Software Requirements Specification (SRS)

Lane Management System (LMS)

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1 Introduction

Automotive manufacturers are innovating new ways to improve the driving experience and driving safety in new vehicles. From autonomous driving to crash prevention, manufacturers are using new technology to help drivers. Lane Management System (LMS) is a driver assistance system that focuses on maintaining vehicle position within a lane. At its most basic functionality LMS is a passive system that can detect the lanes that a vehicle is in, and also calculate the position of the vehicle in the lane. When the LMS is active it can provide convenience to the driver by taking control of the vehicle to steer itself within a lane.

1.1 Purpose

The purpose of this software requirements specification (SRS) document is to provide a detailed and laid out description of the LMS and its subsystems: the Lane Keeping System (LKS), the Lane Centering System (LCS), and the Lane Departure Warning System (LDWS). The SRS is intended to provide the developers a way to fully understand all details of the system before the development process begins, and a way for the clients and stakeholders of the project to have a written document that outlines the developers plan for the project. To accomplish this, multiple diagrams will be provided including a UML domain model, a behavior diagram, and various use case diagrams. In addition, several written sections are identified to target specific details about the project.

1.2 Scope

The Lane Management System is a software product designed with the intent to keep the vehicle in the center of the lane. This system is made up of other subsystems such as the LKS, LDWS and LCS. If a driver is unintentionally leaving the lane, the LMS takes control of the vehicle's steering and speed control to adjust the vehicle's position and direct it back to the center of the lane keeping both the driver and the vehicle safe. The LMS does this with the use of LiDAR sensors and camera system which detects the lane markings on the road. This data is then transferred to its software subsystems to correct the vehicle's position. Through the use of the turn signal, the driver is able to switch lanes without any corrections from the LMS. The LMS is solely assistive and when it determines the vehicle is leaving the path; it suggests and slightly adjusts the steering wheel, but does not autonomously drive the vehicle.

1.3 Definitions, acronyms, and abbreviations

- **LMS:** Lane Management System. The main system of the project, which is composed of and uses, subsystems to identify when a vehicle moves outside of its lane and then warns the user and corrects the positioning of the vehicle.
- **LCS:** Lane Centering System. A subsystem that takes control of the vehicle when it departs from the lane and smoothly transitions the vehicle back to the center of the lane.
- **LKS:** Lane Keeping System. An intermediate system that receives information about lane departures and sends messages to the Lane Centering System to readjust the vehicle to the center of the lane.
- **LDWS:** Lane Departure Warning System. Makes use of the lane detection system and sends messages to the User Interface and the Lane Centering System to display a lane departure warning and correct the vehicle's position respectively.
- **CSS:** Camera Sensing Subsystem. A subsystem that takes information from the onboard cameras and LiDAR sensors and passes it on to the Image Processing Subsystem.
- **IPS:** Image Processing Subsystem. Takes the images from the CSS and uses them to calculate the position of the lane lines relative to the vehicle, position of the vehicle relative to the center, etc.
- **VSES:** Vehicle State Estimation Subsystem. A subsystem that receives information from the shared information within the vehicle or the IPS and determines details about the road such as curvature, speed, steering angle, etc.
- **PPS:** Path Prediction Subsystem. System that receives information from the LCS and VSES in order to predict the path of the vehicle.
- **UIS/GUI:** User Interface/Graphical User Interface. The combination of buttons and lights on the dash, and/or screen that the driver can interact with.
- **SCS:** Supervisory Control System. A system that can enable and disable the other subsystems within the LMS should something go wrong or needs repair. This system differs from the overall functionality of the LMS as it can only enable or disable other (sub)systems. It cannot notify the driver, detect lane markers, etc.
- **Warning:** A notification that can be visual, physical, or auditory that notifies the driver of a lane departure, subsystem in need of repair, etc.
- **Passive:** Passive mode is a state that the system will enter when the LKS or VSES determine that the system cannot properly identify the lane markings of the road and calculate the position of the vehicle. Passive mode will result in the system still running but it will not issue any warnings or make any lane corrections. The system will remain in passive mode until the system is able to operate properly. Passive mode will also be enabled when the vehicle is driving at a speed of less than 35 miles per hour.
- **GPS:** GPS System data. This collection of data is developed internally and updated regularly. The purpose of this data is to supplement the onboard sensors in case they are damaged or cannot obtain enough data from the immediate environment. Data contained in this collection includes but is not limited to: speed limit, road curvature, slope of the road, etc.
- **LiDAR:** LiDAR is a type of sensor that is onboard the vehicle. It uses a laser and light detection to determine the distance an object is from the sensor. LiDAR will be used to detect how far the lane markers or other obstructions are from the vehicle. This information will be used to calculate the vehicle's position in the lane relative to the center.

