Software Requirements Specification (SRS)

Project Lane Management System (LMS2)

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1 Introduction

When looking at vehicle accident statistics, tens of thousands are injured or killed each year by incidents where a vehicle has left their lane unintentionally [3]. Moreover, the most deadly type of lane departure collisions are head-on collisions. Head-on collisions were the cause of 14% of all U.S. traffic fatalities in between 2016 and 2018 [2]. To address these tragic events and prevent future occurrences, development of technologies that prevent lane drifting and unwanted lane departure is needed in an effective system.

This document details the requirements and expected elements and functionality of the Lane Management System (LMS). The LMS is an assistance system to prevent the driver's vehicle from lane drifting. In Section 1 we can find the purpose and scope of the system as well as a guideline to definitions, acronyms, and abbreviations used throughout the document and a description of the overall organization of the document.

1.1 Purpose

The purpose of this SRS document is to provide information to interested parties, developers, stakeholders, management, etc. The SRS document is intended to provide a detailed understanding of the software requirements needed for the development of the LMS system that will behave and operate as expected.

1.2 Scope

The LMS is an embedded automotive system. The LMS is designed to increase convenience and safety when driving. It will serve as an assistance to the driver and is not intended to be used as a substitute for careful and attentive driving and will only provide brief redirection. It is not meant to be a hands free driving system.

The LMS is composed of smaller subsystems. This includes the Lane Keeping System (LKS) which contains a camera system and evaluates the vehicles position in the lane as well as redirecting the vehicle if needed. A Lane Departure Warning System (LDWS) which alerts the driver if they are possibly drifting out of their lane. A Lane Centering System (LCS) which centers the vehicle in the lane. As well as a deactivation system which will deactivate the system via driver override or if lane markings are not detected. The LMS has cameras and sensors to monitor the vehicle and its position in the lane. When the LKS detects possible lane drifting the DS will display a warning message and re correct the vehicles positioning if needed. The driver is able to override the lane correction by taking control of the steering wheel or turning on their turn signal. If there is ambiguity or no lane markings detected then the display system will alert the driver that the LMS is not currently in effect and is not detecting the vehicle's position at that time. The display will inform the driver to remain alert while driving. The LMS's goal is to assist the driver in remaining centered in their lane and will provide constant feedback with the driver about the status of the system and alerts them before taking any action.

1.3 Definitions, acronyms, and abbreviations

Acronym	Term	Definition
LMS	Lane Management System	The overall system
LKS	Lane Keeping System	The subsystem the monitors the vehicles position in the lane
LDWS	Lane Departure Warning System	Display system that alerts the driver of the current status of the system
SRS	Software Requirements Specification Document	Outlines the requirements for the LMS
LCS	Lane Centering System	Centers the vehicle in the lane via steering override

1.4 Organization

The remainder of the document is organized as follows:

Section 2 provides an overall description of the LMS as well as the details of the system's functions, characteristics, constraints, assumptions, dependencies, and possible future improvements.

Section 3 Includes an enumerated list of requirements for the LMS. This includes specific requirements such as primary requirements that describe system behavior, secondary requirements, global invariants which must always be true, and cybersecurity requirements.

Section 4 we can find visual representations and models of expected behaviors and functionality of the LMS. In this section we can find various use case diagrams, high level class diagrams, and state diagrams for all key classes.

Section 5 provides a detailed description of how the prototype can be utilized to display the LMS's functionality.

Section 6 lists all of the sources referenced throughout the SRS document.

Section 7 is the last section of the SRS document. Section 7 provides a point of contact if more information is needed.

2 Overall Description

The following sections shall describe how the LMS operates in a vehicle in depth. Section 2.1 outlines the perspective of the system along with the constraints on the system. Section 2.2 outlines the functions that the software shall perform. Section 2.3 describes the expectations the users shall have when using and operating the system. Section 2.4 describes the additional constraints placed on the system. Section 2.5 describes the assumptions and dependencies on the LMS. Finally, in Section 2.6 approportioned requirements shall be described.

2.1 Product Perspective

The LMS is a product in vehicles that is responsible for keeping the vehicle centered in the driving lane and to prevent any unintentional lane switching. The system is an independent feature in the car, however it comprises several other subsystems which all rely upon each other in order for the LMS to function to its highest extent. The subsystems include a LKDS, LKS, and the LCS. Even though the LMS is an independent system in the vehicle, the communication between all of its subsystems is vital for optimized performance in the system.

User role is vital in the overall system, and contributes to many of the system's functions. The user must be able to operate the vehicle which includes functions such as steering, acceleration, deceleration, and turn signal usage. Along with these functions, the user must be able to see and understand the car's dashboard GUI in order for the user to understand the warnings and signals the LMS is showing. Lastly, the user must be able to disable the system by turning off the system via a button or if the vehicle's speed is not above 35 miles per hour.

Hardware components are also a vital part to the success of the system. Cameras are placed on the sides of the vehicle so the lanes are able to be detected. The dashboard of the vehicles must include a visual display in order for warnings and signals to be detected by the user. Sensors are also found along the sides of the vehicles which determine the speed, steering angle and road curvature for the system. No other main hardware component is needed for optimal functionality of the system.

The system needs to have software components that allow for accurate information passing between the subsystems of the LMS. Fast and accurate information communication is needed in the subsystems so that the correct response is chosen by the main system. The subsystems provide and calculate data such as distance to lane and determining the angle the car is driving. Without good communication between the subsystems, there is a possibility of accidents and an overall unreliable LMS.

Figure 1 shows how information and actions flow in the system. The vehicle is the main actor in the diagram and is what activates the systems. Cameras and Sensors are both vital for sending information to the system in order to understand the distance to the lane markers. The Lane Management System is responsible for receiving information from the sensors and calculating if the car is about to cross the lane. The Lane Keeping system is activated when there is about to be a breach in the lane, and results in overriding the steering to move the car back to the center of the lane. Displays for lane crossing, unintentional swerving, and if the system is active are all found in the DS.

