Software Requirements Specification (SRS)

Project Lane Management System -1

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1 Introduction

This Software Requirements Specification (SRS) aims to present the Lane Management System (LMS). This SRS document covers the system's requirements, scope, and functionality and includes use-case scenarios and a prototype. The main sections of this document include:

1. Introduction: The introduction aims to provide background and the project's scope and provide useful information to navigate this document.

2. Overall Description: This section provides the system's context and functionality while providing its constraints.

3. Specific Requirements: The system's requirements as the development team understands the customers' wants and need for the system.

4. Modeling Requirements: Models that illustrate the system requirements.

5. Prototype: The system functionality is shown via examples, scenarios, and use cases.

6. References: The citations for referenced material found through the SRS document.

7. Point of Contact: Should any issue arise that needs attention, the contact information for the professor of CSE 435.

1.1 Purpose

This document aims to describe the LMS system's requirements and explore the functionality of the system. The intended audience for this document is Mr. Ayush Agrawal of General Motors and Dr. Betty H. C. Cheng of Michigan State University.

1.2 Scope

The software product in development is the LMS, along with several subsystems. The Lane Departure Warning Systems (LDWS) issues warnings to the driver when the vehicle leaves its lane without either the turn signal activated or enough torque on the steering wheel, in which case the LDWS assumes the driver is intentionally leaving their lane. The Lane-Keeping System (LKS) enhances the LDWS and adjusts the vehicle's position within the lane. This system is a critical safety one because control is removed temporarily from the driver. This control is returned to the driver once the vehicle is center in its lane.

The Lane Centering Systems (LCS) measures the vehicle's location within its lane and activates the LKS and LDWS when action is required. Additional subsystems that assist the LCS in processing the vehicle's location include the Image Processing System (IPS), which processes images from the vehicles onboard cameras, and GPS. With all this information at its disposal, the LCS can accurately determine the vehicle's lane position and act accordingly.

The LMS's benefits include the LKS, which keeps the vehicle centered in its lane while the system is engaged. The LDWS ensures that the system users are informed should the vehicle move from outside of its lane. The LCS automatically steers the vehicle back into the lane's center should the vehicle require such action.

The primary goal for LMS is to ensure driver safety. The system provides safety through the subsystems that provide the driver with alerts and assistance to staying in their lane. The LMS system has the authority to temporarily take control of the vehicle from the driver and adjust the vehicle to facilitate the return to the driver's intended lane. At the same time, the LMS system informs the user and can adjust the vehicle's speed.

The LMS does not automate the vehicle's driving and avoid collisions and does not replace an informed driver or consider local laws and regulations. Therefore, it is outside the system's scope to fully automate the vehicle's driving or avoid collisions.

1.3 Definitions, acronyms, and abbreviations

Name:	Definition:
CSS	The Camera Sensing Subsystem captures images and video of the outside of the vehicle and the lane markers. This information sends to the Image Processing Subsystem.
GPS	Global Positioning System. This information is used in conjunction with the path prediction subsystem to determine vehicle location and lane positioning.
HUD	The Heads-up Display. This system informs the driver when the LMS makes an action in some way. Up-to-date information to inform the driver of the system's status.

IPS	The Image Processing System. This system processes the images and video sent to it via the Camera Sensing Subsystem. This information determines the lane markers and if another system needs to act.
LCS	The Lane Centering System. Rather than warning the driver, this system moves the vehicle into the center of its lane. By design, this system assists the driver with steering so that the vehicle remains centered.
LDWS	The Lane Departure Warning System. This system warns the driver when the vehicle has drifted or moved from its intended lane. This system does not attempt to correct the vehicle's position. It only alerts the driver. By design, this system does not alert the driver when the turn signal is engaged or if the driver applies enough torque to the steering wheel.
LKS	The Lane-Keeping System. This system actively takes control away from the driver to facilitate steering to adjust the vehicle's location.
LMS	The Lane Management System. A system designed to be installed into the vehicle's onboard computer and used to prevent unintentional lane changes.
PPS	The Path Prediction Subsystem. This system uses the Camera Sensing Subsystem and Image Processing Subsystem information to predict the vehicle's intended path. This information warns and corrects any violations of the other lane systems.
SRS	The Software Requirements Specification.
System Idle	The system state that the LMS is in when it is engaged and processing data but is not actively adjusting the vehicle. A sample use case for this is when the driver is going under 35mph. The system is still processing data, but it won't act upon it because of the vehicle's speed.
System Off	The system state system is off and not processing data. A sample use case for this is when the driver manually turns off the system.
System On	The system state that the LMS is in when it is on and processing data. The data determines if the other systems need to be activated.
SCS	The Supervisory Control System. This system controls all other subsystems turning them on or off when necessary. This system also helps with transferring information between subsystems.
UIS	The User Interface system. This system receives driver inputs, sends them to the system, and receives system messages to send them to the driver.
VSE	The Vehicle State Estimation system. This system uses various sensors to determine the vehicle's speed, steering wheel angle, and road curvature.

1.4 Organization

The remainder of this document has the following organization. Section 1 provides a brief overview of the document and acronyms and definitions of regularly used keywords throughout the document. Section 2 focuses on the system itself, including its function and a complete description of its specifications. Section 2 also describes the system constraints and how they fit into the vehicle in conjunction with other subsystems. Section 3 details the system requirements and their hierarchy, mentioning various essential and logically ordered requirements that are clear and concise. Section 4 showcases various diagrams, including a use-case diagram where each system's goal is addressed and satisfied. The domain model gives a brief description of the system in English.

The sequence diagrams and state diagrams show all the use cases, risks, and associated concerns with the system. Section 5 shows the prototype of the system, along with sample scenarios and their explanations. Section 6 details the references used in creating this SRS report and attributes proper credit to the sources used, along with links to the original documents should readers of this report wish to investigate that information themselves. Section 7 provides a further point of contact should any information in this document or project need further clarification.

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2 Overall Description

This section outlines an in-depth description of the LMS. It provides product perspectives and context, a complete description of the specified product, and how the product fits into the vehicle overall. Following this is a section focused entirely on the LMS's functions and ensures that the LMS meets the customer's requests. User exceptions to the product are also detailed.

Section 2.1 is devoted to the constraints and descriptions of the safety-critical properties and the LMS's remaining properties, including the properties of minimum vehicle speeds and the road's curvature. A section devoted to the system's assumptions and dependencies follows and lists LMS's dependencies to operate successfully. Finally, section 2 lists approportioned requirements as well as other requirements that are outside of the scope of this project.

2.1 Product Perspective

LMS's primary purpose is to keep the vehicle in its desired lane unless the driver is intentionally making a lane change. The LMS interfaces with the rest of the vehicle to maintain this functionality. In particular, the LMS relays information to the Heads-Up Display (HUD) to notify the driver of its actions. The LMS also uses the vehicle's braking and steering systems to keep the vehicle centered in the lane, even when following a curved road. [2]

The LMS has different subsystems that it interfaces with to function, as detailed below. These subsystems are the Camera Sensing Subsystem (CSS), the Image Processing Subsystem (IPS), the Vehicle State Estimation system (VSE), the Path Prediction Subsystem (PPS), the User Interface system (UIS), and the Supervisory Control Systems (SCS).

The CSS is used to capture images in front of and on the sides of the vehicle. The IPS receives the images and processes them, which provides lane marker detection information. The VSE is composed of sensors that determine the vehicle's current state's speed, steering angle, and road curvature. The PPS is a software subsystem that takes in the information from the IPS and the VSE to predict the vehicle's future path. Suppose this path requires some warnings or corrections; the LMS processes these warnings or corrections and sends them to the UIS. The UIS is where the driver and LMS exchange control and data information. The SCS controls all other subsystems and decides when to enable and disable other subsystems or provide diagnostic information.

2.2 Product Functions

The LMS is composed of three main features: Lane Centering System (LCS), Lane Departure Warning System (LDWS), and Lane-Keeping System (LKS). Each of these features cooperates to ensure the vehicle is adhering to LMS as a whole. LCS ensures the vehicle is centered as much as possible in its current lane. LCS calculates the relative position of the vehicle within its identified lane to center the vehicle. LDWS issues warnings to the driver when the vehicle is about to depart its current lane. Warnings are displayed as icons on the dashboard when the driver makes an unintentional lane departure, and the driver is alerted by a sound. LKS is an enhancement to LDWS in which LKS adjusts the steering to position the vehicle back into its lane. The driver overrides corrective steering when he/she exerts enough torque on the steering wheel. [2]

2.3 User Characteristics

A licensed driver is using the LMS, and they can enable and disable the system. The driver should be alert and attentive when the system issues warnings to either correct or override LKS or LCS when necessary. Depending on which subsystem activates, the driver is issued warnings to correct the vehicle's position, or if severe enough, the vehicle makes this corrective action independently of the driver. System failure warnings are issued to the driver if the LMS can no longer perform as desired. These warnings are possible if lane lines are no longer detected, if the speed is not sufficient (below 35 MPH) for the system to perform, or if the hardware or software fails to function correctly.