1.4 Organization

The remainder of the SRS is organized as follows. Section 1 introduces the system along with the scope of the project. Additionally, it outlines the purpose of the system and the various definitions, acronyms, and abbreviations needed to understand this SRS document. Lastly it identifies how the remainder of this SRS is organized.

Section 2 contains a high level description of the LMS. This description contains details about the product's perspective, functions, user characteristics, constraints, assumptions and dependencies, along with what is considered out of the scope of this project.

Section 3 provides an enumerated list of requirements for the product. This information is organized hierarchically, by the type of requirement, and by order of importance to the system.

Section 4 contains multiple types of diagrams and models which describe LMS. There is a domain model that outlines the general structure of the LMS, and other various diagrams that state the intended behavior of the system in different scenarios.

Section 5 contains pictures of a prototype that visually shows the intended behavior of the system. These scenarios include descriptions of the scenario and the intended behavior of the LMS in the scenario. In addition, section 5 includes instructions on how to operate the prototype.

Section 6 contains references to sources in, IEEE form, that were used in the development of this document including the link to the project website.

Lastly, Section 7 contains the contact information for the instructor of this course who can provide further information about this project.

2 Overall Description

The following section provides a high level overview of the LMS. Section 2.1 outlines the perspective/context under which the system is used. Section 2.2 outlines the main functionality of the system. Section 2.3 describes the expectations about the user. Such as background, skill level, and general expertise. Section 2.4 gives the possible constraints of the system. Section 2.5 outlines the assumptions made about the hardware, software, environment, and user interactions with the system. Section 2.6 tells us the scenarios that would be considered out of scope of the current project as outlined through talks with the customer.

2.1 Product Perspective

The LMS is a software product used in order to enhance the convenience and safety in driving. The LMS is an independent system within a vehicle and consists of smaller subsystems that cooperate and pass information between each other. It is not required to coordinate with the rest of the systems in the vehicle but can access the shared data within the vehicle.

The system interacts with the user in many ways. These would include but are not limited to: buttons on the dashboard to turn the system on and off, if there is an onboard screen then the driver will be able to receive notifications from the system, see a visual representation of the vehicle's position within a lane.

Every vehicle can have a maximum of two cameras and a LiDAR sensor installed somewhere on the vehicle. The LMS will be active once the vehicle is moving with a speed of 35 mph or greater. When this happens, the onboard sensors take pictures of the lane once per second so that the software systems can calculate the vehicle's position relative to the center of the lane and correct it if necessary. Other constraints would be a GPS system that is to act as a supplement to the sensors or secondary source of information.

Every subsystem must have a way to communicate with other subsystems within the LMS. For instance, the LDWS must be able to tell the vehicle controller of a lane departure that is in need of correction.

The last constraint that should be addressed is the memory usage of the system. Since the LMS will be part of the vehicle and uses both physical hardware and digital software, there is a limited amount of space that the hardware can take up. Therefore the amount of memory that the system can hold at any given time will also be limited.

2.2 Product Functions

The LMS's main function is to detect when the vehicle has or is drifting out of it's lane unintentionally when the vehicle is above a certain speed threshold. The system uses data from 2 cameras, a LiDAR sensor, GPS data from an in house database, and other information that is gotten from the vehicle's shared information database in order to achieve this. Other functions that are included in this process are image processing, path prediction, and speed manipulation.

The first step in the process is utilizing the connection between LMS and the speed sensor system that exists in the vehicle. Through the VSES, LMS will communicate with the speed sensor system to have continuous knowledge of the speed of the vehicle. If the speed sensor system sends data that states the vehicle is traveling below the speed threshold of 35 mph, then LMS will enter passive mode until speed is determined to be greater than or equal to the threshold.

The next step is using the onboard cameras, LiDAR sensor, and GPS data in order to locate the vehicle's position relative to the center of the road and lane lines. The cameras will take pictures once every second and send the images to the CSS for processing.

Afterwards the IPS will process the images and use them to detect where the lane lines are (if the road has them). The images are then sent to the LCS to determine the vehicle's relative position with respect to the lane's center. If the lane lines cannot be found, the system will instead use the in house GPS data to determine the position of the vehicle.