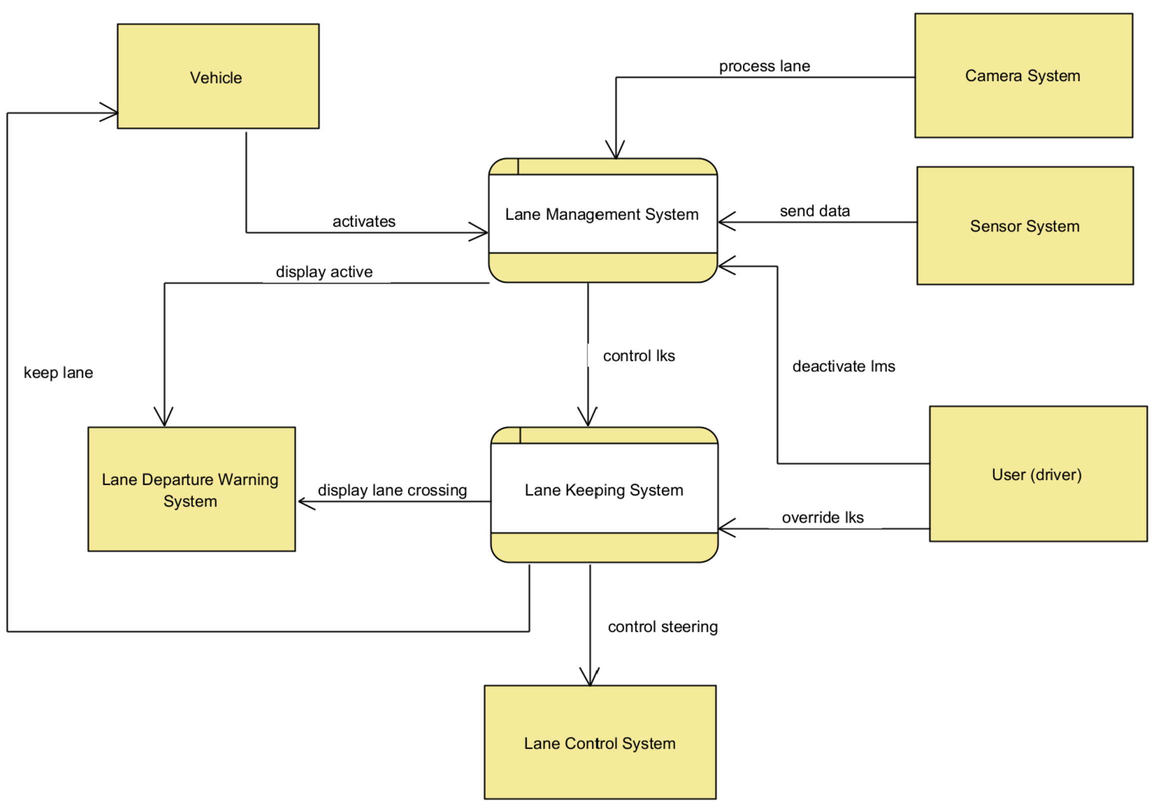

Figure 1: Data Flow Diagram for the LMS

2.2 Product Functions

The LMS serves as a helpful tool to ensure the vehicle remains centered within its designated lane and prevents inadvertent lane changes.The high-level goal is to provide safety for the driver by keeping the vehicle in the lane they should be in. Safety is provided by using many different systems in the vehicle, such as cameras and sensors which accurately provide data as to where the lane markers are. The vehicle shall keep inside its current lane regardless of speed, road curvature, and low visibility of lane markers. Warnings shall be displayed in the dashboard display which indicate if the LMS is active and if any lane is about to be breached.

Figure 2 shows a high-level goal diagram for the LMS. At the top, the main goal of the system is presented which is to avoid crossing the lane markers. Branching off of the main goal, the system is to keep the car in the center of the lane, avoid crossing the lane unintentionally, and to warn the user if the lane is about to be breached. In order to achieve these goals, the lane markers and data needs to be processed and sent to the system. Cameras and sensors help to gather the data needed. The user is able to override the system by using turn signals or applying enough torque to the steering wheel to indicate a lane switch.

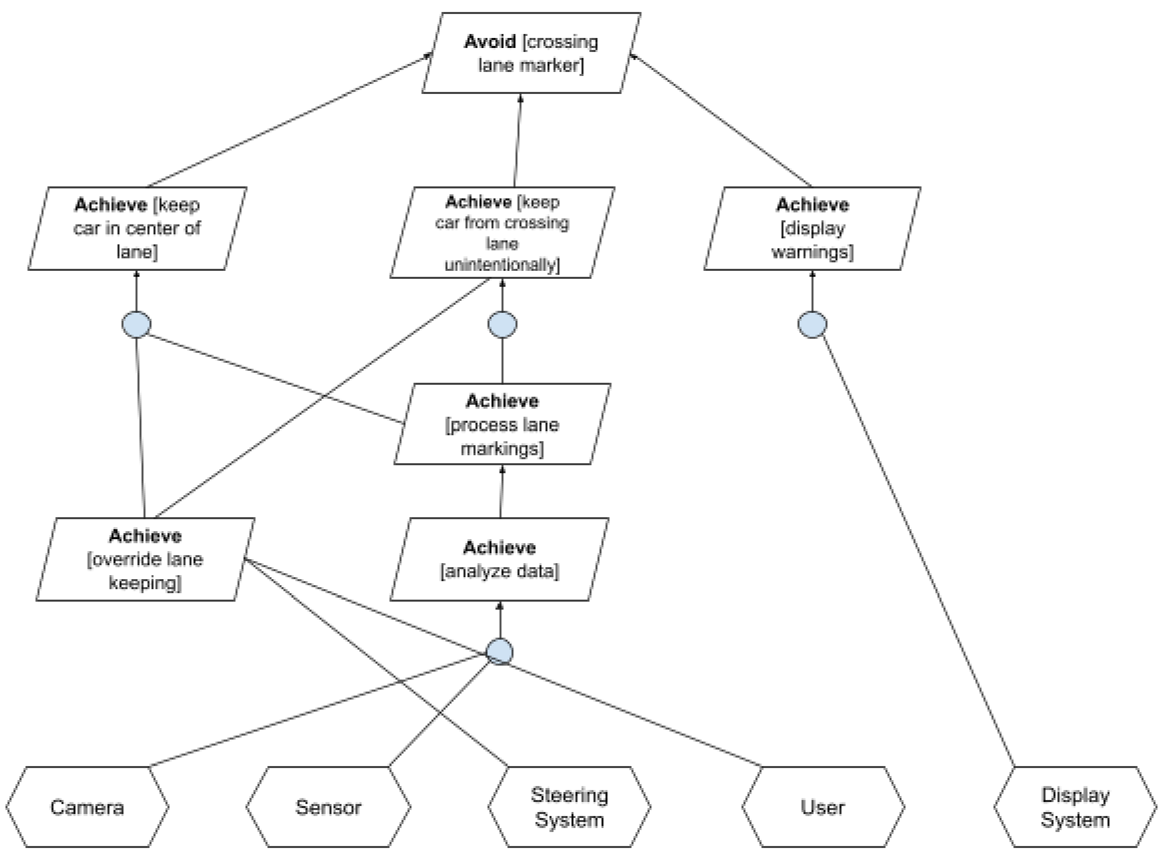

Figure 2: KAOS goal model for the LMS

2.3 User Characteristics

The expectations for a user of the LMS are described here. In order for the user to operate and use the system, they must be legally allowed to drive. The user must be able to follow all of the rules and regulations of the road in the given location of operation. In addition to following the rules, the user must be able to have full functionality of the acceleration, braking, steering wheel, and turn signals. The user should be able to see the displays given on the dashboard and also be able to hear any sound warnings the system presents. Finally, the user should use the system as a driving assistance instead of any form of autonomous driving feature.

2.4 Constraints

The constraints set for the LMS are presented in this section. The system may only be able to become active when the vehicle is set to drive mode and the current speed of the vehicle is at or above 35 miles per hour. While the system is active, the camera and path detection system must be able to operate if the lanes are fully present, if there is any curvature on the road, and if there is limited visibility of the given lanes. The correct detection of the lanes is a safety-critical property due to the potential risk if the system fails. With failure, there are possibilities of accidents and other life-threatening circumstances.

Another safety-critical property is for the cameras and sensors to be fully operational and weather conditions to be optimal. If the cameras are damaged or obstructed there may be discrepancies when detecting the correct lane distance. If weather conditions are not optimal, such as snow or heavy rain, the cameras and sensors may not be able to detect the lane markers. If any of the sensors or cameras are not operational, the system should not be able to be activated, and a warning should be displayed on the dashboard telling the user the system is not active.

Other constraints include the ability to disable the system correctly. The system must be disabled if the user activates the turn signal to indicate they are switching lanes, and if the user applies enough torque on the steering wheel which overrides the system. Without the ability to disable the LMS, there is a huge risk of accidents or unintentional lane keeping, thus making this a very important safety-critical property.

Finally the LMS must be able to display and provide sound warnings. The user must be warned if there is any form of unintentional swerving, the lane is about to be breached, and if the system is disabled. Warnings are vital to the system in order to provide the user with the most updated information about what is going on with the system and if there is any potential danger while staying in the lane. The communication between the user and the system is vital in order for the most safe and optimal driving experience possible.

