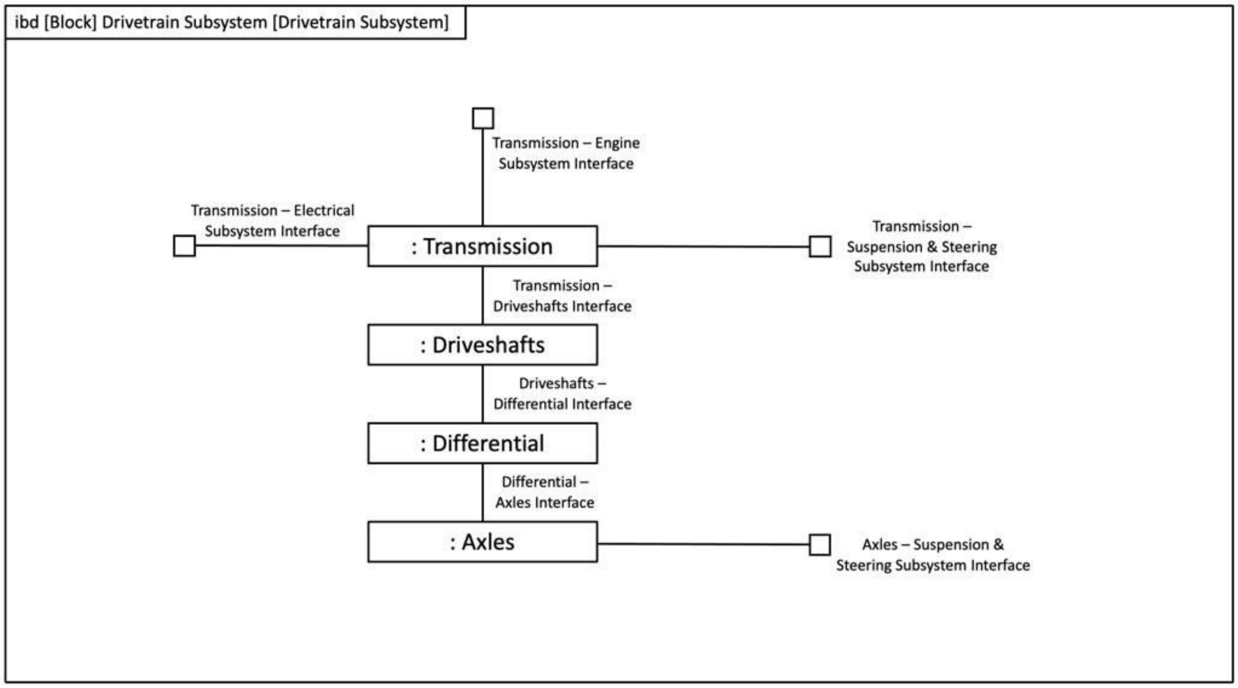

Figure 13: Drivetrain Subsystem Tier 3 Physical Architecture

Tier 3: Ignition Subsystem Physical Architecture

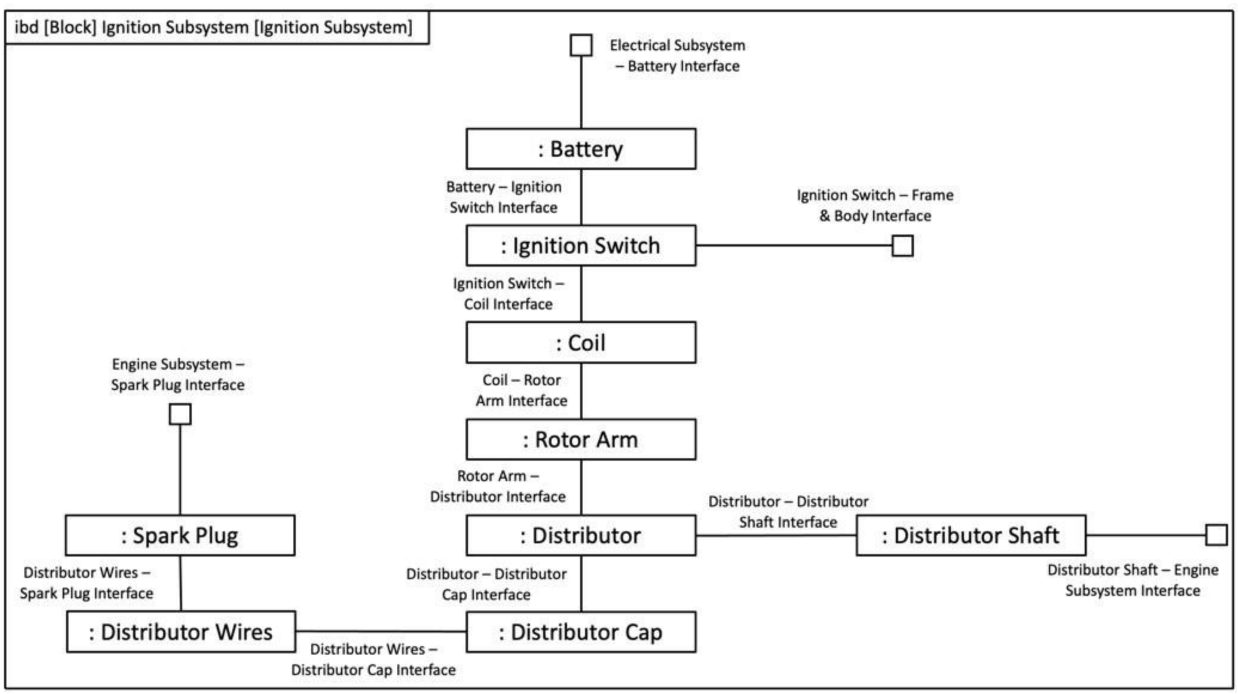

Figure 14: Ignition Subsystem Tier 3 Physical Architecture

Tier 3: Fuel Handling Subsystem Physical Architecture

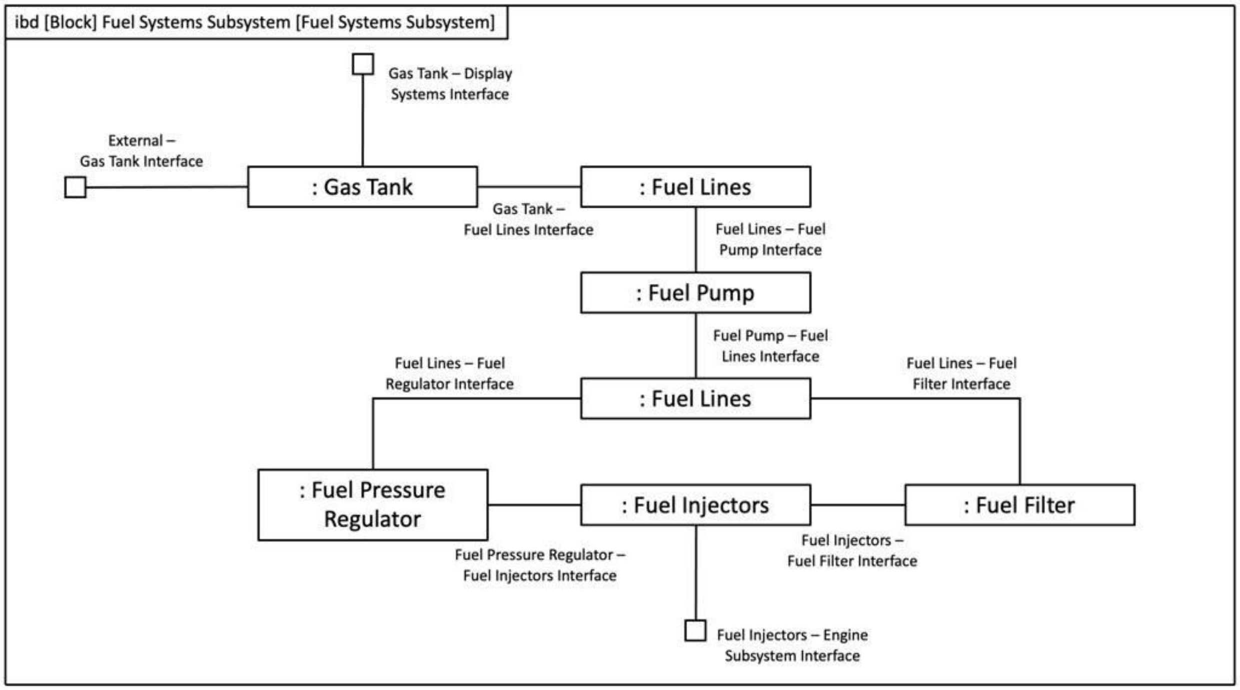

Figure 15: Fuel Handling Subsystem Tier 3 Physical Architecture

Tier 3: Exhaust Handling Subsystem Physical Architecture

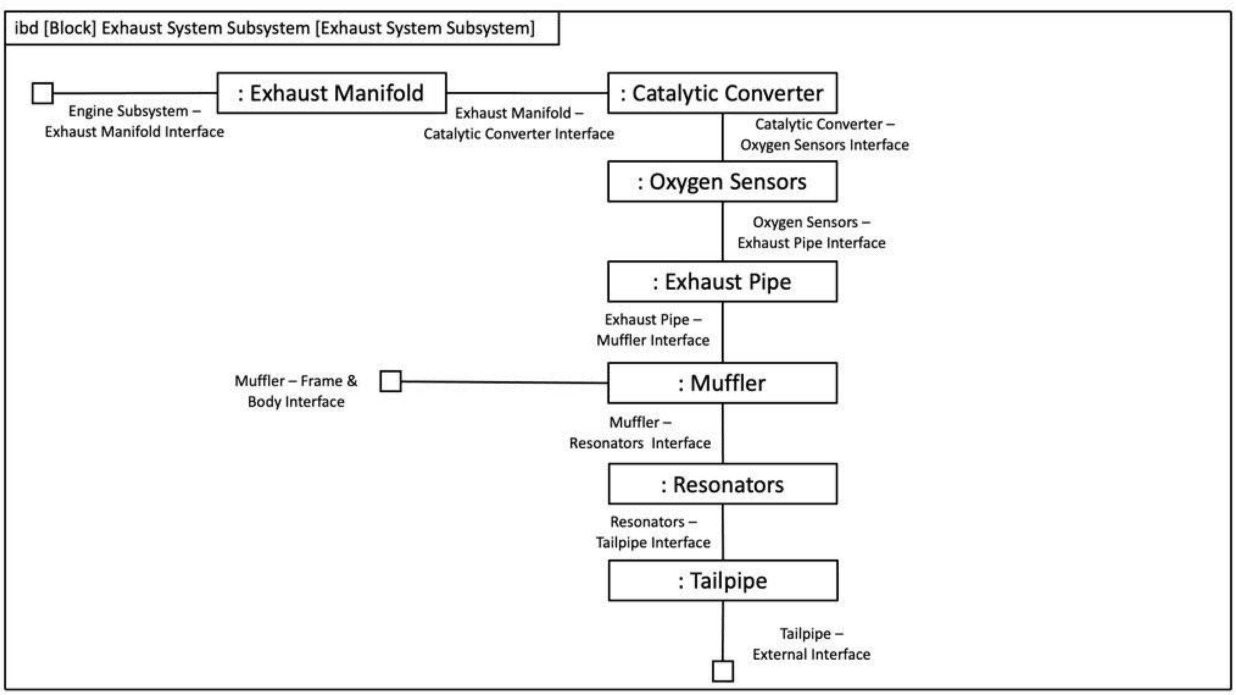

Figure 16: Exhaust Handling Subsystem Tier 3 Physical Architecture

Tier 3: Electrical Subsystem Physical Architecture

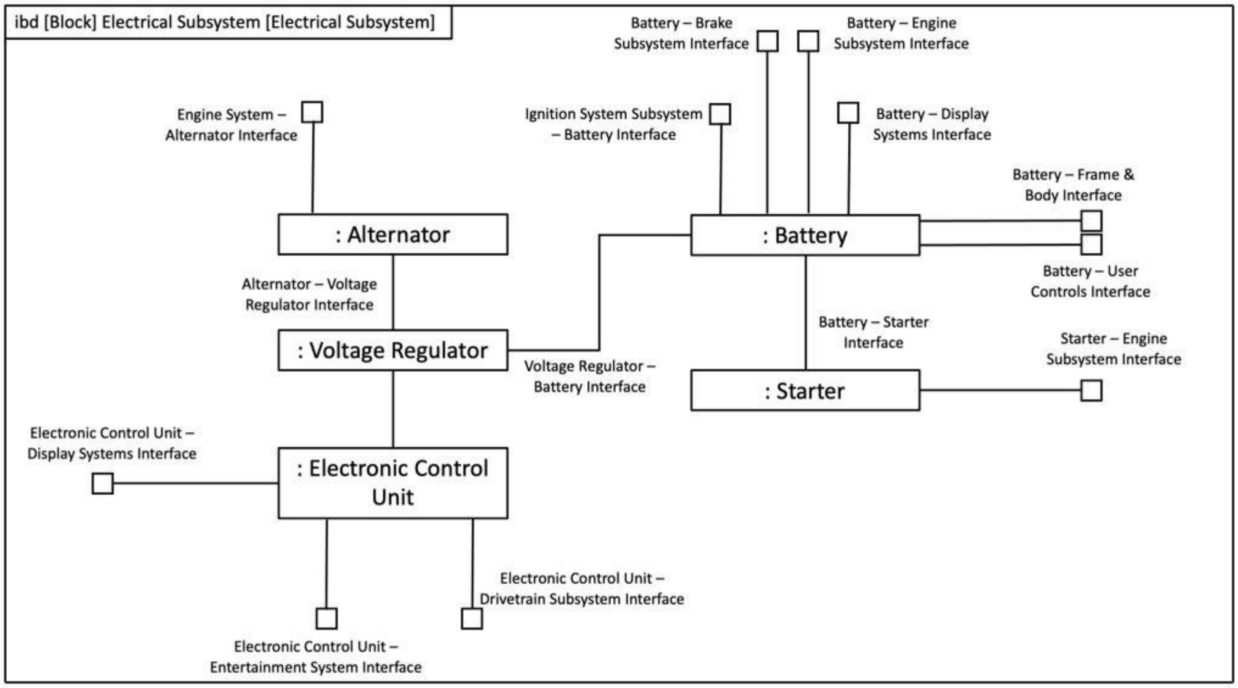

Figure 17: Electrical Subsystem Tier 3 Physical Architecture

Tier 3: Suspension & Steering Subsystem Physical Architecture

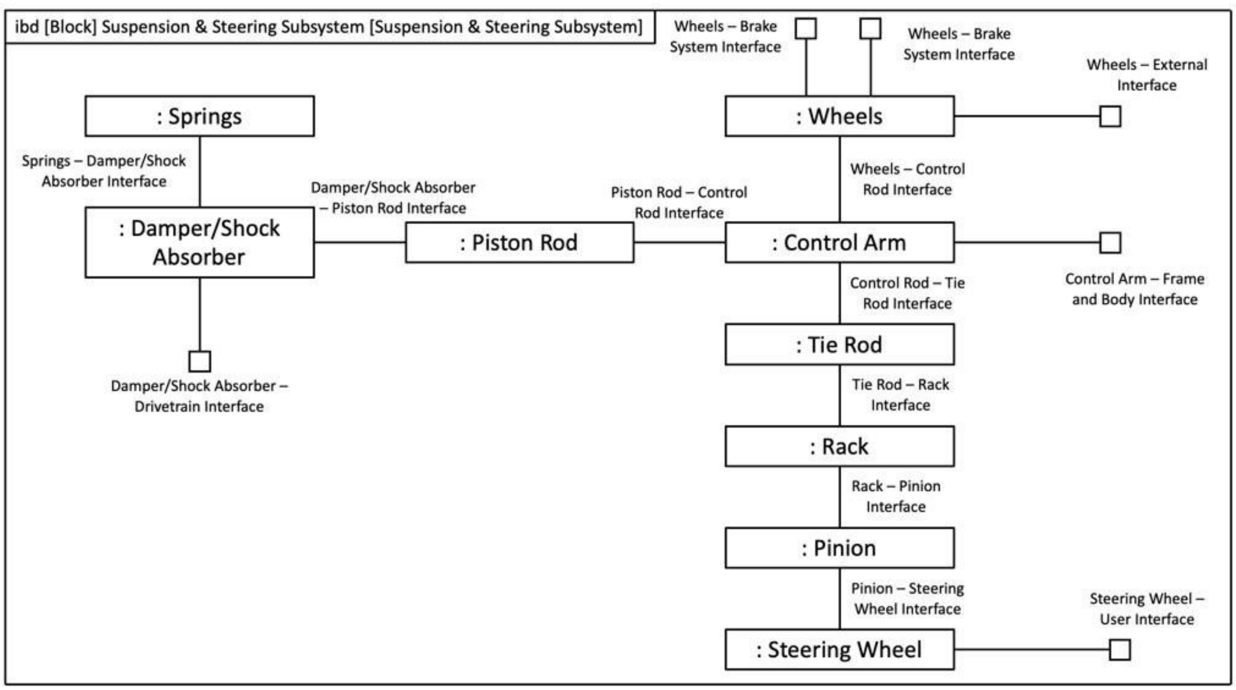

Figure 18: Suspension & Steering Subsystem Tier 3 Physical Architecture

Tier 3: Brake Subsystem Physical Architecture

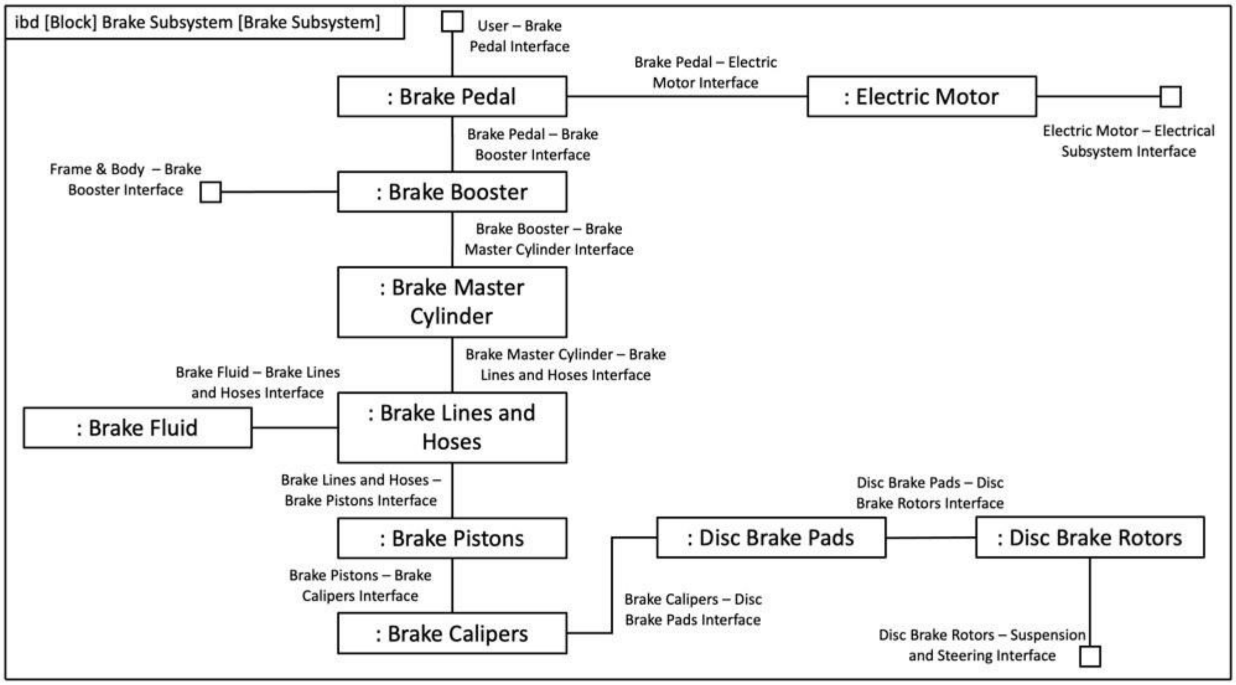

Figure 19: Brake Subsystem Tier 3 Physical Architecture

Tier 3: Entertainment Subsystem Physical Architecture

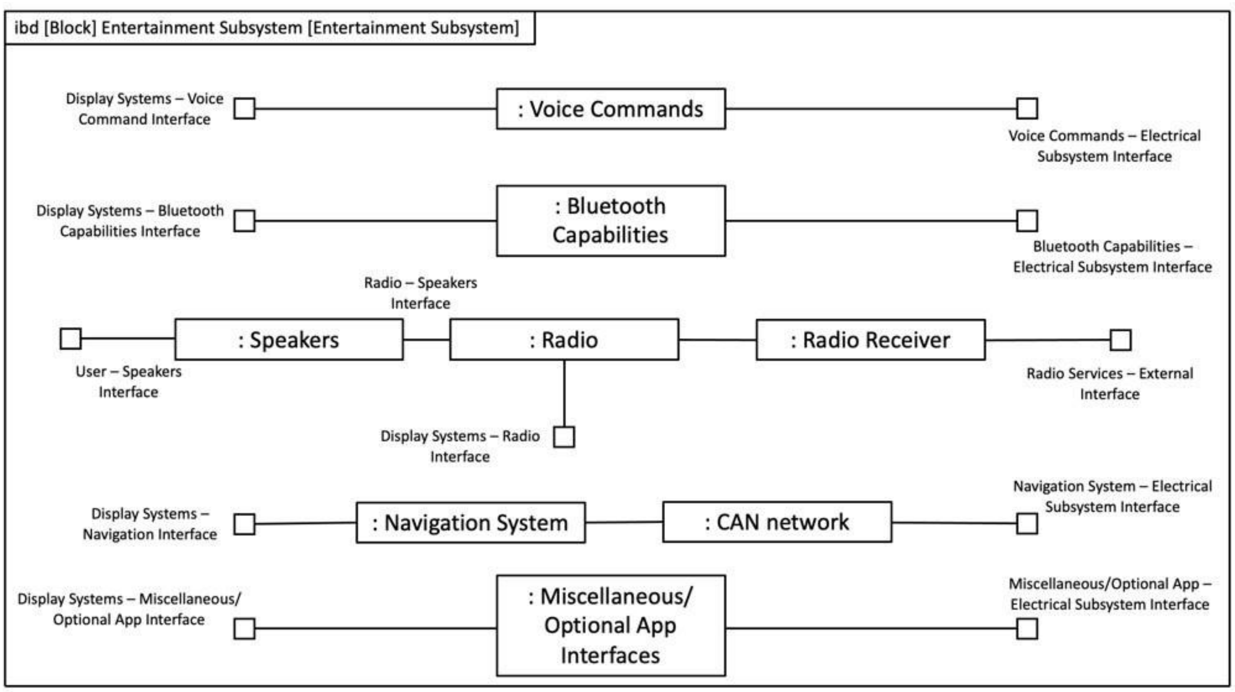

Figure 20: Entertainment Subsystem Tier 3 Physical Architecture

Tier 3: User Controls Subsystem Physical Architecture

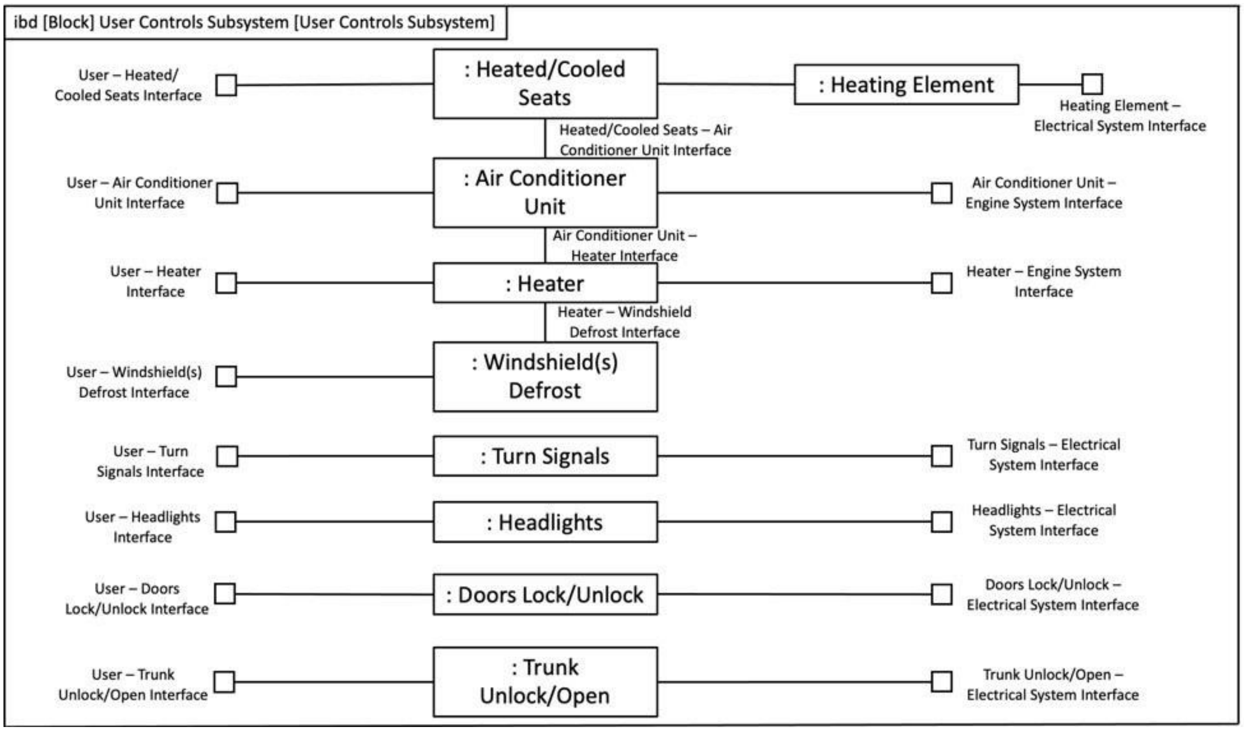

Figure 21: User Controls Subsystem Tier 3 Physical Architecture