2.4 Constraints

The LMS operates under a few constraints. First, the LMS must be able to categorize unintentional vs. intentional lane departures correctly. A lane departure is when the vehicle crosses lane boundaries. If this occurs, the LMS takes corrective action to center the vehicle in the lane. However, a lane departure can be intentional if the driver activates the turn signal or applies enough torque to the steering wheel. If either of these conditions is true, the LMS takes this as an intentional lane departure and allows the vehicle to cross lane boundaries. Secondly, the LMS and its subsystems must be secure against cybersecurity risks. Attackers should not be able to gain access to the vehicle's systems for malicious intent. Thirdly, the LMS uses algorithms that should be accurate and efficient enough to immediately make lane management decisions. Lastly, the driver must always have full control over the status of the LMS. That is, the driver must be able to toggle the system on or off at any time.

There are several safety-critical constraints that the LMS operates within. While performing lane-keeping and centering, the LMS adjusts the speed and makes lane corrections at stable levels. On curved roads, the LMS makes safe adjustments to the speed and steering angle. The LMS disables itself and informs the driver when weather conditions (snow, heavy rain, fog, etc.) make it impossible for the system to be active. The LMS must be as accurate as possible using information gathered from the vehicle's cameras and sensors. Lastly, the LMS cannot control other drivers or poor road conditions. The driver must be aware that the system does not drive for them, and they must pay full attention to the road as they would in any other vehicle. The LDWS and LMS function in a way that minimizes alarms to the driver. Including fraudulent alarms.

2.5 Assumptions

The vehicle is assumed to be operating normally. In regular operation, the vehicle's subsystems and sensors operate as intended and are not registering problems with other systems in the vehicle. The braking and acceleration systems are assumed to be operating as intended, so the LMS can use them to perform corrective lane-centering actions. It is assumed that the driver knows how to operate the vehicle and its LMS effectively. It is also assumed that the driver knows how to enable and disable the LMS as they choose.

For the LMS to function correctly, it depends on meeting certain conditions. The vehicle must be on for the LMS to function. Road conditions are ideal unless otherwise noted. The steering system, as well as warning lights, are 100% functional. Lastly, other vehicle systems that share subsystems with the LMS must not interfere with LMS functionality.

1. The vehicle is operating as it should.
    - The vehicle's subsystems and the vehicle's sensors do not register problems with the vehicle's other systems.
2. The braking and acceleration system is functional and operating as intended.
3. The driver knows how to operate the Vehicle and LMS.
4. The driver can enable and disable the system as they choose.

2.6 Dependencies

1. Road conditions are ideal unless otherwise noted.
2. The vehicle is on.
3. The steering system is functional.

4. The warning lights are functional.
5. Other systems in the vehicle using the same systems as the LMS do not interfere with the LMS's functionality.

2.7 Approportioning of Requirements

This section outlines the requirements that are outside of the LMS's scope. The LMS does not handle vehicle collision avoidance; It is the driver's responsibility to avoid collisions with objects and other vehicles on the road. The LMS is not aware of country-wide or local driving laws. The LMS cannot function when lane markers are not visible. The LMS cannot function if obstructions are interfering with the sensors or cameras. The LMS cannot function if there are damaged or malfunctioning sensors and cameras.

2.7.1 Outside of Scope Requirements

1 Vehicle and object collision avoidance
2 Country and local laws
3 The vehicle's driver has adequate information on how to use the LMS system.
4 The LMS cannot operate on roads which do not have painted lane markers
5 Obstructed view of the lane via damaged/malfunctioning sensors and cameras.

3 Specific Requirements

For the LMS to be fully functional, it must adhere to all general and invariant requirements. The following requirements pertain to the behavior of the vehicle using LMS while prioritizing the driver's safety.

3.1 General Requirements

1. The vehicle knows the center of the lane as long as lane lines are detectable.
   - The system does not function if lane lines are not visible.
2. LMS detects and ignores intersecting lines.
   - LMS performs normal lane-keeping and correcting while ignoring intersecting lines.
3. LKS and LDWS are dependent on LCS to function correctly.
4. The driver can override corrective steering by exerting force on the steering wheel or activating the turn signal.
   - When there is no longer force on the steering wheel or the turn signal is deactivated, the system switches back on and continues controlling the car.
5. Corrective steering is toggleable by the driver.
6. The driver has a button on the steering wheel to enable or disable corrective measures or departure warnings at any time.
7. The system has preventative measures in place to help avoid being compromised by cybersecurity attacks.

3.2 Invariant Requirements

1. Turn signals must temporarily disable the system.
    - An active turn signal indicates that the driver is intentionally departing their lane.
2. The vehicle must be traveling at least 35 mph for the system to work.
3. Always issue a warning when the system is enabled.
4. Whether on, off, or idle, the system's state is always on display on the dash.
5. Lane departure should always have some audio alarm.
6. When lane marker lines are not detected, the system enters the idle state.
7. Warnings automatically turn on when the car starts.
    - Unless the driver has set the default state of the system to off.
8. When the car starts, there is a full system check.
    - The full system check is to ensure that the required subsystems are functional so the LMS can function.
9. Any failure or error that occurs in any system or subsystem turns the entire LMS system off.
    - If the system has a subsystem that fails, the entire system must turn off.

3.3 Cybersecurity Requirements

The vehicle's threat vectors are the paths that a hacker can use to gain access to the LMS. These points of weakness include malware, Bluetooth, the camera system, the alert system, and the steering system. While the camera and alert subsystems do not directly relate to the driver's safety, the GPS data is encrypted.

The LMS's threat types include monitoring and copying data, DOS attacks, and modification (done through a virus removing or changing data). These threat types can cause the system to lose control and possibly harm the user or be a privacy concern. The system must prevent these threats as frequently as possible.

Due to the concerns posed by the threats to the LMS, preventative measures should be put in place to address these concerns. As a preventative measure, LMS can reduce the risk of a cyber-attack by manually preventing users from installing updates to the system's firmware. Instead, the system automatically updates when a new version of the software is available. For combating the possible vulnerabilities of the Bluetooth system, the system removes older versions of Bluetooth. It only allows for the newest release, ensuring that older Bluetooth versions are not a security risk. If the camera and alert subsystems turn off during an attack, the LMS registers that the subsystems are not working and disables LMS. Disabling LMS during an attack prevents fraudulent information from leaking. Also, both GPS data and system data are encrypted. This encryption prevents the reading or modification of this data.

4 Modeling Requirements

It is not enough to merely list the requirements of a (safety-critical) software system like the LMS. Diagrams visually illustrate the requirements, such as use case diagrams, class diagrams, sequence diagrams, and state diagrams. Models provide more details about how elements and subsystems interact with each other as part of the LMS. They are crucial to understanding how the system behaves in general and in specific conditions. We have use case diagrams to demonstrate how actors interact with the system from the outside. The class diagram is a hierarchical structure made with elements of the LMS. Sequence diagrams represent the system in specific scenarios, and there are state diagrams for each subsystem of the LMS to outline their behavior and actions.

4.1 Use Case Diagram

Figure 1 shows the use case diagram for the LMS. Actors are outside the system boundaries (denoted by the blue box). An oval shape denotes each use case, which describes high-level functions of the system. Use cases communicate with each other through extensions and inclusions. For example, the "Center Vehicle" use case "extends" the "Correct Vehicle Position" use case, which means it performs the same actions, plus added functionality. Similarly, a use case can "include" another one, which means that one use case can call/trigger another one.