2.5 Assumptions and Dependencies

For the seamless functionality of the LMS, it is important that the designated hardware components are installed correctly within the vehicle. The operational integrity of the system depends on the proper functioning of both cameras and sensors. The software embedded in the LMS should not only facilitate communication among its subsystems but also extract fundamental vehicle information, such as speed and direction. Under ideal weather conditions and within suitable environments, the system must exhibit flawless operation. Whether encountering lane markings or negotiating road curvature, the LMS should execute its lane management operations without any fail. Users are required to understand the system's warnings and functionalities, acknowledging that the LMS solely serves as a driving assistance tool.

2.6 Apportioning of Requirements

The scope of the LMS is limited in size but in the future, the requirements could be improved to include more functionality. One additional requirement that is currently out of scope would be for the cameras to be able to detect if there is another vehicle in the lane that is about to be switched to. The ability to detect other vehicles can improve the overall safety of the user. Another requirement would be to have a display for possible cameras or sensors that are either not functioning or an outside factor is not allowing them to work properly. The final requirement would be the ability to change any setting such as warning tone or the type of visual display that shows up on the dashboard.

3 Specific Requirements

This segment outlines a structured hierarchy of requirements for the SRS system. They are arranged in descending order of importance, starting with Global Invariants, Primary Requirements, Secondary Requirements, to Cybersecurity Requirements.

3.1 Global Invariants:

3.1.1. The user will always have control of the vehicle at all times.

3.1.2. One of the system’s purposes is to prevent lane drifting.

3.1.3. The system will alert the driver of drifting via the LDWS.

3.1.4. The system’s purpose is to prevent accidents.

3.1.5. The system shall maintain continuous monitoring of the vehicle and the lane boundary under all road and environmental conditions.

3.1.6. When the user intervenes, the vehicle shall disregard the system's instructions and behave based on the user's instructions.

3.1.7. The system will not change the speed and will proceed at the current speed, and it will only change the direction of the vehicle

3.1.8. Continuously reevaluate the vehicle's position through the Camera System to find the distance, location, and angle of the lane in regards to the vehicle.

3.2 Primary Requirements:

3.2.1 The car shall have a LKS.

3.2.1a. If the system detects that the car is not near a certain range of the center of the lane, it shall enable the system to override and take over to gently move you back into the center at the current speed.

3.2.1b. Users shall be able to override the LKS through pulling the wheel applying a certain torque.

3.2.2. The system shall have a LDWS.

3.2.2a. The LDWS shall accurately update the driver about the vehicle's positioning in the lane, using the calculations of the Path prediction Subsystem, that predicts the optimal and safest path back to the center of the lane.

3.2.2b. The system shall alert the driver through a warning, both visual and audio, if it has found the vehicle is drifting out of the lane. The system detects lane drifting via the cameras and sensors.

3.2.2c. There shall be a warning signal in the vehicle's panel to let the driver know when the system is about to intervene. There shall be a display in the LDWS.

3.2.2d. Before the system takes control, the system must first make sure that the user did not intentionally try to leave the lane. If there is a turn signal, then it means the driver is intentionally leaving the lane, while no turn signal lets the system know that the driver is not intentionally leaving the lane.

3.2.2e. Turning the turn signal on signals the intention to switch lanes and shall not cause an alert.

3.2.3. The system shall include a LCS.

3.2.3a. The system shall have cameras that will monitor the sides of the vehicle.

3.2.3b. While active, the LCS must use the Path prediction Subsystem, which determines distance and angle, to accurately calculate if the car is centered in the lane or not.

3.2.3c. In a lane that is not linear, there shall be an estimation system that predicts and determines the speed, angle, and road curvature. In a lane that is linear, it shall predict as normal without the angle and curvature.

3.2.3d. Images are then sent to processing to determine length, distance, and angle.

3.2.3e. The system's cameras shall monitor the exterior sides of the vehicle.

3.2.3f. The system shall recognize different types of lane markings: solid lines, dashed lines, and double lines. It shall only warn the user when the vehicle's about to cross solid and double lines, or when the vehicle's crossing dashed lines with signals left off.

3.2.3g. Reevaluation of the car's position should occur in a set amount of distance so that it can continuously and periodically reevaluate the situation.

3.2.4. The system shall continuously monitor the status of hardware components.

3.2.4a. When inputs from the hardware are inconsistent or unreliable due to hardware failures or hazardous environmental conditions, LMS shall warn the user and be deactivated.

3.2.5. The system can be turned off by the user through the user interface.

3.2.5a. The LMS and display system shall still receive a warning whenever the path prediction system detects that the car is getting too close to the lane's border.

3.2.5b. The system shall still check whether the car is leaving the lane, and alert the driver.

3.3 Secondary Requirements:

3.3.1. There shall be a disclaimer that the LMS is not a substitute for paying attention and driving carefully.

3.3.2. The driver shall be alerted if the LMS is turned off if it is not able to detect lines.

3.3.3. The system can be turned off by the driver.

3.3.4. The system shall provide brief steering nudges and not aggressive movements.

3.3.5. The LDWS should be able to gently alert the driver through visual warning on the panel or an audio warning that is not too loud that the vehicle is leaving the lane without a warning that would impede the ability to operate the vehicle.

3.4 Cybersecurity Requirements:

3.4.1. Threat Vectors

3.4.1a. Unpatched vulnerabilities in the software

3.4.1b. Malware in the LMS

3.4.2. Threat Actors

3.4.2a. Hackers

3.4.3. Types of cybersecurity vulnerabilities

3.4.3a. If there was a global road system that indicated where the lane markings would be through the Camera System, it could be hacked and the lane markings would change. This would cause the LMS to give incorrect predictions that could result in accidents. One way to prevent this would be to have a very secure system, and rely partially on physical markings.

4 Modeling Requirements

This section presents multiple models to visualize the functionality of the LMS system. We show Use Case Diagrams, a Class Model with a data dictionary describing classes, Sequence Diagrams, and State Diagrams.

4.1 Use Case Diagram

Figure 3 depicts the use case diagram for the LMS. The purpose of the use case diagram is to illustrate the desired observable system behavior. The blue rectangle in the use case diagram in **Figure 3** defines the system boundary. The use cases are enveloped in the blue ovals. External actors represented by the stick figures outside the system boundaries are linked to the use cases. The use cases are further described in **Table 1**, which cross reference the requirements in Section 3. The use case diagram shows that the user of the car and LMS can activate the LMS which displays the LMS system status. The system status can also display the system's activity. Detecting the lane markers is also part of the system display since it extends into it.