After determining the relative position of the vehicle, then the PPS will use that data in addition to the vehicle's speed, steering angle, and other information to predict the path of the vehicle. Should the vehicle be predicted to drift outside the lane *and* the vehicle's corresponding turn signal is off, then the LDWS sends a warning which is issued to the driver. Concurrently, a correction command will be sent to the vehicle controller through the LKS, in order to correct the path of the vehicle back to the center of the lane. Should either of the aforementioned conditions fail, (i.e. will not drift outside the lane or the corresponding turn signal is *on*) then the system will not act to correct it's path.

Once the correction command is received by the vehicle controller, then the LMS will take control of the vehicle, correct the speed and steering angle in order to gently steer the vehicle back to the center of the lane. Once the vehicle is back in the center of the lane, control of the vehicle is returned back to the driver.

In addition to the above functions, the driver should be able to manually override the correction functionality by applying enough torque to the wheel (turning at a big enough steering angle) or by manually shutting down the system using the dashboard button.

2.3 User Characteristics

The user of the lane management system will be an experienced driver who possesses a driver's license. The user is also expected to have knowledge of the driving laws for the state that the driver is currently operating in. They must possess the ability to fully interact with the system including but not limited to its notifications, warnings, and the user interface. The user must also understand the limitations of the system and to not become over-reliant on the features; they are expected to follow safe driving practices and to be prepared to operate the vehicle without the system in case of shutoff.

2.4 Constraints

In order to provide proper functionality and ensure the safety of the driver, the LMS has multiple constraints. Foremost, the system relies on both cameras, the LiDAR sensor, and map data in order to determine the size of the lane, the positioning of the vehicle, and any changes in the road; if the system cannot develop an accurate image of the road, then the system must enter passive mode until a sufficient image can be obtained. Without these features operating properly, the system cannot properly determine the positioning of the vehicle relative to the lane, putting the driver's safety at risk due to an unintentional lane adjustment.

Secondly, another constraint on the LMS is the conditions of the road and weather. Without the use of an LMS, poor driving conditions already present a risk to the driver, but when software is involved in the control of the vehicle, the risks increase. Using data sent from internal GM servers, the LMS will not operate while poor conditions are detected. Examples of poor conditions include severe weather, road flooding, heavy snow, and icy roads. Poor driving conditions present many issues when in conjunction with the LMS; examples include heavy snow or rain can obstruct the camera view, sudden lane changes being needed to avoid any obstructions created by severe weather, and flooding or icy conditions causing the vehicle to swerve. Any of these factors can prevent the LMS from working properly.

In addition to the previously mentioned constraints, the system has multiple other constraints. These include entering passive mode if the vehicle speed is below 35 MPH, turning off when hardware maintenance is required, and not operating when lane markings are not present (i.e. dirt roads and freshly paved roads). If the system did not turn off while any of these conditions were present, the safety of the driver could be put at risk due to system malfunctions. In contrast to not turning off, if the LMS continues to operate while the vehicle's turn signal is on would also jeopardize the safety of the driver.

Lastly, the LMS must also be able to operate concurrently with other systems in the vehicle such as the cruise control and blindside warning system. With the blindside warning system, there must be sufficient logic that prioritizes which system's warnings are displayed. For the vehicle's cruise control, the LMS must be able to temporarily take and return control of the vehicle's steering and speed systems to the cruise control. Failure to do either of these would result in the safety of the driver being compromised.

2.5 Assumptions and Dependencies

In order to develop the LMS, assumptions need to be made about the vehicle and other systems within the vehicle as a way to determine the proper behavior of the LMS. First off, the system assumes that all hardware in the vehicle is fully operational and there are no major afflictions affecting its functionality. Using feedback systems, LMS will learn of any issues affecting the vehicle (i.e. steering, braking, audio, etc.) and promptly cease operation until those issues are fixed. Similarly, the LMS assumes all subsystems are functional including the LKS, LCS, LDWS, CSS, IPS, VSES, and PPS. The SCS will be used to monitor these subsystems and identify any issues; if one of these subsystems is found to fail, then the whole LMS will be shut down. Additionally, it is assumed that the user of the system understands how the system works on marked and unmarked roads (as is described in this SRS document) and that the user operates the vehicle in its intended, proper way.