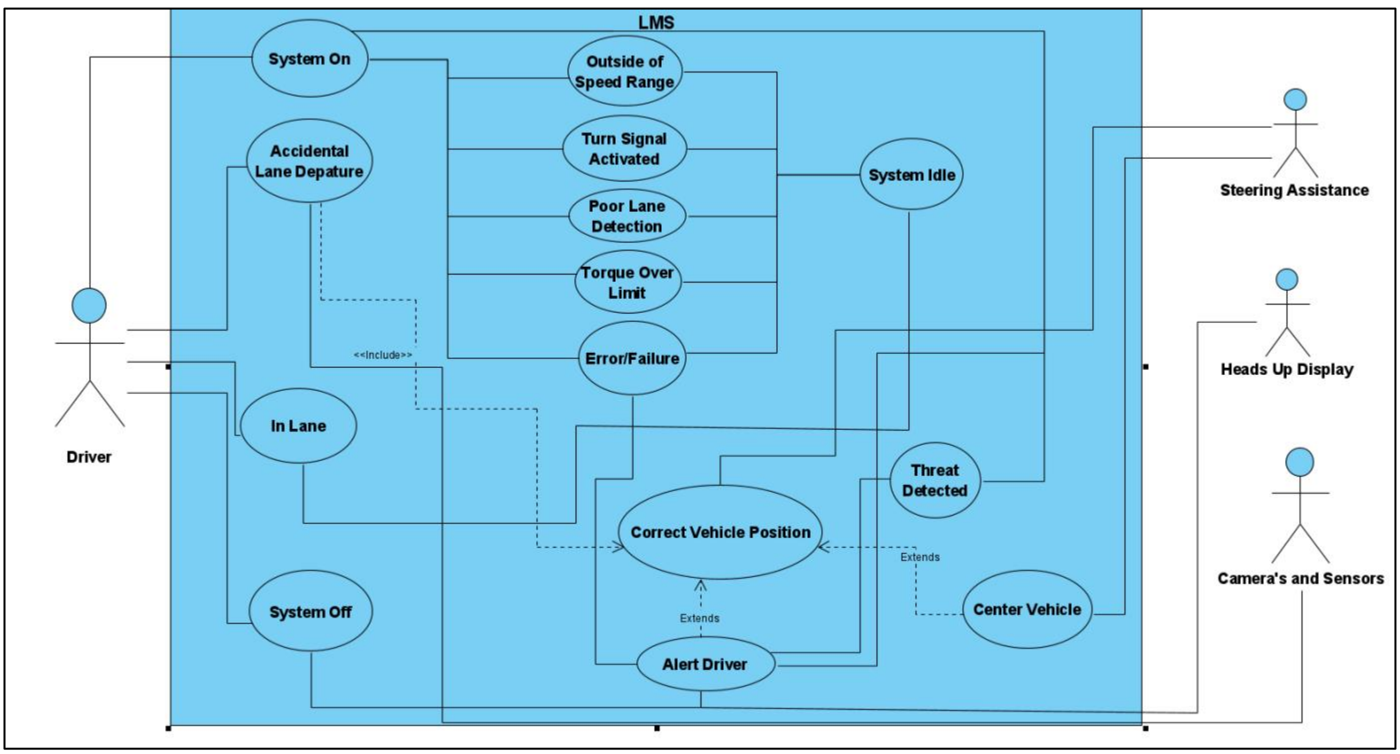

FIGURE 1 THE USE CASE FOR THE LMS SYSTEM

Use Case:	Accidental Lane Departure
Actors:	Driver, Cameras, and Sensors

Type:	Primary
Description:	The system's primary goal is to detect and correct accidental lane departures. Cameras and Sensors should recognize this and take corrective action if the system deems it necessary. When this occurs, a notification alerts the driver.
Includes:	Correct Vehicle Position
Extends:	N/A
Cross References:	G1, I5
Connected Use-Cases:	Correct Vehicle Position

Use Case:	Alert Driver
Actors:	Heads Up Display
Type:	Primary & Essential
Description:	When the system is off, an alarm sounds and a notification alerts the driver on the dashboard. Various alerts and warnings notify the driver when driving close to a lane or if the system turns off. This use case extends onto the Center Vehicle use case.
Includes:	N/A
Extends:	Center Vehicle
Cross References:	I3, I4
Connected Use-Cases:	System On, System Off

Use Case:	Center Vehicle

Actors:	Steering Assistance
Type:	Primary & Essential
Description:	The vehicle is re-centered between lane markers by the steering assistance system. This use case extends onto the Correct Vehicle Position use case.
Includes:	N/A
Extends:	Correct Vehicle Position
Cross References:	G1, I9
Connected Use-Cases:	Alert Driver, Correct Vehicle Position

Use Case:	Correct Vehicle Position
Actors:	Steering Assistance
Type:	Secondary & Essential
Description:	Assistive steering brings the vehicle back into a lane if it starts to cross lanes unintentionally.
Includes:	N/A
Extends:	N/A
Cross References:	G1, G3, G4, G5
Connected Use-Cases:	Center Vehicle, Accidental Lane Departure

Use Case:	Error/Failure

Actors:	System (initiator)
Type:	Secondary & Essential
Description:	If any subsystem fails within the system, LMS alerts the driver and turns the system off. The system checks for errors and failures when the vehicle starts up.
Includes:	N/A
Extends:	N/A
Cross References:	I8, I10
Connected Use-Cases:	System Off, Alert Driver

Use Case:	In Lane
Actors:	Driver
Type:	Primary & Essential
Description:	Ideally, the vehicle should always be in the center of a lane.
Includes:	N/A
Extends:	N/A
Cross References:	I9, G1
Connected Use-Cases:	System Idle

Use Case:	Outside of Speed Range

Actors:	System (initiator)
Type:	Secondary & Essential
Description:	Once the system is on, the system continues to stay on until it is outside the speed range. If it is outside the speed range, the system becomes idle, and the driver controls the vehicle.
Includes:	N/A
Extends:	N/A
Cross References:	I2
Connected Use-Cases:	System On, System Idle

Use Case:	Poor Lane Detection
Actors:	System (initiator)
Type:	Secondary & Essential
Description:	On streets where lanes are indistinguishable or in harsh weather conditions, the system enters the idle state, and the driver is in control of the vehicle.
Includes:	N/A
Extends:	N/A
Cross References:	I6
Connected Use-Cases:	System On, System Idle

Use Case:	System Idle

Actors:	System On
Type:	Primary & Essential
Description:	The system goes to an idle state after several different use cases. In this state, the driver has full control of the vehicle. The system can still process data but will not actively notify the driver or take corrective action. Once the system can turn back on again (turn signal deactivated, speed above a threshold, lanes detectable, etc.), it will.
Includes:	N/A
Extends:	N/A
Cross References:	I2, I1, I6, I9, G2, G4, G3
Connected Use-Cases:	In Lane, Turn Signal Activated, Outside of Speed Range, Poor Lane Detection, Torque over Limit

Use Case:	System Off
Actors:	Driver
Type:	Primary & Essential
Description:	The driver can manually turn off the system via a switch. Errors/failures can also turn the system off.
Includes:	N/A
Extends:	N/A
Cross References:	G6
Connected Use-Cases:	Alert Driver

Use Case:	System On

Actors:	Driver
Type:	Primary & Essential
Description:	The driver can manually turn on the system via a switch. By default, the system is on when the car starts.
Includes:	N/A
Extends:	N/A
Cross References:	G6, I7, I8
Connected Use-Cases:	Outside of Speed Range, Turn Signal Activated, Poor Lane Detection, Torque Over Limit, Error/Failure, Alert Driver

Use Case:	Torque Over Limit
Actors:	System (initiator)
Type:	Secondary & Essential
Description:	Drivers do not always use turn signals when turning the wheel of the vehicle. If a certain amount of torque is applied to the steering wheel, the system goes into an idle state until there is no longer torque applied to the wheel.
Includes:	N/A
Extends:	N/A
Cross References:	G4
Connected Use-Cases:	System On, System Idle

Use Case:	Turn Signal Activated

Actors:	System (initiator)
Type:	Secondary & Essential
Description:	When the turn signal is activated, the system assumes this is a positive indicator that the user intends to turn the wheel and exit the lane. Thus, the system goes into an idle state and waits to re-engage until the driver finishes changing lanes, and the signal is disengaged.
Includes:	N/A
Extends:	N/A
Cross References:	I1
Connected Use-Cases:	System On, System Idle

Use Case:	Threat Detected
Actors:	System (initiator)
Type:	Primary
Description:	The system has preventative measures in place to help avoid being compromised by a cybersecurity attack. If a threat is detected while the system is on, the system alerts the driver and turns off to help mitigate risk.
Includes:	N/A
Extends:	N/A
Cross References:	G7
Connected Use-Cases:	Alert Driver, System On

4.2 Class Diagrams

Below, Figure 2 showcases the domain model for the LMS. Each blue box is a class in the system. Lines between classes show associations between the two classes. A line ending in a white diamond represents aggregation or an ownership relationship. For example, the vehicle consists of

LMS and CSS. A line ending with a black diamond shows composition. For example, LMS has a composition with the LDWS, LKS, and LCS.

An example of this is LMS, which is composed of LCS, LDWS, and LKS. The following is the display for attributes: a dash (-) followed by the name, a colon (:), and a data type. For example, the first attribute in VSES is speed, with a data type of double. The function's name follows a plus symbol (+), and a double parenthesis is how operations are displayed. A line separates attributes and operations to tell them apart quickly.