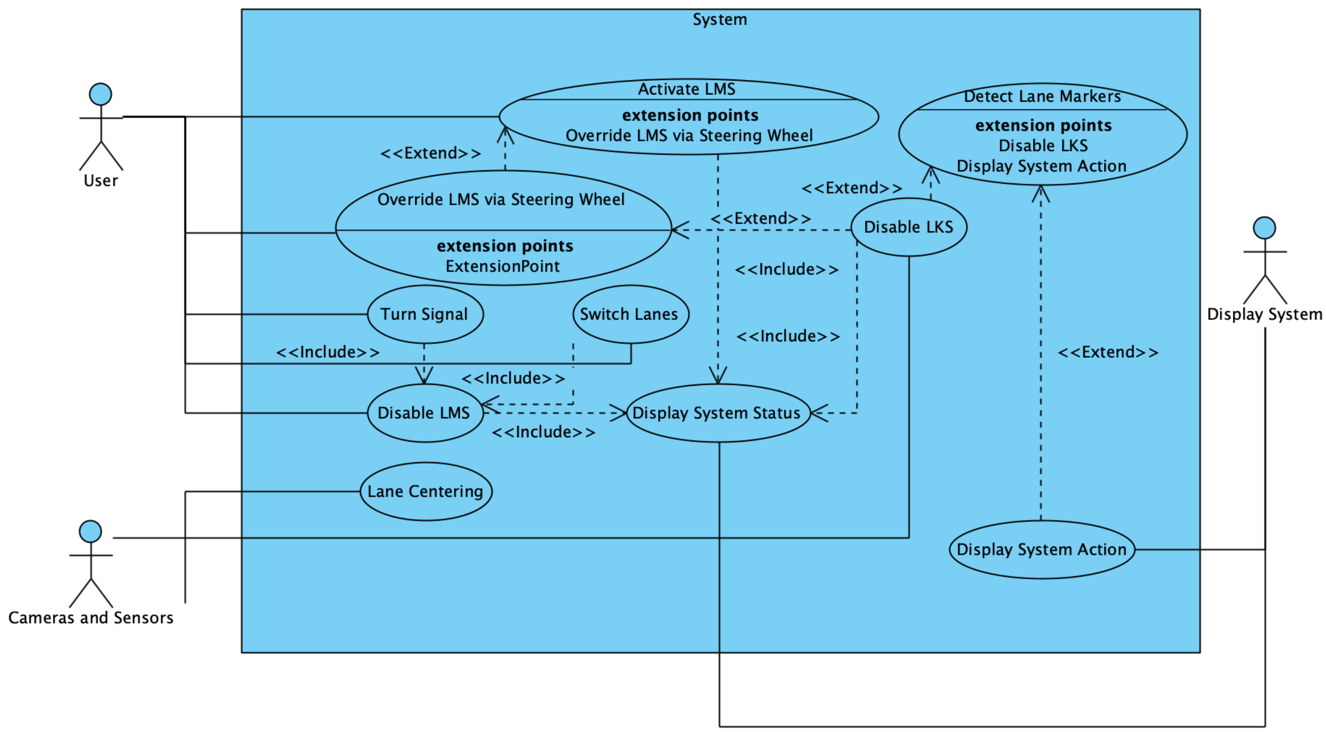

Figure 3: Use case diagram for our LMS.

Table 1: Use case descriptions for the LMS. These describe the use case diagram above and any cross-references for the requirements associated. It also describes the actors and dependencies with other use cases.

Use Case:	***Activate LMS***
Actors:	**User**
Description:	**The LMS shall activate automatically at a speed of 35 miles per hour** **While active, the system shall override gently to ensure the vehicle stays within the lanes detected by the sensors**
Type:	**Primary**
Includes:	**Display system status**
Extends:	**N/A**
Cross-refs:	***N/A***
Use cases:	***Detect Lane Markers***

Use Case:	***Disable LKS***
Actors:	**User**
Description:	**The driver shall disable LKS by correcting via the steering wheel.** **LKS shall be disabled when cameras and sensors cannot detect the lane**
Type:	**Primary**
Includes:	**Display system status**
Extends:	**Detect lane markers** **Override LMS via steering wheel**
Cross-refs:	***N/A***
Use cases:	***Display system status***

Use Case:	***Override LMS via steering wheel***
Actors:	**User**
Description:	**The system shall detect the torque needed and apply to the steering wheel to gently steer the car back to the center of the lane** **When the driver applies torque to the wheel, then the LKS will disable itself**
Type:	**Primary**
Includes:	**N/A**
Extends:	**Activate LMS**
Cross-refs:	**3.1.1, 3.1.6, 3.2.1b**
Use cases:	***Disable LKS, Activate LMS***

Use Case:	***Detect lane markers***
Actors:	**Cameras and Sensors**
Description:	**Cameras and Sensors provide the information of lane markers for the**

	system on a frequent basis The information provided by the sensors shall be used to predict the given path of the vehicle.
Type:	Primary
Includes:	N/A
Extends:	N/A
Cross-refs:	3.1.5, 3.2.3a, 3.2.3b, 3.2.3c, 3.2.3d, 3.2.3e, 3.2.3f, 3.2.3g,
Use cases:	*Disable LKS, Activate LMS*

Use Case:	*Display System Status*
Actors:	Lane Departure Warning System, Driver
Description:	There should be a light on to display if the system is on. LKS on then everything has to be on. LKS can be off and departure warnings can still be present
Type:	Secondary
Includes:	N/A
Extends:	N/A
Cross-refs:	3.3.2
Use cases:	*N/A*

Use Case:	*Display System Action*
Actors:	Lane Management System
Description:	There shall be warning light in the panel to let the driver know when the system is about to intervene The warning light shall display the direction of the system's action The system shall warn the driver when the vehicle is about to cross the lane
Type:	Primary
Includes:	N/A

Extends:	**N/A**
Cross-refs:	**3.1.3, 3.2.2b, 3.2.2c, 3.2.5a, 3.2.5b, 3.3.5**
Use cases:	***Activate LMS***

Use Case:	***Turn Signal***
Actors:	**User**
Description:	**The driver shall turn the signal on. When the signal is on, LMS shall be deactivated and perform no correction.**
Type:	**Primary**
Includes:	**Disable LMS**
Extends:	***N/A***
Cross-refs:	**3.2.2d, 3.2.2e**
Use cases:	***N/A***

Use Case:	***Switch Lane***
Actors:	**User**
Description:	**When the user switches to another lane, LMS should allow the action and perform no correction or display any warning**
Type:	**Primary**
Includes:	**Disable LMS**
Extends:	***N/A***
Cross-refs:	***N/A***
Use cases:	***N/A***

Use Case:	***Disable LMS***
Actors:	**User**
Description:	**The user shall deactivate the LMS via the GUI. When LMS is deactivated, it shall not perform any correction or display any warning.**
Type:	**Secondary**

Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	**3.3.3**
Use cases:	**Turn Signal, Switch Lane**

Use Case:	***Lane Centering***
Actors:	
Description:	**When the car is near the lane border, the system shall perform actions to steer the car back to the center**
Type:	**Primary**
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	**3.1.2, 3.1.4, 3.1.7, 3.2.1a**
Use cases:	***N/A***

4.2 Domain Model

Figure 4 below shows an object-oriented model, or domain model, for the LMS. It uses UML class diagram notation for its corresponding operations and attributes. The boxes describe the different systems that make up the overall LMS. For example the CameraSystem box is associated with the LMS and has attributes which find the distance to the lane and if the lane is present. The line with a diamond on the end signifies aggregation, which shows that one of the classes is part of another. Relationships can be shown with a single line and specifies connections between their instances.