2.6 Apportioning of Requirements

There are several scenarios that have been determined to be out of scope for the current LMS project. Most notably, when the vehicle is operating within a parking lot and within a roundabout. The current iteration of the LMS will not be in use as both of these scenarios are considered out of scope. These operating scenarios are considered out of scope because in parking lots, lane markings are not commonplace (often no lane markers exist at all) which are essential in the determination of the center of the lane, and roundabouts often have overlapping lane markings which interfere with the system's ability to calculate the center of the lane. An implementation of the LMS that accommodates these features may be addressed in future iterations but are currently out of scope.

3 Specific Requirements

This section will describe the requirements for the LMS project. The requirements are separated into hardware, system, and invariant. The system requirements section will also be separated into dedicated software requirements and cybersecurity requirements.

1. Hardware requirements

1.1. Cameras and LiDAR

1.1.1. There must be two functional cameras on both the front right side and the front left side of the vehicle. The cameras should be angled at 45 degrees in order to be able to identify the lane markings on the sides of the road.

1.1.2. In addition to the two cameras, there will be two LiDAR sensors adjacent to the cameras (one of the front left and one on the front right). The LiDAR sensors work in conjunction with the cameras to identify the distances between the vehicle and the lane markings. GPS information can be supplemented into the calculation if other sensor information is insufficient.

1.2. Audio System

1.2.1. The audio system is used with the warning system to alert the driver of any unexpected lane changes. The audio system will also be used to warn the driver if the system enters passive mode or is shutdown for any reason. Let it be known that the audio system is not solely being used for the LMS and can be used by other software and hardware systems in the vehicle

1.3. Visual Display

1.3.1. Similarly to the audio system, the visual display plays a role in the warning system for the LMS. When an unexpected lane change is detected there will be a display for the driver that warns them of the system being activated. If the lane change continues and the system takes over control of the vehicle, then a separate message will be displayed for the driver. In addition to the warning system, the visual display will be used to show the driver that the system is currently turned on.

1.4. Dash button

1.4.1. The dash button will be used by the driver to turn the system on or off. Using the visual display and an LED light on the dash button, the driver will know whether the LMS is active or not.

1.5. Turn Signal

1.5.1. The vehicle must have a working turn signal as the turn signal being turned on lets the system know whether a lane change being made is intentional or if it is unintentional.

1.6. Steering wheel

1.6.1. The vehicle must have a working steering system for the LMS to operate. LMS connects to the steering system of the vehicle to adjust the steering wheel when lane corrections are needed.

1.7. Speedometer

1.7.1. A working speedometer should be present on the vehicle. The speedometer allows the user of the LMS to know if the vehicle is operating at a speed greater than or less than the 35 mile per hour threshold.

2. System requirements

2.1. Software requirements

2.1.1. The LMS will use the cameras and LiDAR sensors to calculate the distance between the vehicle and the lane markings on either side of the road.

2.1.1.1. By calculating the distance from the vehicle to each side of the lane, if the distance between the vehicle and one side of the lane is too small compared to the other, alert the driver.

2.1.1.2. If there is only one lane marking present (center or side) the system will use data from the GPS to supplement the incomplete data. If both the sensor data and GPS data is insufficient, the LMS will enter passive mode and not operate until sufficient data is acquired.

2.1.2. Alert the driver with both an audio and visual warning if the vehicle is moving too far over into an adjacent lane.

2.1.3. If the driver crosses the threshold into an adjacent lane, then the system will take over the steering of the vehicle and adjust the steering wheel to direct the vehicle back into the center of its lane.

2.1.3.1. The driver can override the system adjusting the steering wheel by providing enough steering pressure in the opposite direction.

2.1.3.2. When the vehicle is returned to its center lane position, the system will stop the adjustment of the steering wheel and return full control of the vehicle back to the driver.

2.1.3.3. If the vehicle's turn signal is currently on, then the system will enter passive mode and not initiate any warning signals or adjust the vehicle.

2.1.4. The system will also continuously receive information from GM servers that contain map data about the roads the vehicle is operating on. These are used in conjunction with the cameras and LiDAR sensors to detect obstacles and changes in the roads.

2.1.5. The system will collect data on how many times the LMS detects lane movement and how many times the vehicle must be adjusted. This data is sent to GM servers.

2.1.6. Data from the cameras, LiDAR, and GM maps will be received every 1 second. Additionally, the PPS and LCS use this data to update the predicted path and the current lane position every 1 second.