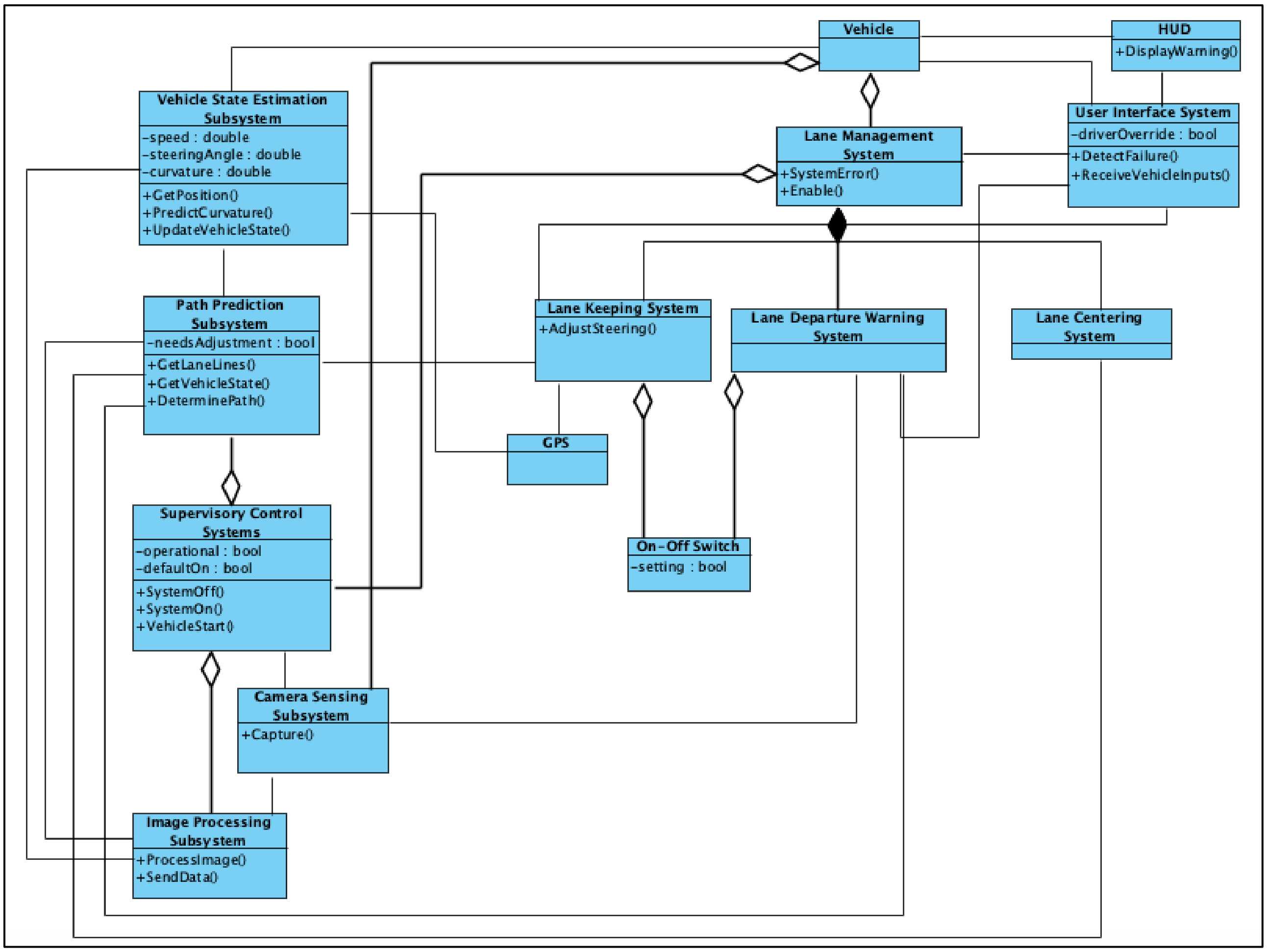

FIGURE 2 DOMAIN MODEL FOR THE LMS

4.3 Data Dictionary

Element Name		**Description**
Camera Sensing Subsystem		This element collects data from the road, such as the lane lines and the vehicle's position within the lane.
Attributes	N/A	

Operations	Capture()	
Relationships	Composes Vehicle. Association with LDWS, Supervisory Control Systems, and Image Processing Subsystem.	
UML Extensions	N/A	

Element Name		**Description**
GPS		This element gets positional data to compare to maps to get the vehicle's position along a road.
Attributes	N/A	
Operations	N/A	
Relationships	Association with LKS and Vehicle State Estimation Subsystem.	
UML Extensions	N/A	

Element Name		**Description**
HUD		This element is a display for the driver.
Attributes	N/A	
Operations	DisplayWarning()	This operation displays warning information via the user interface to the driver of the vehicle.
Relationships	Association with Vehicle and User Interface System.	
UML Extensions	N/A	

Element Name		**Description**
Image Processing Subsystem		This element processes the images taken by the camera system to identify features such as lane lines.
Attributes	N/A	

Operations	ProcessImage()	This operation processes an image to extract road information.
	SendData()	This operation sends the data to other subsystems once the image is processed.
Relationships	Composes Supervisory Control Systems. Association with Camera Sensing Subsystem, Vehicle State Estimation Subsystem, and PPS.	
UML Extensions	N/A	

Element Name		**Description**
Lane Centering System		This element attempts to keep the vehicle in the center of the lane whenever it is active.
Attributes	N/A	
Operations	N/A	
Relationships	Composes LMS. Association with Path Prediction Subsystem.	
UML Extensions	N/A	

Element Name		**Description**
Lane Departure Warning System		This element warns the driver when the vehicle is approaching a lane marker.
Attributes	N/A	
Operations	N/A	
Relationships	Composes LMS. Composed of On-Off Switch. Association with Camera Sensing Subsystem and Path Prediction Subsystem.	
UML Extensions	N/A	

Element Name		**Description**
Lane-Keeping System		This element keeps the vehicle from leaving its lane.
Attributes	N/A	

Operations	AdjustSteering()	This operation adjusts the steering of the vehicle to stay inside the lane.
Relationships	Composes LMS. Composed of On-Off Switch. Association with User Interface System, GPS, and Path Prediction Subsystem.	
UML Extensions	N/A	

Element Name		**Description**
Lane Management System		This element represents the system as a whole. This system is composed of many subsystems.
Attributes	N/A	
Operations	SystemError()	This operation notifies the system that there is an error.
	Enable()	This operation starts the LMS.
Relationships	Composed of LKS, LDWS, LCS, and Supervisory Control Systems. Composes Vehicle. Association with User Interface System.	
UML Extensions	N/A	

Element Name		**Description**
On-Off Switch		A physical button or switch that can enable or disable LKS or LDWS.
Attributes	setting	This Boolean attribute checks the setting of the On-Off switch
Operations	N/A	
Relationships	This relationship is composed of the LKS and LDWS.	
UML Extensions	N/A	

Element Name	**Description**
Path Prediction Subsystem	This element predicts the future path of the vehicle and notifies other systems when intervention is needed.

Attributes	needsAdjustment()	This Boolean attribute determines whether the steering needs to be adjusted. If True, adjustment is needed, and if False, no adjustment is needed.
Operations	GetLaneLines()	This operation gets the lane lines from the image.
	GetVehicleState()	This operation gets the vehicle speed, steering angle, and road curvature.
	DeterminePath()	This operation calculates the path the vehicle would take on a curved road.
Relationships	Composes Supervisory Control Systems. Association with Vehicle State Estimation Subsystem, IPS, LKS, LDWS, and LCS.	
UML Extensions	N/A	

Element Name		**Description**
Supervisory Control Systems		This element controls all subsystems and can enable and disable various systems.
Attributes	operational	This attribute is a Boolean for each system that is true if it is operational and false if it has an error.
	defaultOn	This attribute is a Boolean for the LMS that is true if the user has specified that the LMS is on and false otherwise.
Operations	VehicleStart()	This operation brings the system from the initial state to the first state; it is called when the vehicle starts.
	SystemOn()	This operation turns on any system or subsystem.
	SystemOff()	This operation turns off any system or subsystem.
Relationships	Composed of Path Prediction Subsystem, and Image Processing System. Composes LMS. Association with Camera Sensing Subsystem.	
UML Extensions	N/A	

Element Name	**Description**
User Interface System	This element switches the control and information between the system and the driver.