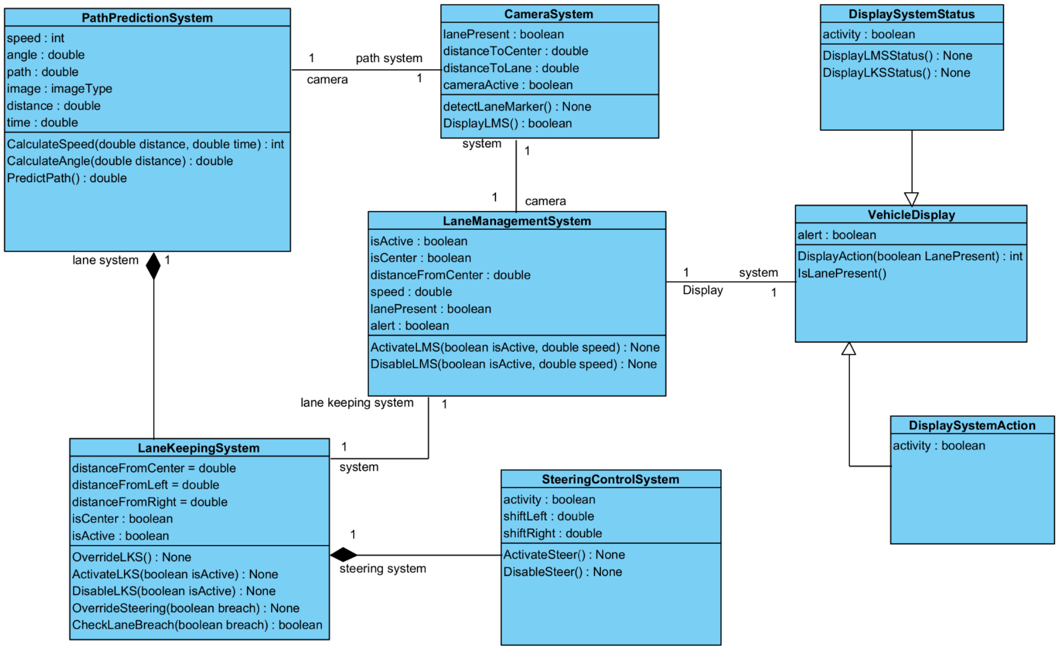

Figure 4: The figure shows a high level domain model for the LMS.

Table 2: Data Dictionary describes the attributes and operations of the classes in the domain model

<table>
<tr><th>Class</th><td colspan="2">SteeringControlSystem</td></tr>
<tr><td rowspan="6">Name</td><td colspan="2">Description (responsibilities) The system shall help steer the car back into the center. Steering is overtaken by the system when the car is drifting from the lane unintentionally. Steering control is relinquished back to the user when the car is back in the center of the lane or the LMS is deactivated.</td></tr>
<tr><td colspan="2">Export control (public: yes/no) No</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: LaneKeepingSystem</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">List of attributes and their primitive types
activity = boolean
shiftLeft = double</td></tr>
</table>

	shiftRight = double	
	List of operations (include parameters and results) ActivateSteer() return None DisableSteer() return None	

Class	Camera System	
Name	***Description (responsibilities)*** The camera system shall detect the lanes present and send data to the path prediction system. Calculations based on where the car is in relation to the lanes is used throughout the other subsystems in the LMS. Distance to the lane helps determine if the car is about to breach the lane.	
	Export control (public: yes/no) No	
	Relationships	Associations: LaneManagementSystem, PathPredictionSystem
		Aggregations:
		Generalization:
	List of attributes and their primitive types lanePresent = boolean distanceToCenter = double distanceToLane = double cameraActive = boolean	
	List of operations (include parameters and results) detectLaneMarker() return boolean DisplayLMS() return boolean	

Class	Path Prediction System
Name	***Description (responsibilities)*** The path prediction system uses the calculations and distances from the camera system to understand the current trajectory the car is on. The path of the car is vital when determining if steering control needs to be overtaken or if the car is about to breach a lane.

	Export control (public: yes/no) no	
	Relationships	Associations: CameraSystem
		Aggregations: LaneKeepingSystem
		Generalization:
	List of attributes and their primitive types speed = int angle = double path = double image = imageType distance = double time = double	
	List of operations (include parameters and results) CalculateSpeed(distance, time) return int CalculateAngle() return double PredictPath() return double OverrideSteering(boolean breach) return None CheckLaneBreach(boolean breach) return boolean	

Class	VehicleDisplay	
Name	***Description (responsibilities)*** The vehicle display alerts the driver of the current system's status. The displays will show that the LMS and/or LKS is currently active in the vehicle. Display icons are shown in the dashboard of the vehicle.	
	Export control (public: yes/no) yes	
	Relationships	Associations: LaneManagementSystem
		Aggregations:
		Generalization: DisplaySystemStatus, DisplaySystemStatus
	List of attributes and their primitive types	

	alert = boolean	
	List of operations (include parameters and results) DisplayAction(boolean LanePresent) return int IsLanePresent() return boolean	

Class	Display System Status	
Name	***Description (responsibilities)*** It displays whether the system is active or not. The display shows whether the LMS system is currently active in the vehicle. The display will also show alerts when the car is caught drifting to either lane markings.	
	Export control (public: yes/no) no	
	Relationships	Associations:
		Aggregations:
		Generalization:
	List of attributes and their primitive types activity = boolean	
	List of operations (include parameters and results) DisplayLMSStatus() return None DisplayLKSStatus() return None	

Class	LaneKeepingSystem	
Name	***Description (responsibilities)*** Keep the car in the center of the lane. By using the cameras, sensors, and path prediction systems, the car is kept in the center of the lane. If the car is about to breach the lane, then the steering control system needs to be alerted to be overridden.	
	Export control (public: yes/no) no	
	Relationships	Associations: LaneManagementSystem

		Aggregations: PathPredictionSystem, SteeringControl
		Generalization:
	List of attributes and their primitive types distanceFromCenter = double distanceFromRight = double distanceFromLeft = double isCenter = boolean isActive = boolean	
	List of operations (include parameters and results) OverrideLKS() return None ActivateLKS(boolean isActive) return None DisableLKS(boolean isActive) return None	

Class	LaneManagementSystem	
Name	***Description (responsibilities)*** Manages the overall system to ensure the car is in the center through the usage of camera path prediction system, LKS, and vehicle display.	
	Export control (public: yes/no) yes	
	Relationships	Associations: CameraSystem, VehicleDisplay, LaneKeepingSystem
		Aggregations:
		Generalization:
	List of attributes and their primitive types isActive = boolean distanceFromCenter = double isCenter = boolean speed = double lanePresent = boolean distanceToCenter = double	

	alert = boolean
	List of operations (include parameters and results) ActivateLMS(boolean isActive, double speed) return None DisableLMS(boolean isActive, double speed) return None

Class	DisplaySystemAction	
Name	***Description (responsibilities)*** Determines whether an action is occurring/ These actions include if the car is about to breach a lane, and the driver will be alerted by an icon appearing on the dashboard of the vehicle.	
	Export control (public: yes/no) yes	
	Relationships	Associations:
		Aggregations:
		Generalization:
	List of attributes and their primitive types activity = boolean	
	List of operations (include parameters and results)	

4.3 Sequence Diagrams

These figures below are the sequence diagrams that illustrate how the different parts of the system interact over time. These describe specific scenarios on how the system may react. The diagrams capture normal and abnormal behaviors to illustrate the system's reactions and how the different components interact in these abstract situations. The bodies are the objects, while the dotted lines represent the lifelines from the objects. Interactions between objects are shown through arrows with the mechanism involved in the interaction.

4.3.1 Lane Centering

Figure 5 shows the sequence diagram for when the car is near the lane border and the LMS centers itself back in the line. The path prediction system calculates and updates the path frequently via the UI. When the vehicle is moving towards either the left or the right lane markers, the LKS overrides the steering to center it back through the path prediction system.