2.1.7. Using additional data from GM servers, if the data detects that weather conditions or road conditions are too severe for the system to operate, the system will enter passive mode until no more severe conditions are detected.

2.1.8. The user interface of the system must always make it apparent to the driver what the state of the system currently is. The driver should easily know if the system is in passive mode, detecting a lane shift, taking over control of the vehicle, or if there is an issue.

2.1.9. The user interface of the system allows the user to adjust which of the subsystems of LMS they wish to be active. The user interface has the ability to access and disable any subsystem through the SCS which manages and runs diagnostics on all systems/subsystems.

2.2. Cybersecurity Requirements

2.2.1. When map data and condition data are sent from the GM servers, the system must check whether the information contained in the packet is valid, sent from a GM server, and does not contain any malicious data or software that could compromise the system.

2.2.1.1. Packets should be encrypted when sent from the servers to the vehicle to prevent tampering.

2.2.2. Using feedback systems and comparing the results from the cameras, LiDAR sensors, and map data the PPS will calculate the most accurate predicted path in order to avoid any false obstacles and changes in the road. False obstacles could include small moving objects like garbage or debris that should not be detected by all sensors as an obstruction.

2.2.3. User login information for GM accounts will be properly hashed and stored in a secure database to avoid unauthorized access.

2.2.3.1. Any unauthorized access is immediately reported to the user, and the account should be shut down. No packets should be sent or received until the account is secured.

2.2.4. Using feedback systems, the LMS should detect if any other systems or hardware that the LMS interacts with has a malfunction or irregularity in its usage. If detected, the system should shutdown until the irregularity is corrected.

3. Invariant Requirements

3.1. Safety of the system and for the driver must be ensured.

3.2. System must give complete control to the driver upon completion of lane correction, an error has occurred that would jeopardize the safety of the passenger, or manual override by the driver. Safety precautions should occur if this fails to complete.

3.2.1. Safety precautions that can occur in this scenario would be shutdown of the LKS or the entirety of the LMS to ensure the steering is no longer controlled by the system. If a driver is overpowering the steering wheel while LMS is in control, the system will give control back to the driver.

3.3. LMS must be able to disable/enable any of its subsystems.

3.4. System must be able to accurately identify the lane markings of the road the vehicle is currently driving on and any changes in the lane that occur.

3.5. The system will issue warnings and correct vehicle position if the vehicle is detected to be making an unintended lane change.

3.6. LMS must have the ability to take control of the vehicle's steering.

3.7. System must be able to accurately identify when an unintentional lane change is occurring.

3.8. The system will not issue warnings or correct vehicle position if speed is less than 35 miles per hour.

3.9. System must never overcorrect the vehicle into the lane; must never make a turn greater than 15 degrees.

4 Modeling Requirements

This section describes the various models that describe the team's interpretation of the LMS. This includes Use Case Diagrams, a Domain Model, Sequence Diagrams, and State Diagrams. All diagrams were created using Unified Modeling Language.

4.1 Use Case Diagram

Figure 1 below shows the use case diagram for the LMS system. The purpose of the use case diagram is to show all the important cases of the system, and how external actors interact with others. The blue rectangle represents the system boundary of the LMS. The stick figures represent actors in the system. Use cases are represented as yellow bubbles. Use cases are connected by dotted arrows with an "include" tag which signifies that the use case uses another use case in the LMS system. Associations between actors and use cases are illustrated by the lines that connect the two.