Tier 3: Display Subsystem Physical Architecture

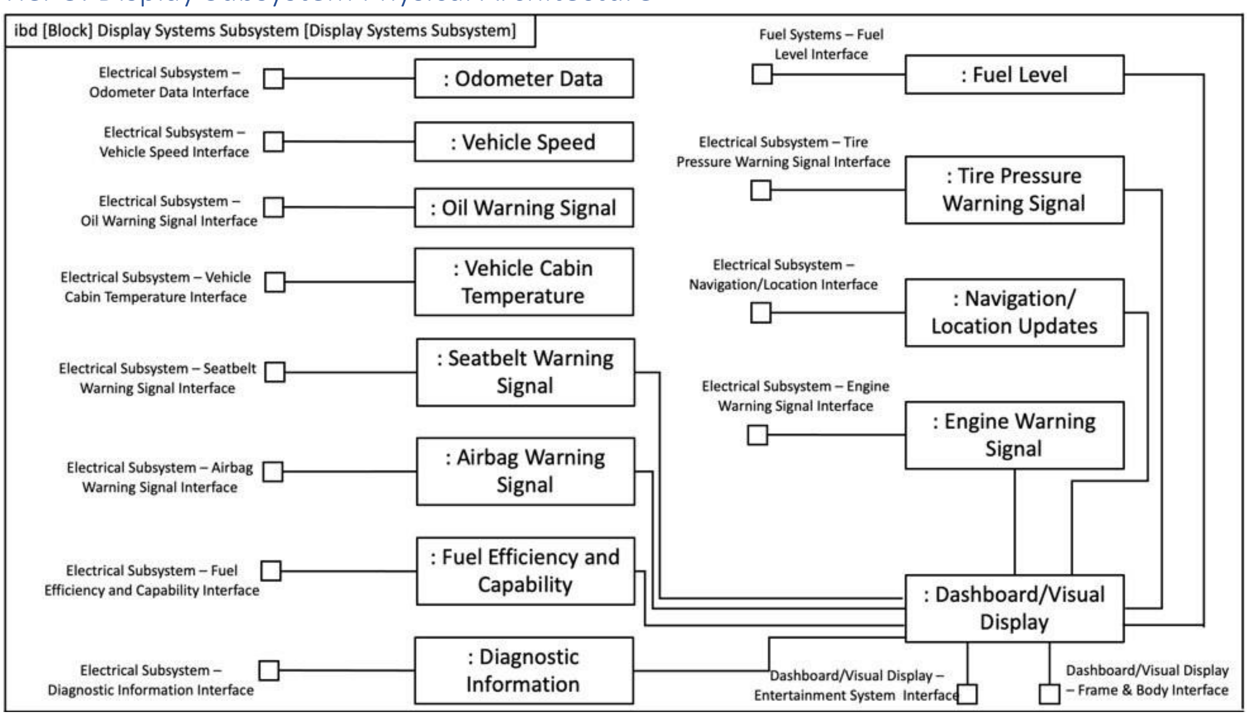

Figure 22 Display Subsystem Tier 3 Physical Architecture

Tier 3: Frame & Body Physical Architecture

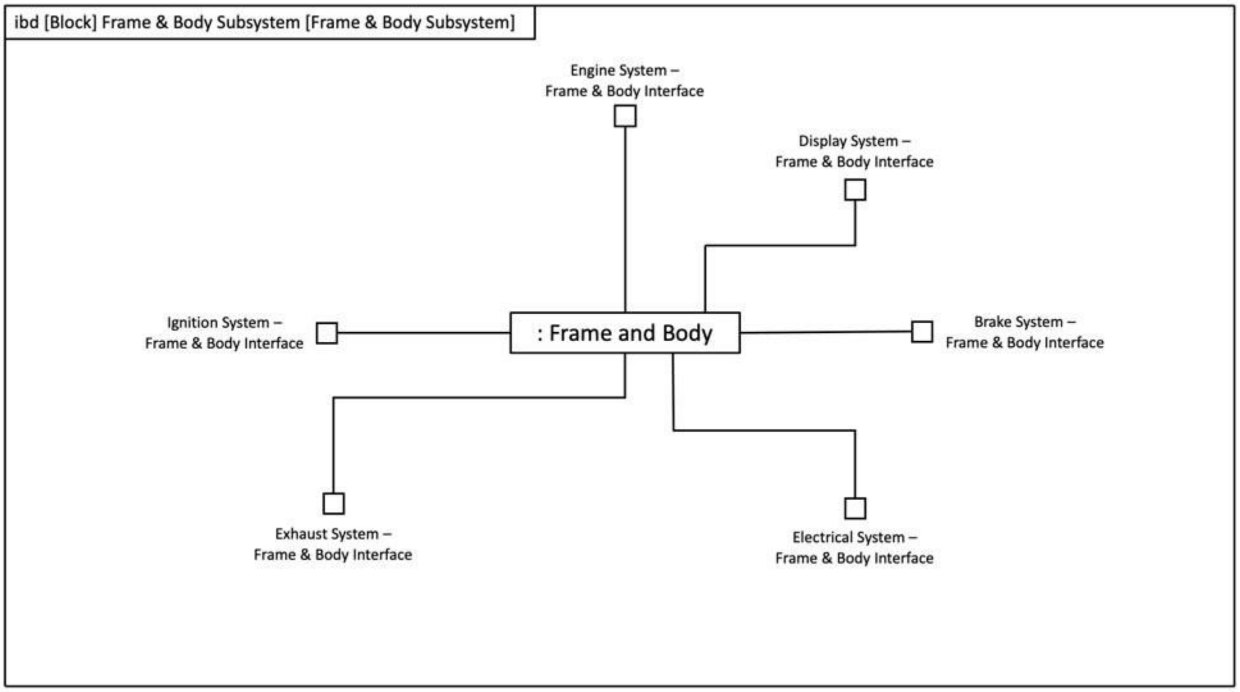

Figure 23: Frame and Body Tier 3 Physical Architecture

Functional to Physical Allocation Matrix

Table 2: Hybrid 4-Passenger Vehicle Function to Physical Allocation Matrix

	Physical Domain [model]	Hybrid Car	Engine Subsystem	Drivetrain Subsystem	Ignition Subsystem	Fuel Systems Subsystem	Exhaust System Subsystem	Suspension & Steering Subsystem	Brake Subsystem	Electrical Subsystem	Entertainment Subsystem	Display Systems Subsystem	User Controls Subsystem	Frame & Body Subsystem
Perform General Hybrid Car Operations		9	7	6	2	1	1	1	4	5	1	2	6	2
Handle Environmental Conditions		↗												
----------- Hybrid car body withstands weather elements														↗
Control Vehicle Access		↗												
----------- Process Electromagnetic Signals										↗				
----------- Authenticate Key Control Command										↗				
----------- Check Door State										↗				
----------- Unlock Cabin/Trunk Doors													↗	
----------- Lock Cabin/Trunk Doors													↗	
Provide Vehicle Access		↗												
----------- Open Cabin Door													↗	
----------- Open Trunk Door													↗	
----------- Storage Materials														↗