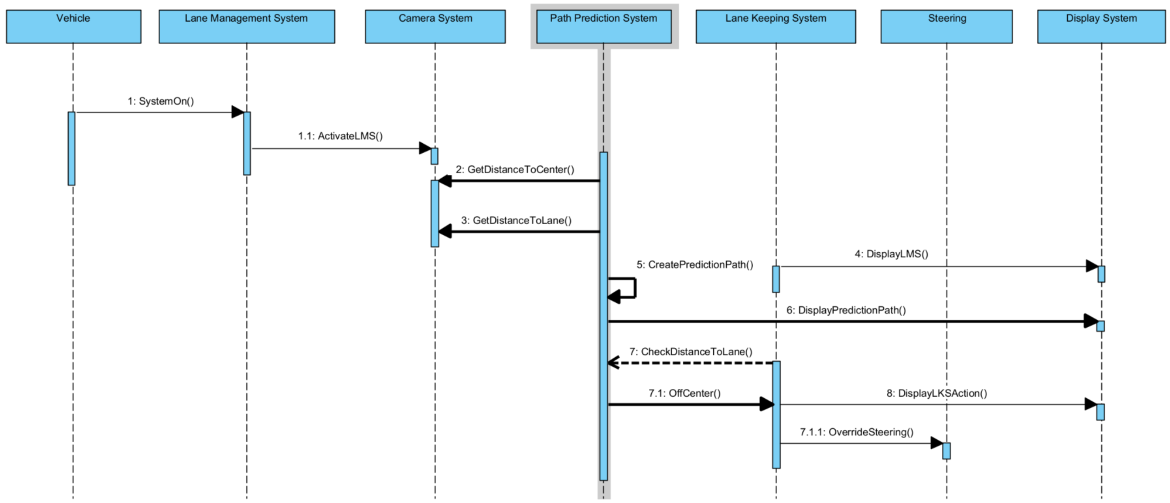

Figure 5: Normal lane centering mechanism scenario. The driver moves near the side of the line where the path prediction system gets information on the distance to the center of the lane, and this allows the system to create a prediction path. The system takes control of the steering wheel and the car is returned to the center.

4.3.2 Switching Lanes

Figure 6 shows the sequence diagram when the car is switching lanes and does not need to be centered. When moving to another lane, the LMS does not need to keep the car centered. The LMS needs to see if the lane is being breached and if it is being breached, then this indicates the car is attempting to move lanes. If the lane is breached, the system does not override the steering and the user maintains control.

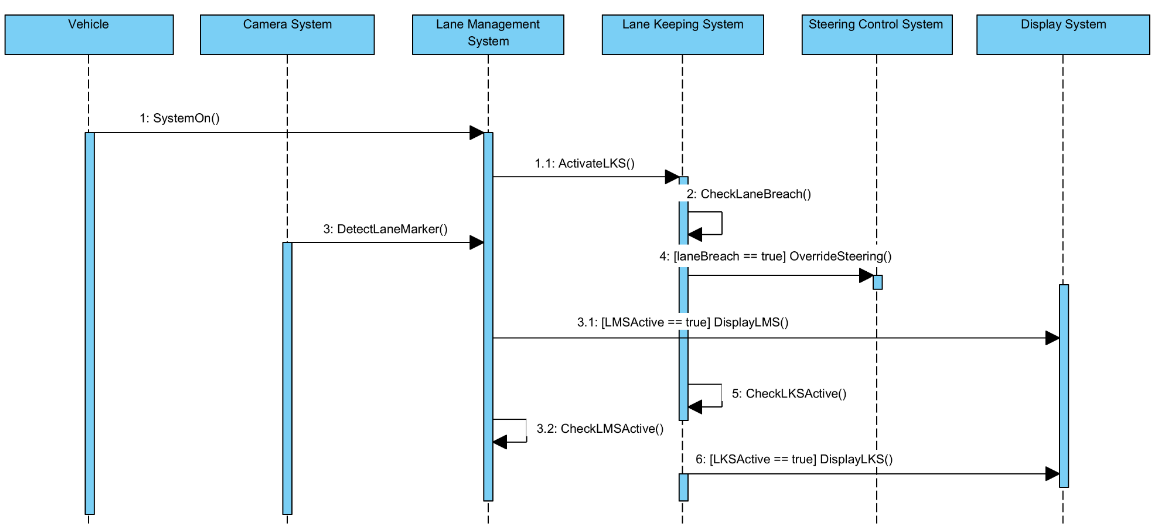

Figure 6: The vehicle is switching lanes and so this means that the LMS is still active and detecting lanes. However, the system checks for a lane breach in the lane keeping system and if this is true, it overrides the steering so that the user maintains control of the steering wheel. It continuously checks the LKS to see if it is true or not when breaching a new lane.

4.3.3 Disable LMS by turning on signal

In **Figure 7** the LMS is turned off when the turning signal is on. The vehicle is attempting to turn and the LMS checks for a turn signal. If the turn signal is active, then it overrides the LKS. This means that detection of the lane is not needed and the LKS is not active. It also displays the activity of the LMS, and since there is a turn signal, it displays that the car is turning.

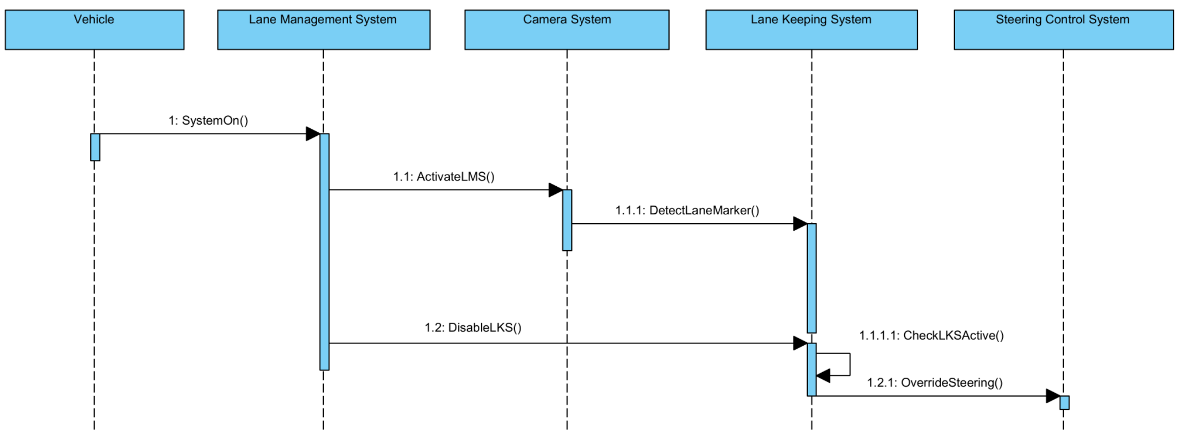

Figure 7: The LMS system is overwritten and does not center when the left or right turn signal is on. When the left or right turn signal is on, the LKS is overwritten and does not allow for the steering to be taken control by the system

4.3.4 Disable LMS via GUI

In **Figure 8** the LMS is turned off by the user interface by the user. The driver turns off the LMS and the display system will receive a warning whenever the path prediction system detects that the car is getting too close to the lane's border. It also checks whether the car is leaving the lane, and if it is, then it will alert the driver.

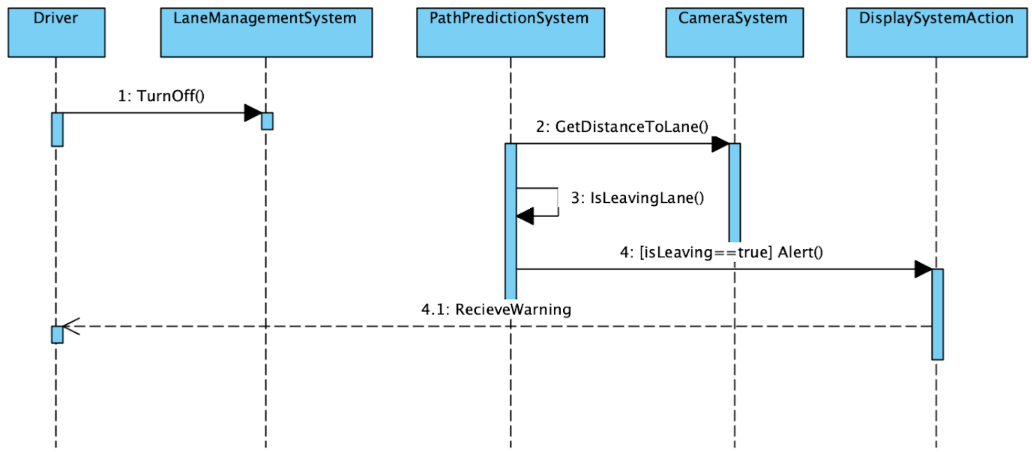

Figure 8: The driver can turn off LMS via the user interface. When LMS is turned off, lane departure warning is still on and displays warning if the vehicle leaves the lane.