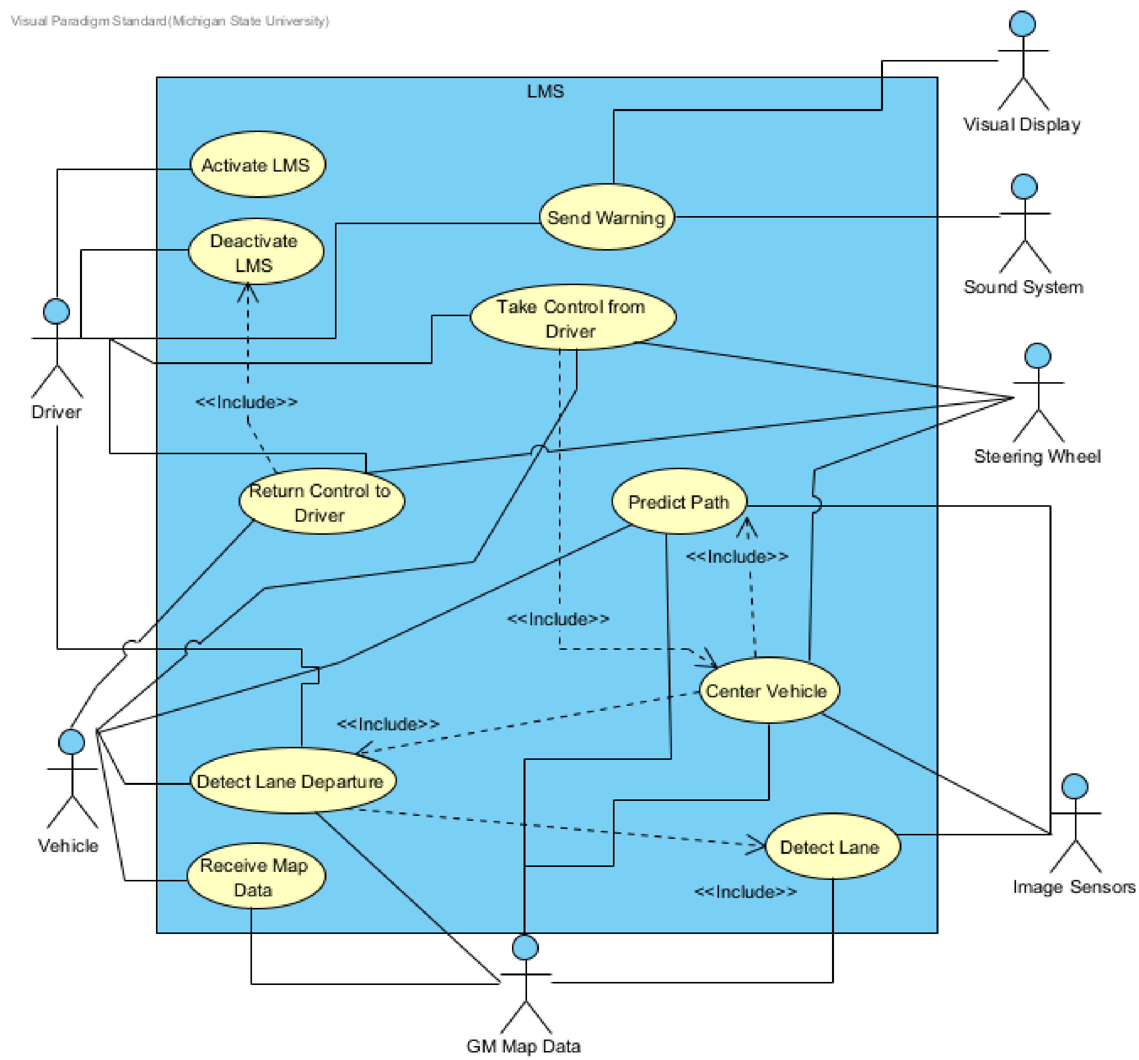


Figure 1: Use case diagram for LMS

Use Case:	*Activate LMS*
Actors:	*Driver*
Description:	*The drive turns on the LMS system. The system gives feedback as to where the vehicle is with respect to the lane.*
Type:	*Primary (essential)*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 1.1.1, 1.3.1, 1.4.1, 1.7.1, 2.1.8, 2.1.9, 2.2.3, 2.2.3.1 Invariants 3.1*
Use cases:	*N/A*

Table 1: Use case description for Activate LMS

Use Case:	*Deactivate LMS*
Actors:	*Driver*
Description:	*When the driver presses the off button, or the LMS does not have enough information to maintain control of the vehicle, the system is shut down.*
Type:	*Primary (essential)*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 1.4.1, 1.7.1, 2.1.3.1, 2.1.8, 2.1.9, Invariants 3.2, 3.2.1, 3.3*
Use cases:	*Return Control to Driver*

Table 2: Use case description for Deactivate LMS

Use Case:	*Detect Lane*
Actors:	*Image Sensors, GM Map Data*
Description:	*From the images that are taken from the cameras and LiDAR sensor, and the map data received from the GM mapping software, the system will calculate where the lanes are relative to the vehicle.*
Type:	*Primary (essential)*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 1.1.1, 1.1.2, 1.7.1, 2.1.1, 2.1.1.2, 2.1.3 Invariants 3.4*
Use cases:	*N/A*