Start Engine		↗												
----------- Process Electromagnetic Signals										↗				
----------- Authenticate Key Signal										↗				
----------- Monitor Brakes									↗					
----------- Check Transmission State				↗										
----------- Change Engine to Enabled			↗											
----------- Initialize Engine Start Procedure			↗											
----------- Monitor Engine Ignition Request Signal					↗									
Provide Vehicle Control		↗												
----------- (ABS) Anti Brake Lock System				↗										
----------- Traction Control				↗										
Manage Vehicle Power		↗												

----------- Accelerate Vehicle				↗										
----------- Control Acceleration													↗	
----------- Manage Combustion			↗											
----------- Release Exhaust Fumes							↗							
----------- Decelerate Vehicle									↗					
----------- Perform Regenerative Braking									↗					
Provide System Status		↗												
----------- Monitor Crash Safety												↗		
----------- Monitor Drivetrain Status				↗										
----------- Monitor Energy						↗								
----------- Monitor Powertrain Status			↗											
Stop Engine		↗												
----------- Power off Engine					↗									
----------- Turn off Display												↗		
----------- Turn off Entertainment System											↗			
Perform Maintenance		↗												
----------- Check Engine Oil Level			↗											
----------- Check Lubricant Level			↗											
----------- Check Transmission Fluid Level				↗										
----------- Check Engine Coolant Level		↗												
----------- Check Power Steering Fluid								↗						
----------- Check Brake Fluid Level									↗					
----------- Check Windshield Wiper Fluid													↗	

Test Plans:

Test 1:

Requirement:

The hybrid car’s engine shall continuously operate at temperatures as high as 195 degrees Fahrenheit (T), 220 degrees Fahrenheit (O) over a 30-day period.

Resources Required:

- Temperature Chamber
- Temperature Gauges
- Pitot Tube
- Fuel Storage Tank
- Powertrain Subsystem
- Industrial Fan
- Safety Equipment (Fire Extinguisher, Protective Shielding, etc)

Test Procedure:

The Engine Heat Stress Test intends to verify whether the hybrid car's engine will be capable of meeting endurance requirements over a 10-year lifecycle. The test is run within a shorter timeframe but with an elevated ambient temperature. This approach intends to simulate what is otherwise an unrealistic timeframe for testing. The subsystem under test is the powertrain. The vehicle's powertrain shall have all the auxiliary equipment it needs to run. Assuming driving speeds at 40mph, the powertrain computer shall set the engine to run at 3000rpm in 4th gear. Fuel shall be pumped to the engine for the duration of 30 consecutive days. A Storage Tank will supply fuel to the engine for the entire duration of testing. An industrial fan shall be set to windspeeds at the 40mph simulated driving speed. A pitot tube shall be used to validate this speed for the duration of testing. Air from the industrial fan shall be supplied in a direct line and within 3 feet of the powertrain cooling subsystem. The environmental temperature shall be set at the objective temperature of 220 degrees Fahrenheit. An additional 30-day test shall be run at the threshold limit of 195 degrees if the vehicle cannot meet the required objective. Temperature gauges shall be added to monitor both ambient temperatures, the engine coolant, and the engine oil reserve. Transmission oil shall also be monitored for the entire duration of testing. Discrete temperature measurements shall be taken at 10-minute intervals. Test data shall provide each temperature gauge recorded over time. Powertrain system warnings shall be monitored for the entirety of testing and plotted as discrete markers on each temperature gauge plot. Test reports for the vehicle shall be compared to other vehicle reports and reviewed to either accept or modify the current design by the Engineering Vice President and Program Chief Engineer. Actual values used for testing shall be kept with ±5% of the nominal values listed herein. Any failure shall be reported.