4.3.5 LMS is overwritten by steering wheel by user

Figure 9's sequence of events is when the LMS is overwritten by steering handle by user. The LMS will detect when the car is getting too close to the edge of the lane. The driver is able to override the LMS when the LMS checks for whether the steering is active by the driver. If the steering is active by the driver, it disables the LKS so that the driver can maintain steering. When the driver is steering around a curve and needs a lane adjustment, the user needs to apply more force to the steering wheel.

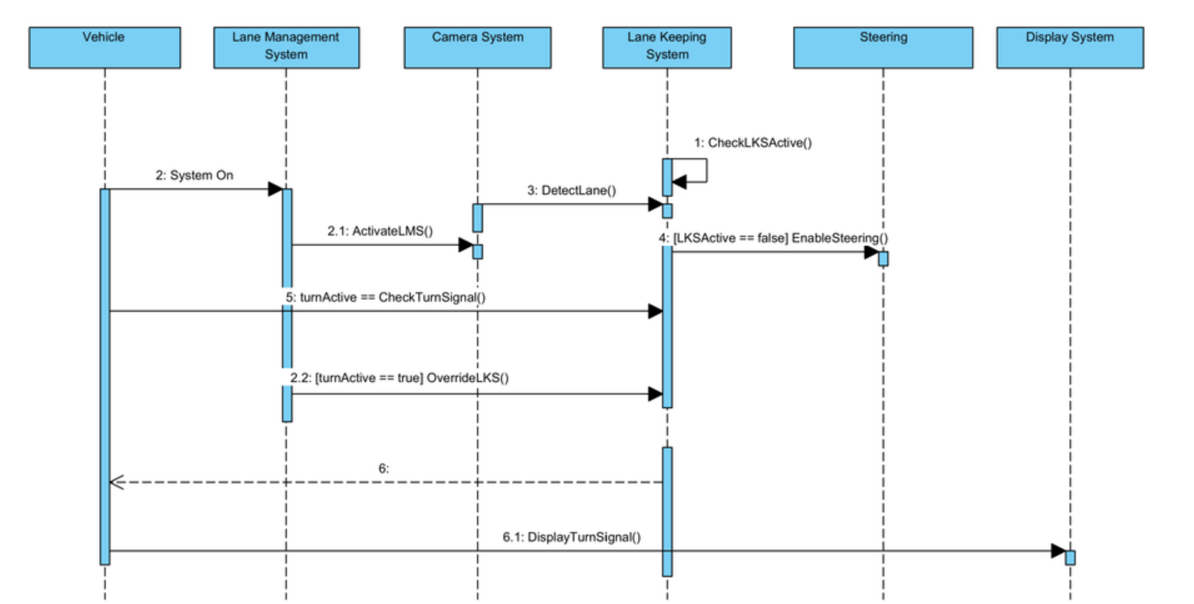

Figure 9: When the user holds onto the steering wheel and personally moves the car back into the center, the LMS system is overwritten and does not take control of the steering wheel. The user can override the system by steering.

4.4 State Diagram

The state diagram section describes how different components of the system move from state to state. In the diagrams, the states are shown with the blue box and the transitions betweens states are denoted with the lines with arrows. The text associated with the transitions show what is causing the state to move and progress. Behavior of the LMS is shown at a high level with the state diagram.

Figure 10 displays the state diagram of the LMS. It starts at the idle state and switches to "Car Leaving Lane" state when the camera and sensor systems detect the lane markers. If the signal is on, the system does nothing. If the signal is off, the system displays a departure warning through the internal UI for the user. If the driver doesn't take any action, another warning is displayed, showing the direction that LKS is about to intervene. LKS is then activated and moves the car back to the lane's center. The system returns to the idle state once LKS has completed its action.

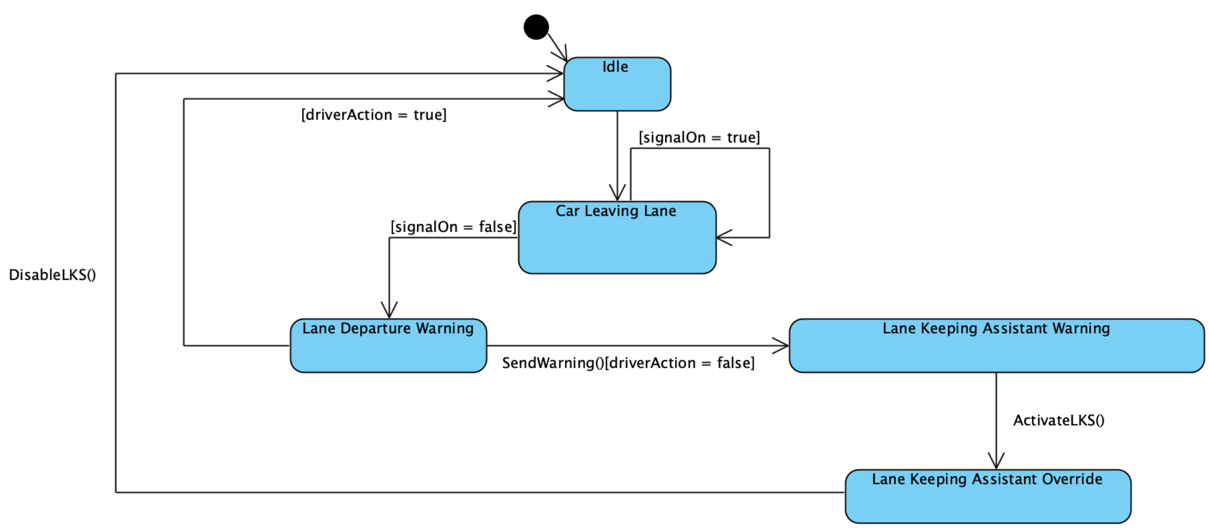

Figure 10: The state diagram shows the different states and conditions of the system and its parts.

5 Prototype

To better understand and investigate the system as a whole as well as analyze edge cases, the team created a prototype to demonstrate the functionalities of the LMS. The prototype provides a mini-world where users can freely experiment with the features that LMS provides. By interacting with the demo program, communication among team members and with customers will be improved.

As the prototype provides a virtual world experience, there is no constriction on how the user interacts with it. This is meant to provide the most realistic experience for the customers and allow the team to test the system in a wide range of scenarios.

5.1 How to Run Prototype

The prototype is built with Unity, a cross-platform game engine. To reduce the complexity of configuration and building the prototype, the team provides a live prototype located on the team website. Users need access to the Internet to access the prototype.

Alternatively, the prototype can be set up locally on the user's machine. By running locally, the user can change the resolution, adjust graphic settings, and use the prototype without an internet connection. To set up locally, please follow the instructions below:

- Download the prototype source code
  - The prototype code is stored on GitHub. The user can download via the GitHub UI or the console/terminal:
    - `git clone https://github.com/truongdd03/lms.git`
- Install Unity
  - Unity can be installed via its official website.
- Open the project
  - Open Unity and select the LMS prototype
- Build and Run project
  - Select the build icon on the top of the view to run the prototype.