Attributes	driverOverride	This attribute is a Boolean for the LMS that is true if the user overrides the system. The user overrides the system by either using their turn signal before changing lanes or using sufficient torque in the lane change. This attribute returns false if the user does not override the system.
Operations	ReceiveVehicleInputs()	This operation receives the torque and the turn-signal state of the vehicle.
	DetectFailure()	This operation detects if there is a failure in the system.
Relationships	Association with HUD, Vehicle, LMS, LKS, and LDWS.	
UML Extensions	N/A	

Element Name		**Description**
Vehicle		This element represents the vehicle.
Attributes	N/A	
Operations	N/A	
Relationships	Composed of LMS and Camera Sensing Subsystem. Association with Vehicle State Estimation Subsystem, HUD, and User Interface System.	
UML Extensions	N/A	

Element Name		**Description**
Vehicle State Estimation Subsystem		This element contains values determining the vehicle's current state.
Attributes	speed: double	This attribute represents the speed of the vehicle.
	steeringAngle: double	This attribute represents the turning angle of the vehicle.
	curvature: double	This attribute represents the curvature of the road.
Operations	UpdateVehicleState()	This operation estimates the vehicle's state at a specific point in time.

	PredictCurvature()	This operation predicts the curvature of the road.
	GetPosition()	This operation gets the vehicle's position at a given time.
Relationships	Association with Vehicle, Path Prediction Subsystem, IPS, and GPS.	
UML Extensions	N/A	

4.4 Representative Scenarios of Systems

There are a few different scenarios in which the system can operate. Below are three separate sequence diagrams that model four general scenarios. Sequence diagrams consist of two main entities: lifelines, or classes within the system, are located across the top of the diagram, and messages or functions allow for communication between these classes, connect the lines under each lifeline. The messages lower in the diagram occur later. Numbers before each message also shows the order in which events occur.

4.4.1 Normal Operation Sequence Diagram

The first scenario is figure 3 below. It depicts LMS operating in a scenario where nothing is disrupting the system. This sequence diagram represents how the system acts in both straight and curvy roads, the difference being the values and amount of corrective action would be sent to LKS at the last step. The first event that happens is the SCS turns on all systems in the car if they are operational. Once the system is on and operating, the CSS captures a photo and sends it to the IPS to process the image and extract features. The CSS then sends data to the VSES to determine the road curvature ahead and the rest of the data to the PPS to begin analyzing the lane lines to correct the vehicle's position as needed. GPS also sends positional data to VSES to help in determining future road curvature. Once the VSES processes the data, it sends vehicle information and road curvature to the PPS so it can finish determining the current path of the vehicle and then send values to LKS to alter the path so the vehicle stays in the center of the lane. [2]

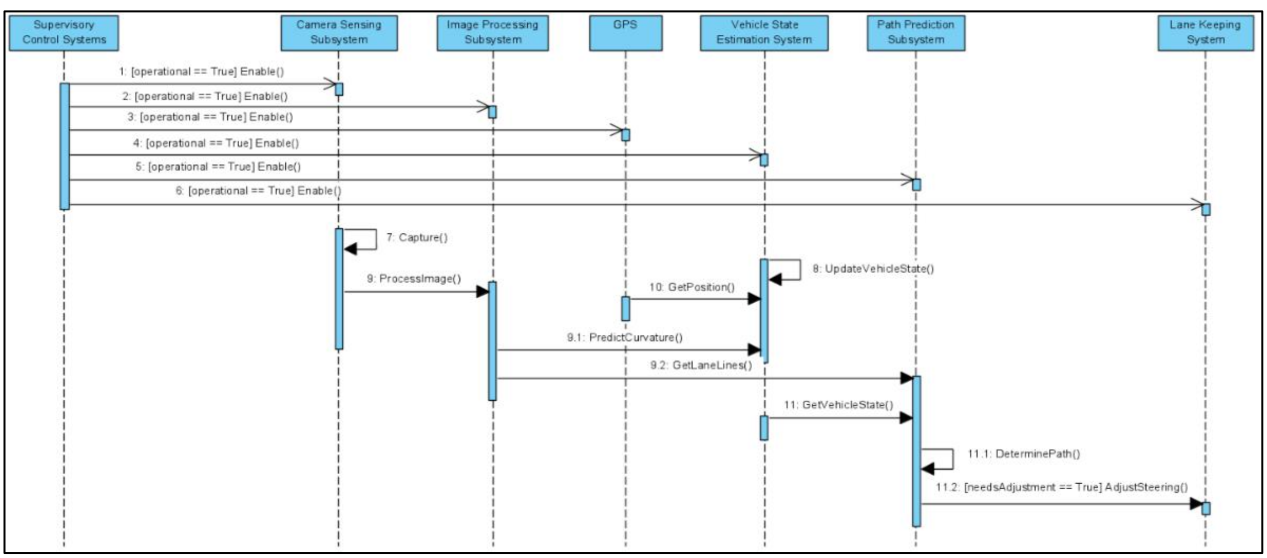

FIGURE 3: LMS COLLECTING DATA FROM CAMERAS AND SENSORS TO DETERMINE AND TAKE CORRECTIVE ACTION TO STAY IN THE CENTER OF A LANE.

4.4.2 Driver Override Sequence Diagram

The following figure shows a scenario where the driver of the vehicle overrides the system. Everything that happens before the AdjustSteering operation call from the PPS to LKS is precisely the same, so the image has been cropped for better readability. In figure 4 below, the UIS receives a signal from the vehicle signifying the driver has made an action that results in an override, for example, a turn signal or force on the steering wheel. Actions like this tell the HUD to display that the system has become inactive and then sends information to LKS to disable temporarily corrective steering.

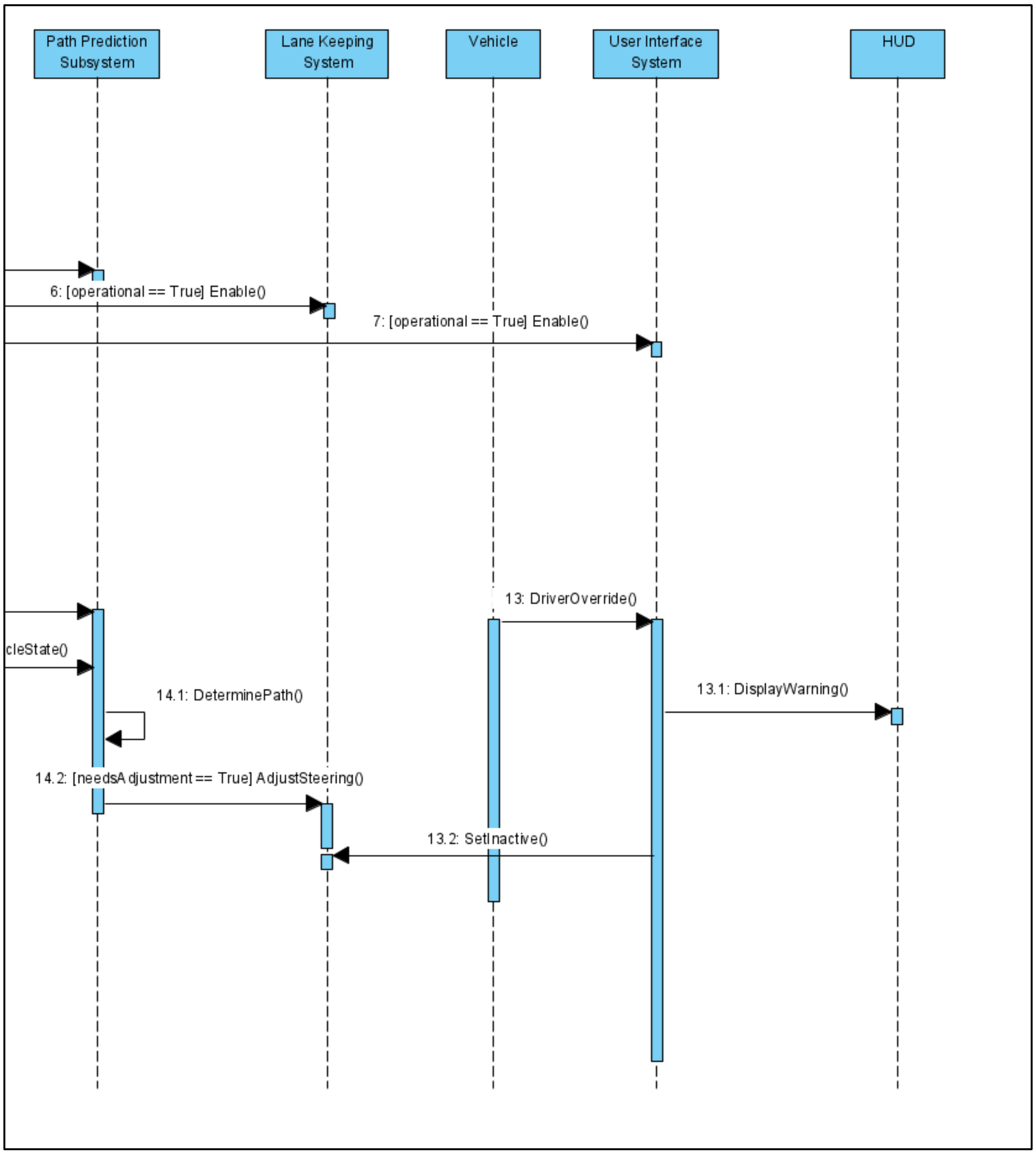

FIGURE 4: UIS COLLECTS INFORMATION FROM THE VEHICLE THAT THE USER WOULD LIKE TO OVERRIDE LMS

4.4.2 Internal System Error Sequence Diagram

The last scenario, in figure 5, depicts how the system would recognize and react to an error in various subsystems. Every time the system activates, the SCS checks each system's integrity to ensure that it is operable. If any system returns that it is not functioning correctly, an error occurs, and SCS disables all the subsystems and disables LMS. An error sends to the UIS, which sends a message to the HUD to display the offline system. Every time the user attempts to start the system, it performs this full system check to ensure everything is working.