Test 2:

Requirement:

The hybrid shall recharge to 80% in 20 minutes (T), 15 minutes (O) with fast charging.

Resources Required:

- OEM Hybrid Car Battery
- OEM Battery Charger
- OEM Fast Charger
- Multimeter

Test Procedure:

Test Procedure: Hybrid vehicles have rechargeable batteries, this battery life is very important as it used to operate the vehicle but also operate features like Entertainment, climate control, GPS, and the display systems. With hybrid vehicles using so much power they come equipped special chargers to recharge the vehicle's battery. The operator should ensure to read and follow all the manufacture recommended safety guidelines before charging the vehicle. To ensure an accurate battery health test. The vehicle should first have 0 charge equating to a dead battery. The battery should first be charged for 20 minutes, a multimeter can be used to confirm the correct power output for additional validation. After 20 minutes the vehicle should be started and then confirm the vehicle's displayed battery life. If you choose to use the fast charger for the vehicle the test procedure will be the same. For the fast charger you would repeat all these steps expect this time only for 15 minutes and then validate with the vehicle's battery life display.

Test 3:

Requirement:

The hybrid car shall have an average dry braking distance from 60-0 mph of 120 ft (T) 110 ft (O).

Resources Required:

- Prototype cars (3) equipped with four-wheel disk brakes and ABS
- Brake system – new original equipment brake linings, brake rotors, and tires
- Track test fifth wheel and Labeco Performance Monitor Model 625
- A brake pedal force transducer and brake lining thermocouples
- Professional Test Drivers

Test Procedure:

Stopping distance tests will be conducted according to the FMVSS 135 test procedure to the extent possible. This includes a brake pedal force limit of 500 N. Also, the brake lining temperature prior to each stop was required to be between 65- and 100-degree C. The stops are in a straight line and began at 100 km/h. The drivers are instructed to achieve the shortest stopping distance possible within the pedal force limits and with no wheel lock-up in the cases where the ABS was disabled. FMVSS 135 tests will be conducted on dry concrete, the peak friction coefficient of the concrete of the Vehicle Dynamics Area is regularly monitored by TRC with a skid trailer using an ASTM E1136 tire according to the ASTM E1337-90 test procedure.

The vehicles' anti-lock brake systems will be disabled for some stops to simulate a vehicle without ABS. This would show if driver effects were different for vehicles not equipped with ABS. The ABS will be disabled by removing the fuse for the system. For stops conducted with ABS-on, the driver rapidly will apply full pedal effort up to 500 N. The shortest of six or three stops respectively for each test condition will be the performance measure. Although the braking performance of an ABS-equipped vehicle with the ABS disabled may not be the same as a vehicle not equipped with ABS, the driver effects are assumed to be the same.

Test 4:

Requirement:

The hybrid car’s internal combustion engine (on a full tank) shall take the driver 300 miles (T), 350 miles (O).

Resources Required:

- Prototype car with all major subsystems present
- Chassis Dynamometer
- Hose or “bag” to collect engine exhaust
- Exhaust analyzer
- Engineers and technicians

Test Procedure:

Fuel economy of a car’s internal combustion engine can be conveniently tested by creating a prototype of the car and placing it on a chassis dynamometer. A dynamometer uses large rollers in the ground to aid in simulating driving environments without going outdoors. Before beginning the test, the gas tank needs to be full, and the car turned on. Now, the rollers of the dynamometer can be activated, and the car can be operated as it would on the road.

The EPA has already created different “cycles” that a vehicle can run on a chassis dynamometer and emulate driving schedules. These cycles include: a city test, a highway test, stop-and-go driving conditions, high acceleration/aggressive driving, and air conditioning driving. Each test runs for a pre-determined number of miles. During each test, a hose or “bag” will collect exhaust emissions for data collection. At the end of the test, the carbon will be measured from the engine exhaust via an exhaust analyzer of some type and used to calculate how much fuel was used during the cycle. Knowing the amount of fuel in the fuel tank, basic math can be done to determine how many miles the vehicle can go on a full tank of gas for each cycle. Fuel efficiency is an important factor for the consumer when selecting a car. Reporting inaccurate fuel efficiency can produce a poor outcome for the company. Since this type of test replicates real driving conditions and uses all the performance subsystems simultaneously, it is an ideal way to validate an internal combustion engine’s fuel efficiency.

Test 5:

Requirement:

The hybrid car shall accelerate to 62 mph in 4.4 seconds (T) 3.4 seconds (O).

Resources Required:

- Prototype car with all major subsystems present
- Driver
- VBOX
- GPS data logger (uses GPS to record speed, position, and acceleration)
- GPS base station (used to correct GPS positional inaccuracy)
- Closed Street
- Street

Test Procedure:

The Accelerate Test intends to verify if the hybrid car can meet acceleration benchmarks, outlined under capability requirement 1.8.1. We shall test our vehicles' standing start acceleration time in a closed off street where launch traction is low. To ensure road closure, we will enlist help from the police department within the jurisdiction of the chosen street. Two officers will be stationed on each side of the road, blocking the test site. Engines create different levels of power in different weather conditions, so we will test our vehicles over a multi-day time frame, in which the vehicle will experiences different conditions to adjust for weather. Our test will require ten launches on each day to get the best possible time. To account for wind our results are the average of the best runs in opposite directions on both days. During each launch, the drivers speed and acceleration data will be recorded by the GPS data logger. The time it took to achieve our speed will be recorded through the VBOX. After each launch, we'll use the GPS base station to adjust for any positional inaccuracy. Finally, our test will factor in rollout, which will be subtracted from each acceleration figure post launch, providing us with our result. Any failure to reach our threshold or objective shall be recorded to investigate and evaluate, what went wrong and if regression testing is necessary. Many consumers place high value on their vehicles, acceleration and speed. Thus, it is essential we understand the environment in which we are operating and how it effects our data. Since this test replicates real driving conditions involving different scenarios, while also using test equipment subsystems in tandem, it is an ideal way to validate our vehicles standing start acceleration time.

Risks:

Risk 1: Regenerative Braking Risk

If regenerative braking is not managed properly, then the vehicle may not respond adequately to deceleration from the user's brake pedal force and a vehicle collision could occur.