When the prototype is up and running, users can interact with it via the keyboard. To move the car forward, users simply need to press the up arrow key. Turning can be achieved by pressing the left or right buttons. The down arrow key is used for reversing, while the spacebar functions as a brake.

5.2 Sample Scenarios

The prototype provides a constriction-free experience for the users. There are endless possibilities for how the prototype can be used to test the LMS and to improve its functionality. However, at the root of the prototype, there are eleven main scenarios that are described below:

5.2.1 Straight line road

Straight line road is the ideal condition of LMS. **Figure 11** describes this scenario. The LMS status is active, as it is able to detect both lane markers and the car is traveling more than 35 mph. The system remains alert and ready to intervene once the vehicle becomes off-center of the lane.

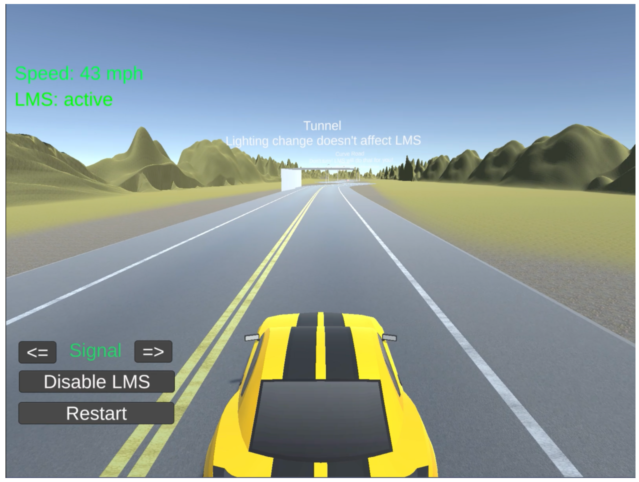

Figure 11: Vehicle traveling on a straight line road

5.2.2 Curve road

Curve road describes the most common and challenging scenario for lane management systems. In this scenario, the LMS must be able to accurately detect the lane boundaries and keep the vehicle within the lane, even when the road is curving. In **Figure 12**, the vehicle is approaching a curve at the speed of 70 mph. LMS is active since the system is able to detect the lane markers on both sides of the vehicle.

Figure 12: Vehicle approaching a curve

Figure 13 shows that the vehicle is entering the curve. The driver is not controlling the vehicle at the time. LMS intervenes with the steering wheel to slightly steer the vehicle to the left. The LMS status display was changed from “active” to “<=====”, indicating the direction that the system is steering toward.

Figure 13: Vehicle entering the curve

In **Figure 14**, the vehicle has exited the curve safely without the intervention of the driver. The LMS display status switched from “<=====” back to “active”, as the system no longer intervenes with the steering wheel. LMS remains active and ready for future road changes.

Figure 14: Vehicle exiting the curve

5.2.3 No lane marker

Figure 15 describes the scenario where lane markers can't be detected. In this situation, the LMS disables itself automatically and displays its status as "inactive". The system will not perform any steering correction in this mode.

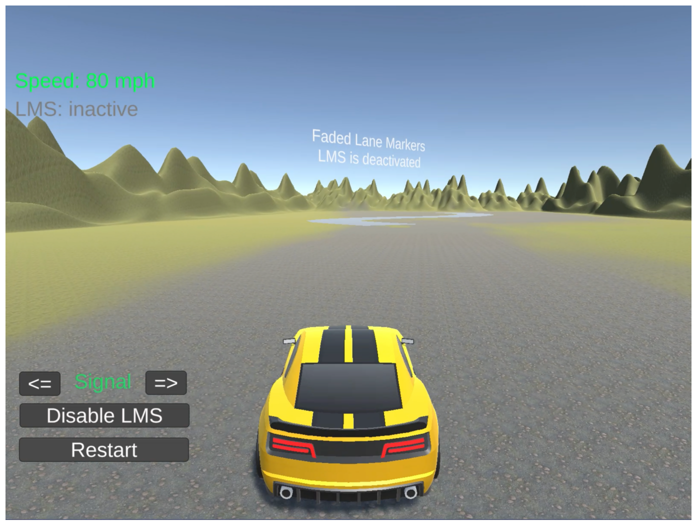

Figure 15: Vehicle traveling off-road

5.2.4 Override by driver

Figure 16 describes the situation when the driver intentionally pulls the vehicle over. Although LMS is active and the system detects the vehicle leaving the lane, no steering correction is performed. Once the vehicle gets back to the lane and no torque is applied to the steering wheel by the driver, LMS will become active again and perform any corrective actions if necessary.

Figure 16: Driver intentionally pulls the vehicle over

5.2.5 Unexpected lighting change

LMS is also capable of adapting to environmental changes. One example is when the vehicle enters a tunnel as described in **Figure 17.** Tunnels pose a challenge for the system due to the sudden change in lighting conditions. As the vehicle enters the tunnel, LMS enters a transition phase to adapt to the new condition, remaining active and ready to perform any steering correction.

Figure 17: Vehicle entering a tunnel

5.2.6 Other types of lane divider

LMS not only works with lane markers but also with other types of lane dividers. For example, **Figure 18** describes a scenario where cones are used to divide the lanes. The system adapts to the change and remains active as expected.

Figure 18: Cones are used to divide lanes

5.2.7 Faded Lane Markers

Figure 19 describes a scenario where the lane markers are faded. Since the system is not able to detect the lane boundaries on both sides of the vehicles, the status shows “inactive”.

Figure 19: Faded lane markers

5.2.8 Lane departure warning

When the system detects the vehicle leaving the lane, LDWS will display a warning to notify the driver. **Figure 20** describes this scenario.

Figure 20: Lane departure warning

5.2.9 Override via turn signal

Figure 21 describes the scenario where the driver turns the signal on. Although the car is traveling faster than 35 mph and the system is able to detect the lane markers, the status is still deactivated. The system does not perform any steering correction or display any departure warning.

Figure 21: The system is overridden via turn signal

5.2.10 Override via GUI

Figure 22 describes another scenario where the system is overridden. The driver can turn off LMS via internal GUI anytime. Once the LMS is turned off, the status is displayed as “Off”. However, if the car departs the lane unintentionally, LDWS is still active and will display necessary warning messages.

Figure 22: The system is disabled via GUI

5.2.11 Demonstrate the working system

The whole working system is demonstrated in the interactive prototype on the team website. LMS is able to handle different situations and change control back and forth between itself and the driver. To test and play with the system, please visit https://cse.msu.edu/~truongd1/prototype.

6 References

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[2] *Head-on Crashes - Safety.Fhwa.Dot.Gov*, U.S. Department of Transportation, Federal Highway Administration, safety.fhwa.dot.gov/roadway_dept/strat_approach/brochure/docs/FHWA-SA-21-025_Head_On_Crashes.pdf. Accessed 8 Nov. 2023.

[3] Jessica B. Cicchino, Effects of lane departure warning on police-reported crash rates, Journal of Safety Research, Volume 66, 2018, Pages 61-70, ISSN 0022-4375, https://doi.org/10.1016/j.jsr.2018.05.006. (https://www.sciencedirect.com/science/article/pii/S002243751730556X)

7 Point of Contact

For further information regarding this document and project, please contact **Prof. Betty H.C. Cheng** at Michigan State University (chengb at msu.edu). All materials in this

document have been sanitized for proprietary data. The students and the instructor gratefully acknowledge the participation of our industrial collaborators.