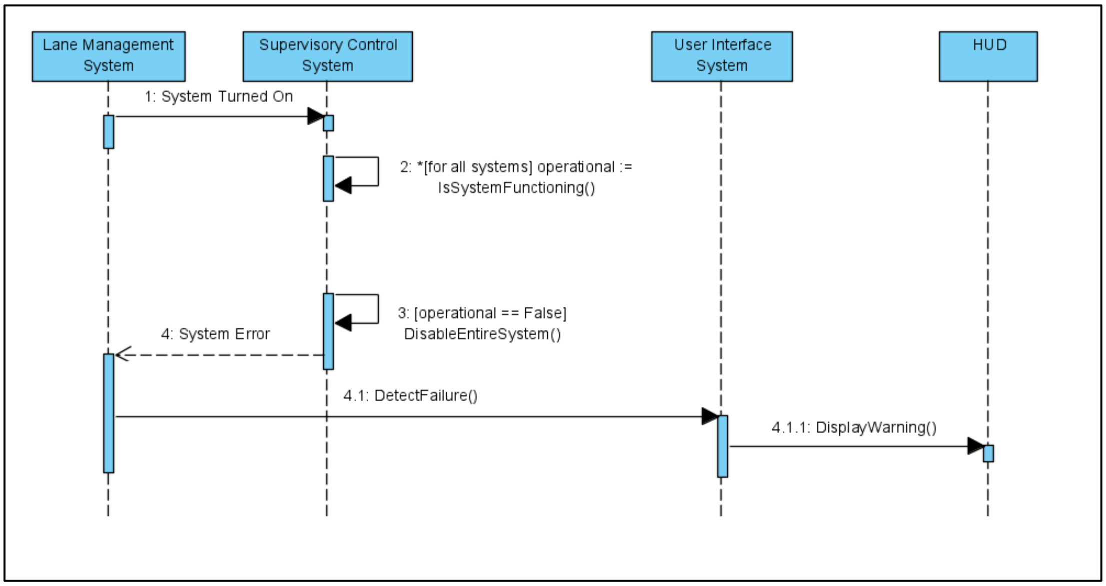

FIGURE 5: LMS TURNING OFF AS A RESULT OF AN ERROR IN ONE OF ITS MANY SUBSYSTEMS.

4.5 State Diagrams

LMS has many subsystems, and each system has tasks that it performs. The state diagram for most of these systems is represented below in figures 6 – 13. These diagrams follow a similar syntax. The black circle represents a systems initialization, and it transitions to the first state. Arrows identify transitions, and they contain guards, operations, and outputs. Guards are Boolean statements written inside of square brackets. Operations are all immediately followed by a parenthesis. Outputs are all preceded by a forward slash. "And" is represented as an ampersand: &, and "or" is represented as two vertical bars: ||.

4.5.1 Camera Sensing Subsystem

The LMS uses the CSS to determine where lane lines are in the world. The system is off initially, and when enabled, routinely captures images and sends them off for processing. The system responds to errors by turning off.

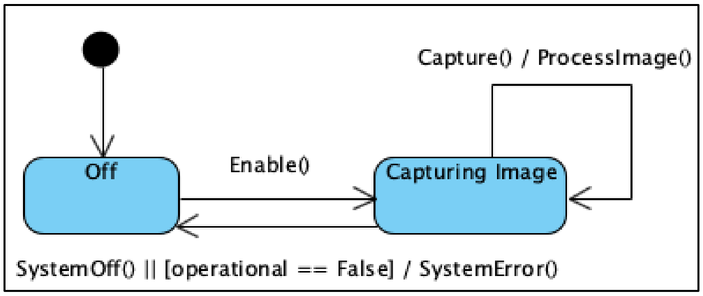

FIGURE 6: CAMERA SENSING SUBSYSTEM (CSS) STATE DIAGRAM

4.5.2 Image Processing System

The IPS starts in the off state, and once the system is operating, it moves to an idle state. The system can then either be turned off by the driver or start processing the images that it receives. The various events that cause the IPS to change its states are listed below.

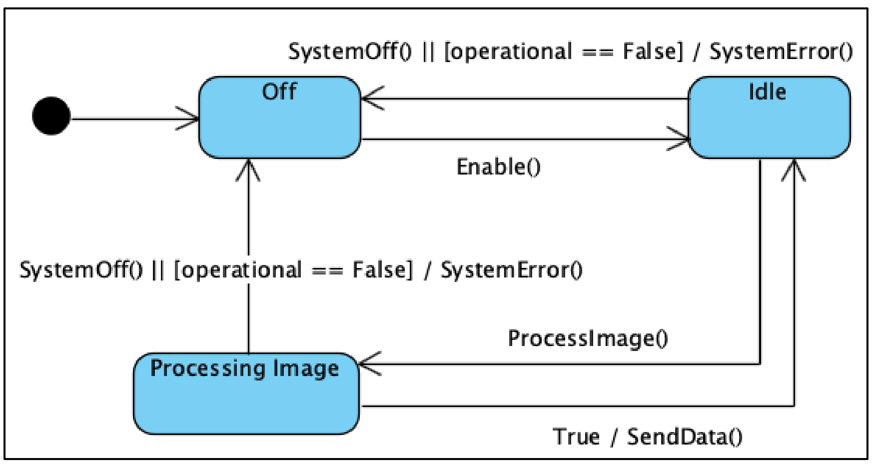

FIGURE 7: IMAGE PROCESSING SYSTEM (IPS) STATE DIAGRAM

4.5.3 Lane Departure Warning System

The LDWS has two separate sets of states. The first starts in the off state and moves to idle if the LMS functions and the systems are active. Should the driver intentionally leave their lane, the driver receives no warnings. If the driver unintentionally leaves their lane, the system sends a message to the driver and information to other systems to correct the vehicle's lane position.

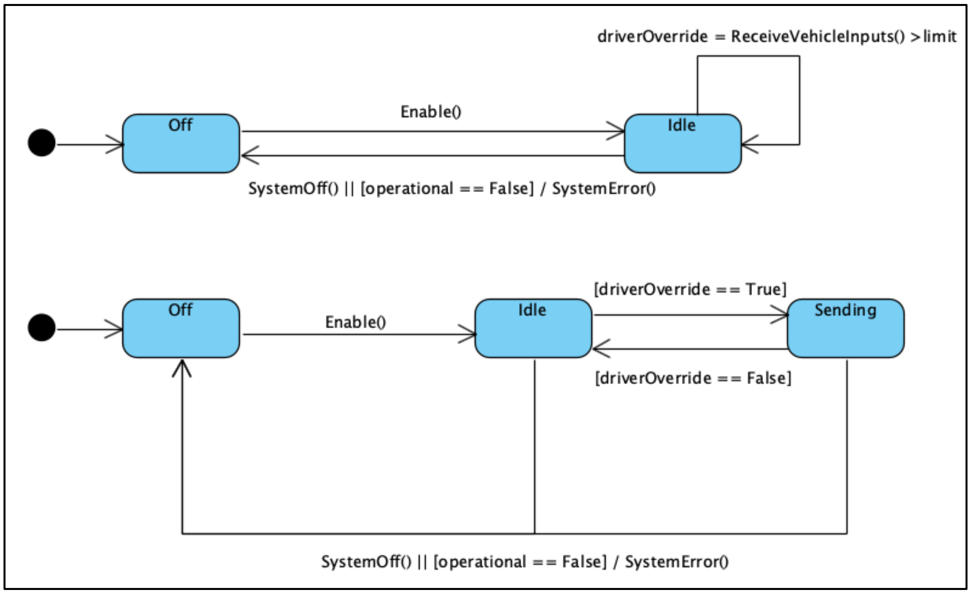

FIGURE 8: LANE DEPARTURE WARNING SYSTEM (LDWS) STATE DIAGRAM

4.5.4 Lane-Keeping System

The LKS state diagram is below. Initially, it is off and turns off if any errors are detected. Otherwise, it remains idle and only adjusts the car's steering when the PPS tells it to, and there is no driver override.