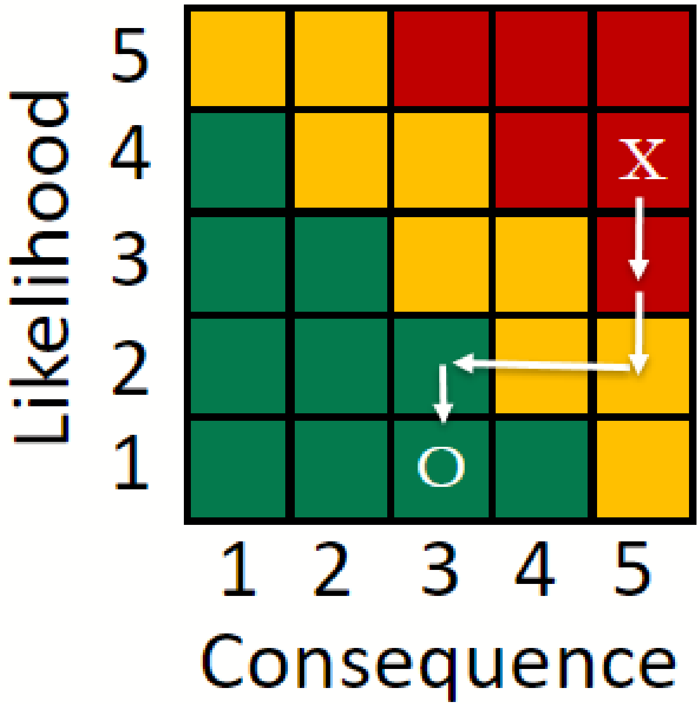

Figure 24: Regenerative Breaking Risk Matrix

Mitigation Plan: Regenerative Braking Risk

Table 3: Regenerative Braking Collision Mitigation Plan

Step	Plan	Outcome
1	Integrate Brake Control Software	L : 3
2	Create Regenerative Brake Performance Model	L : 2
3	Integrate Proximity Sensor Hydraulic Brake Automation	C : 2
4	Perform Operational Testing to Refine Software Control	L : 1

Regenerative braking systems transfer torque from the vehicle drivetrain to an electric generator. This torque works to decelerate the vehicle, but it is limited in magnitude. Vehicle operations typically require torque at much higher values to decelerate the vehicle in hazardous conditions. Therefore, hydraulic braking is still necessary for vehicle operation. Managing regenerative braking and hydraulic braking introduces a potential for risk in the system. Without mitigation, regenerative braking will likely not be adequately managed. Additionally, the risk of a vehicle collision is a grave consequence.

Step 1: Brake Control Software must be integrated into the vehicle to engage the hydraulic braking system at different levels as braking pressure from the user varies. This software reduces the likelihood that brake management will not occur.

Step 2: Additionally, a regenerative brake performance model should be created to understand the physics of various driving requirements. This performance model can be fed into the control software for a better brake response in off-nominal conditions.

Step 3: Additionally, a system for redundancy can be introduced to reduce the consequence of any failure in the brake control software. For instance, integrating a proximity sensor to sense incoming collisions could work to override brake control software and automatically slow the vehicle thereby reducing the consequence of our initial risk significantly.

Step 4: Finally, operational testing should be run to refine software control. Operational testing provides real-world data that can be leveraged to improve the mathematical models underlying the brake control software for our vehicle.

Risk 2: Headlight Shortage Risk

If headlights get shorted, the car will not be operable at night. This will decrease safety and visibility which may lead to a car accident.

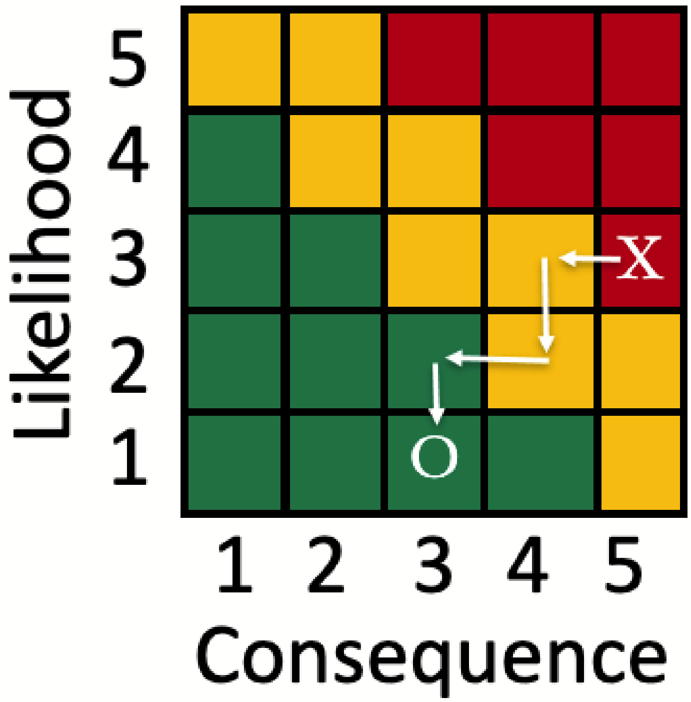

Figure 25: Headlight Shortage Risk Matrix

Mitigation Plan: Headlight Shortage Risk

Table 4: Headlight Shortage Mitigation Plan

Step	Plan	Outcome
1	Check for any leaks	C : 4
2	Check for any cracks	L : 2
3	Spare bulbs in dashboard	C : 3
4	Owner's manual with instructions in center console	L : 1

Risk 3: Electronic Shock Hazard

Some electronic components may store dangerous amounts of electricity even when the vehicle is off and the battery isolated. If unwary servicing, repair, maintenance and rescue worker touches the hybrid car electronic components with stored high electricity and high voltage (even when the vehicle is off and the battery isolated); then it can result in serious injury or death.

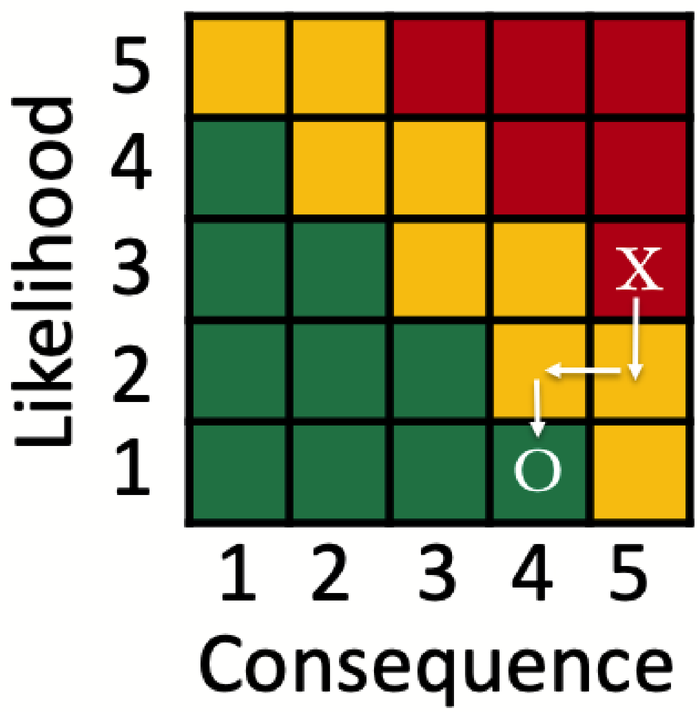

Figure 26: Electronic Component Danger Risk Matrix

Mitigation Plan: Electronic Shock Hazard Risk

Table 5: Electronic Shock Mitigation Plan

Step	Plan	Outcome
1	Create procedures for repair and maintenance to warn others about the current state of the vehicle being worked on and use safety signs to assist in ensuring that correct procedures are being adhered to	L : 2
2	Create mandatory safety procedures/plans to only use insulated tools when carrying out repair or maintenance work on the vehicles and wear safety clothing	C : 4
3	Create safety plans to isolate the potentially dangerous subsystems before working on the hybrid vehicles.	L : 1

Risk 4: Exhaust System Robustness

If there is a faulty component present in the exhaust subsystem, then the vehicle power will not be properly managed, and the overall performance will decrease.