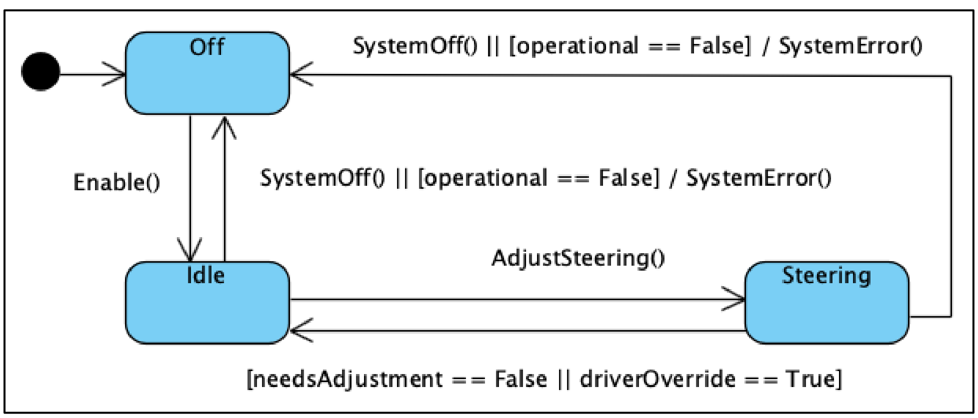

FIGURE 9: LANE-KEEPING SYSTEM (LKS) STATE DIAGRAM

4.5.5 Path Prediction System

The PPS attempts to predict the future path that the vehicle takes using GPS and other systems. If the PPS determines that adjustments must happen, it sends information to different systems to make the corrections.

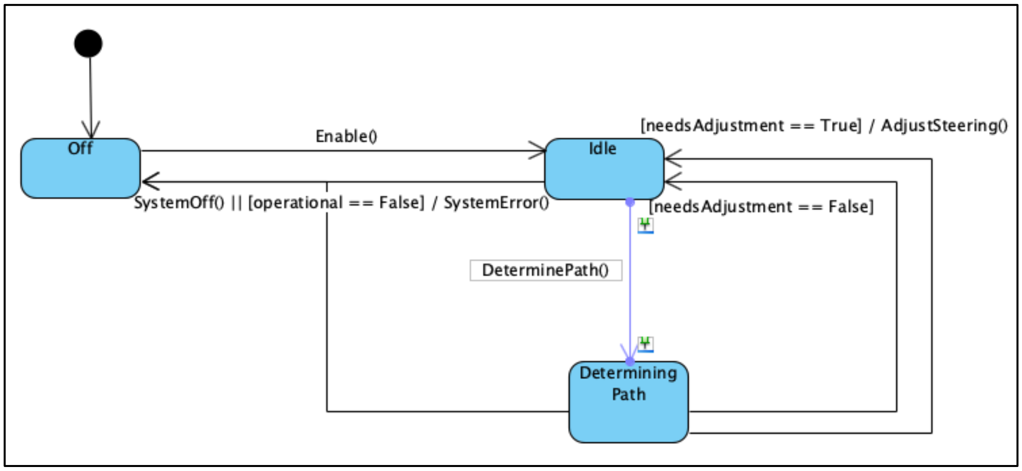

FIGURE 10: PATH PREDICTION SYSTEM (PPS) STATE DIAGRAM

4.5.6 Supervisory Control System

The Supervisory Control Systems is a complex parallel state machine. The first partition starts when the vehicle is turned on and turns on and off other subsystems. The first state checks the user's preferences to determine if the LMS should be on or off. If the default is off, it goes to the off state until the user turns the system on. If the default is on, then it checks to make sure all subsystems are operational. If anything is not operational, the system turns everything off. If everything is operational, it enables all subsystems. It goes to the Operating Normally state, where it stays until a subsystem runs into an error or the driver turns off LMS. When this occurs, SCS turns every system off.

The second partition starts when the first partition calls Enable (), and it handles the transfer of information between subsystems. The first state captures an image, which then sends an output to process the image. After processing is complete, it sends this data to another system to predict the curvature and determines the path. If steering corrections are needed and no driver overrides, it sends steering changes to LKS. If there are no changes needed, it restarts the loop by capturing an image. Each state transitions to an off state if an error arises or if the driver turns off the system.

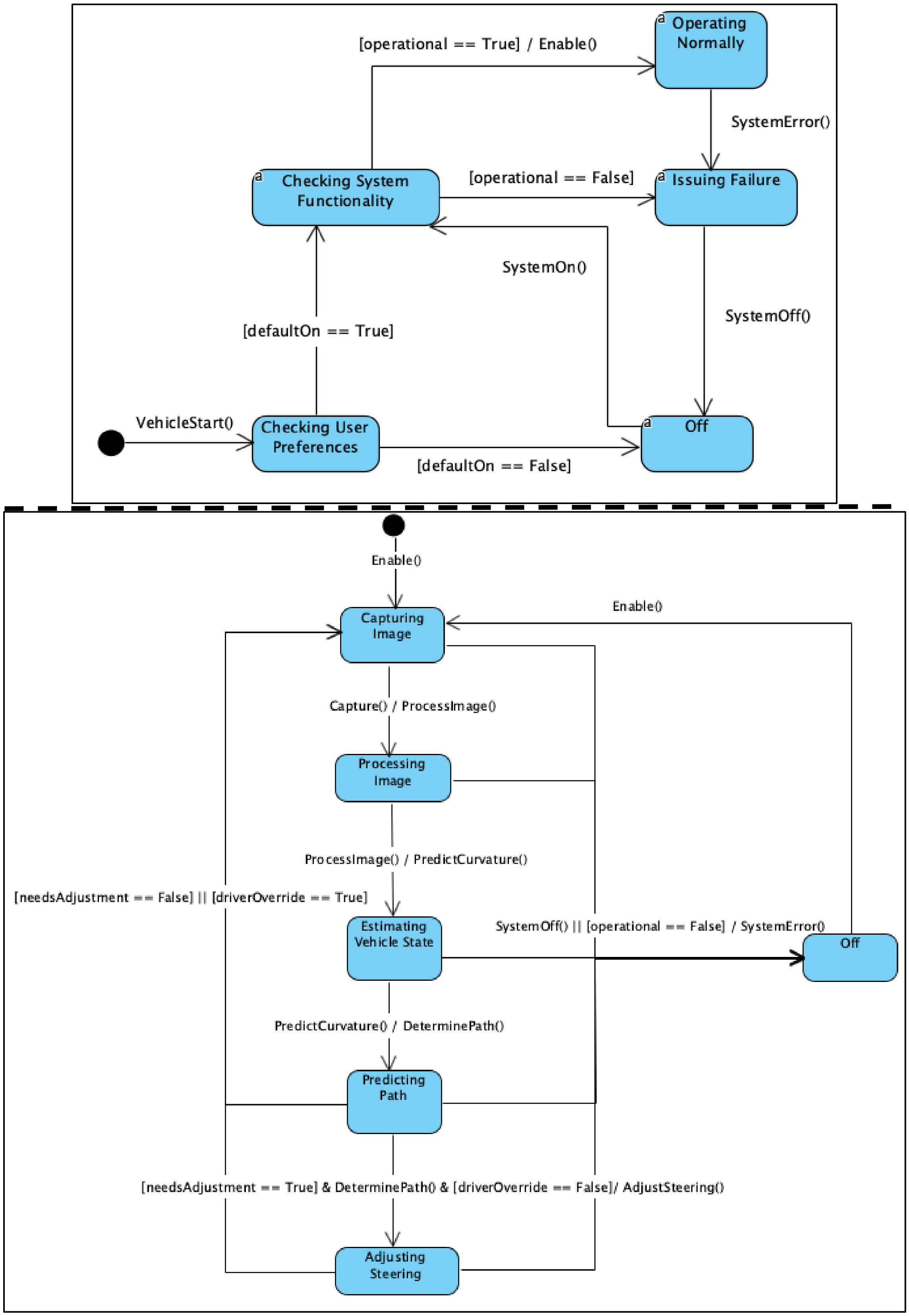

FIGURE 11: SUPERVISORY CONTROL SYSTEMS (SCS) STATE DIAGRAM

4.5.7 User Interface System

The user interface system has two concurrent state systems. They are both off initially and respond to errors by turning off. The UIS checks to see if conditions exist for a driver override to occur. It also notifies the driver of any warnings occurring in other subsystems of the LMS.