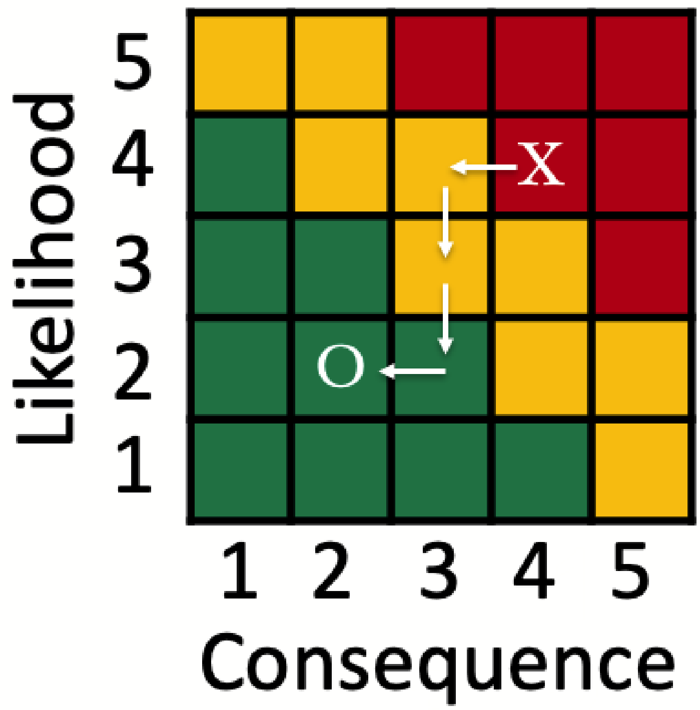

Figure 27: Exhaust System Risk Matrix

Mitigation Plan: Exhaust System Robustness Risk

Table 6: Exhaust System Mitigation Plan

Step	Plan	Outcome
1	Reduce component materials that can rust easily	C : 3
2	Install O2 sensor warning signals to maintain performance	L : 3
3	Install a sensor to detect a clog in the catalytic converter	L : 2
4	Use a material that can better withstand high heat and multiple chemicals on the exhaust manifold	C : 2

Step 1: If components in the exhaust subsystem start to rust, the rust can cause the components to corrode. This can lead to exhaust failure or structural damage within the exhaust subsystem.

Step 2: O2 sensors are vital in maintaining the air/fuel ratio of the engine. Faulty sensors will cause the engine to use more fuel (rich running condition) and in return reduces the engine and vehicle performance.

Step 3: The catalytic converter causes chemical reactions to occur, reducing the harmful emissions created in the engine from being released into the atmosphere. If there is a clog in the catalytic converter, there will be an increase of back pressure into the engine and a resulting decrease in vehicle power.

Step 4: The exhaust manifold funnels exhaust gases away from the cylinders in the engine to the exhaust subsystem. A leak or hole due to high temperatures or constant interaction with these gases in the exhaust manifold will allow the gases to escape and cause poor O2 sensor readings.

Risk 5: Vehicle Overheating

If the vehicle experiences overheating, then the engine and its components could be subject to serious damage. An overheated engine results in decreased performance and is hazardous on busy roads and steep inclines.

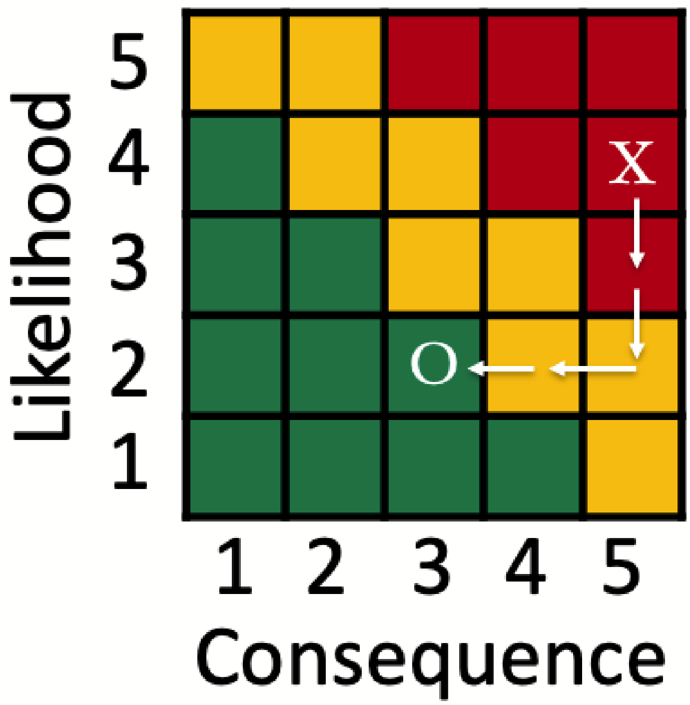

Figure 28: Vehicle Overheating Risk Matrix

Mitigation Plan: Vehicle Overheating Risk

Table 7: Vehicle Overheating Mitigation Plan

Step	Plan	Outcome
1	Provide low fluid level alert	L : 3
2	Provide temperature gauge hot alert	L : 2
3	Provide coolant leak detector	C : 4
4	Provide periodic radiator flushing alert	C : 3

Step 1: Low fluid levels are one of the most common reasons behind overheating. When fluid levels reach a low threshold, the driver shall receive an alert requesting the car be serviced.

Step 2: The temperature gauge should always point towards the center. As it edges closer to hot and goes beyond normal temperatures, the driver shall receive an alert requesting for the car to be serviced.

Step 3: If a coolant leak occurs, the driver shall receive an alert requesting for the car to be serviced.

Step 4: Coolant, despite being at its optimum levels needs to be replaced periodically. Every year, the driver shall receive an alert requesting for the car to be serviced for its periodic radiator flushing. This ensures the car’s best performance.

Conclusion

Every system has a need that drives its inception. There is a need to reduced dependency on fossil fuels in the global market. Hybrid Vehicles repurpose energy lost from braking subsystems to provide better overall fuel efficiency to meet this demand.

Analysis is critical to understanding a system's intended mission. Visuals like context diagrams and mission scenarios help capture functions that are required in a systems design. For the 4-passenger hybrid vehicle design, we captured functions like security, power management, access, system status, etc.

The functional domain in every system should map to its physical architecture. A hybrid vehicle has a unique power management system, for example. It's regenerative braking function requires the inception of a new physical architecture with additional interfaces that must be managed by the systems engineer.

Testing is helpful to verify that the system meets its requirements. Every test requires a rugged plan that must be thought through in advance.

Every system has risk associated with it. Risk management involves implementing mitigation steps to either lower the likely hood of a risk or reduce its consequence.