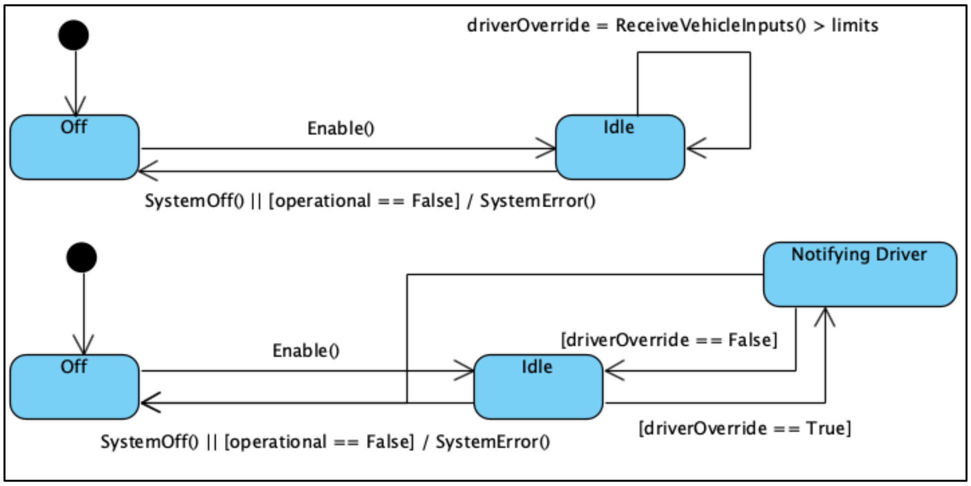

FIGURE 12: USER INTERFACE SYSTEM (UIS) STATE DIAGRAM

4.5.8 Vehicle State Estimation System

Figure 13 displays the VSES state machine. The VSES estimates the vehicle's state at a specific point in time. The VSES begins in the off state and, once enabled, moves to an idle state. In the idle state, the vehicle's state updates every second, denoted by "timeout (1s)" and "UpdateVehicleState()." The VSES could either move on to the Predicting Curvature state from the idle state where VSES predicts the road's curvature or to Off if the system turns off or fails. Suppose the system finds road curvature, the vehicle state updates with the new position.

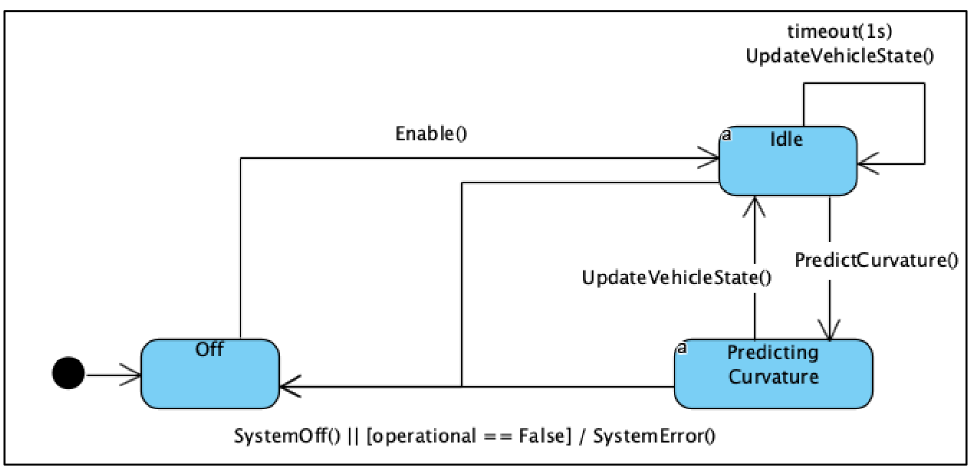

FIGURE 13: SUPERVISORY CONTROL SYSTEMS (SCS) STATE DIAGRAM

5 Prototype

The prototype visually shows how LMS acts under various scenarios. The gifs presented are from the driver's point of view, who then perform both intentional and unintentional actions. Five different lights appear on the dash, informing the driver about the state of the system. The first, a yellow warning exclamation mark inside a triangle, tells the driver when they are unintentionally drifting toward a line marker, and the system takes corrective actions. The light on the dash of a green car crossing lanes shows that the system is active. The orange car crossing lanes show that the system is idle and won't make any corrections. The red vehicle vertical lanes show that the system is off. Lastly, the red exclamation mark with a circle shows that the system failed internally and had to turn off. Each of these lights is shown below in figure 14.

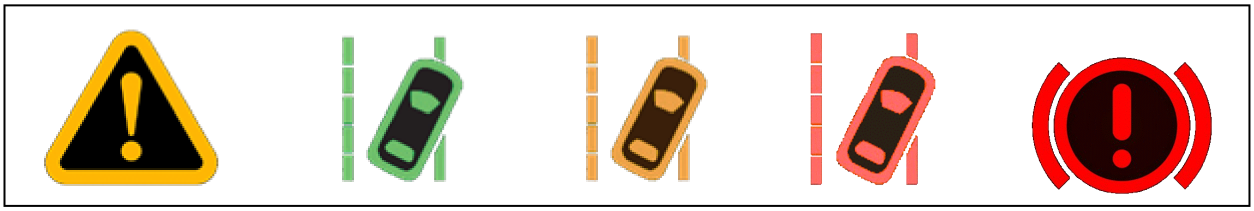

FIGURE 14: THE ICONS AND WARNING LIGHTS USED WITHIN THE PROTOTYPE.

5.1 How to Run the Prototype

The prototype can run in virtually any internet browser. The first thing to do is turn the system on by clicking the "System On?" switch. Once it is on, there are radial buttons to the left of the gif to select different scenarios that run on a loop. Simply click each button to observe each scenario. There is a brief description of each scenario under each gif and a legend on the page's right side explaining the dashboard's lights. The prototype can be found here [4].

5.2 Scenarios

The prototype shows several different scenarios. One scenario shows the system running under ideal conditions with just a slight drift. When above 35 mph, the light is indicating that the system is on and active is displayed. The car drifts toward the lane marker to the left until the warning light is displayed. After the warning light is displayed and the car continues to drift, the LMS takes corrective action and steers the vehicle back into the middle of the lane. Figure 15 shows this below. If the car is below 35 mph and starts to drift, the system does nothing and remains idle.

FIGURE 15: PROTOTYPE SHOWING THE VEHICLE TAKING CORRECTIVE ACTIONS AFTER STARTING TO DRIFT OUT OF THE LANE.

Another scenario shows how the system behaves on a curved road. When the vehicle is above 35 mph, and the system is enabled, it successfully stays within its lane through the curves. When below 35 mph, the system is in its idle state, so it continues driving straight and could likely lead to a crash. If the system is not showing the green icon, no corrective actions take place.

FIGURE 16: PROTOTYPE SHOWING THE VEHICLE TAKING CORRECTIVE ACTIONS.

A third scenario shows the vehicle's system switching control between the driver and the lane management system. Although there are many ways to transfer control, the most obvious way is when the driver uses turn signals to change lanes. Turn signal activation notifies the system to disengage temporarily. When the driver activates the turn signals, the system goes into an idle state. Once the user has finished their lane change, and the turn signal is disengaged, the system goes back into an on and active state. Figure 17 depicts this scenario below. Another method the driver can use in the prototype is using force on the steering wheel to disengage.

FIGURE 17: PROTOTYPE SHOWING THE DRIVER USING THE TURN SIGNAL TO TRANSFER CONTROL OF THE VEHICLE TO THE DRIVER TO PERFORM A LANE CHANGE.

The final scenario shows the system encountering an error and shutting off as a result. When a system fails, the on or idle icon switches to off, and a red warning displays on the dashboard, signifying that the system encountered some error type. The system shuts off to ensure the safety of the driver. If any part of the system does not work optimally, it does not operate without that part and shuts down until resolved.

FIGURE 18: PROTOTYPE SHOWING THE SYSTEM IS DISABLED DUE TO AN INTERNAL ERROR IN A SUBSYSTEM.

6 References

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[2] B. H. C. Cheng, "Lane Management System", Michigan State University, August 2020

[3] S. Singh, "Critical reasons for crashes investigated in the national motor vehicle crash causation survey" No. DOT HS 812 115, February 2015

[4] B. Kandel, "LMS1 Home Page," LMS1 Project Site, 28-Oct-2020. [Online]. Available: http://cse.msu.edu/~kandelb1/. [Accessed: 15-Nov-2020].

7 Point of Contact

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