Table 3: Use case description for Detect Lane

Use Case:	*Send Warning*
Actors:	*Driver, Sound System, Visual Display*
Description:	*From a warning generated from the LMS, the system will communicate to the driver the given warning, through haptic feedback on the steering wheel, or a visual warning on the GUI*
Type:	*Primary (essential)*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 1.2.1, 1.3.1, 2.1.1.1, 2.1.2, 2.2.4 Invariants 3.5*
Use cases:	*N/A*

Table 4: Use case description for Send Warning

Use Case:	*Center Vehicle*
Actors:	*Image Sensors, GM Map Data*
Description:	*PPS predicts the path of the vehicle and notifies the LKS, which overrides the VehicleController in order to smoothly move the vehicle back to the center of the lane.*
Type:	*Primary (essential)*
Includes:	*Detect Lane Departure , Predict Path*
Extends:	*N/A*
Cross-refs:	*Requirements 1.1.1, 1.6.1, 2.1.6, 2.1.1.1, 2.1.3.2 Invariants 3.1, 3.4, 3.6, 3.7*
Use cases:	*Detect Lane Departure, Predict Path*

Table 5: Use case description for Center Vehicle

Use Case:	*Take Control from Driver*
Actors:	*Driver, Vehicle, Steering Wheel*
Description:	*When the LMS system is activated it controls the speed of the vehicle, turning the wheel slightly to move the vehicle back to the center of the lane.*
Type:	*Primary (essential)*
Includes:	*Center Vehicle*
Extends:	*N/A*
Cross-refs:	*Requirements 1.1.1, 1.2.1, 1.3.1, 2.1.8, Invariants 3.3, 3.4, 3.6, 3.7, 3.8, 3.9*
Use cases:	*Center Vehicle*

Table 6: Use case description for Take Control from Driver

Use Case:	*Return Control to Driver*
Actors:	*Driver, Vehicle, Steering Wheel*
Description:	*When the vehicle has reached the center of the lane or the driver has overridden the LMS the full control of the vehicle is returned to the driver.*
Type:	*Primary*
Includes:	*Deactivate LMS*
Extends:	*N/A*
Cross-refs:	*Requirements 1.3.1, 2.1.3.1, 2.1.8, 2.1.3.3 Invariants 3.1, 3.2*
Use cases:	*Deactivate LMS*

Table 7: Use case description for Return Control to Driver

Use Case:	*Predict Path*
Actors:	*Vehicle, Image Sensors, GM Map Data*
Description:	*Using information from the Image Processing Subsystem and Vehicle State Estimation Subsystem, the Path Prediction Subsystem determines what the future path of the vehicle will be and how the center of the lane will change with the approaching road as well as the vehicle's state relative to the center.*
Type:	*Secondary*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 2.1.4, 2.1.5, 2.1.6, 2.1.7, 2.2.1, 2.2.1.1, 2.2.2 Invariants 3.7*
Use cases:	*N/A*

Table 8: Use case description for Predict Path

Use Case:	*Detect Lane Departure*
Actors:	*Driver, Vehicle, GM Map Data*
Description:	*While the system is active, determine if the vehicle is purposely leaving the lane, or if the vehicle*
Type:	*N/A*
Includes:	*Detect Lane*
Extends:	*N/A*
Cross-refs:	*Requirements 1.5.1, 2.1.3.3, 2.1.6 Invariants 3.2, 3.4, , 3.8*
Use cases:	*Detect Lane*

Table 9: Use case description for Detect Lane Departure

Use Case:	*Receive Map Data*
Actors:	*Vehicle, GM Map Data*
Description:	*From the GM service, send and receive requests for map data from GM. Data received will be used in addition to sensor data to determine vehicle position with respect to the lane, and assist centering the vehicle.*
Type:	*Primary*
Includes:	*N/A*
Extends:	*N/A*
Cross-refs:	*Requirements 2.1.4, 2.1.5, 2.1.6, 2.1.7, 2.2.1*
Use cases:	*N/A*

Table 10: Use case description for Receive Map Data

4.2 Domain Model

The diagram below shows the domain model of the LMS. It uses UML class diagram notation for functions and attributes of different classes and the interactions between those classes. Every class has a one sided black or white arrow that points to another class. The black arrows show the actions that one class may take on another. For example, the SupervisoryControlSystem can Enable or Disable the CameraSensingSubsystem. In addition to the domain model, there is a data dictionary that describes in more detail, all of the classes present in the domain model.

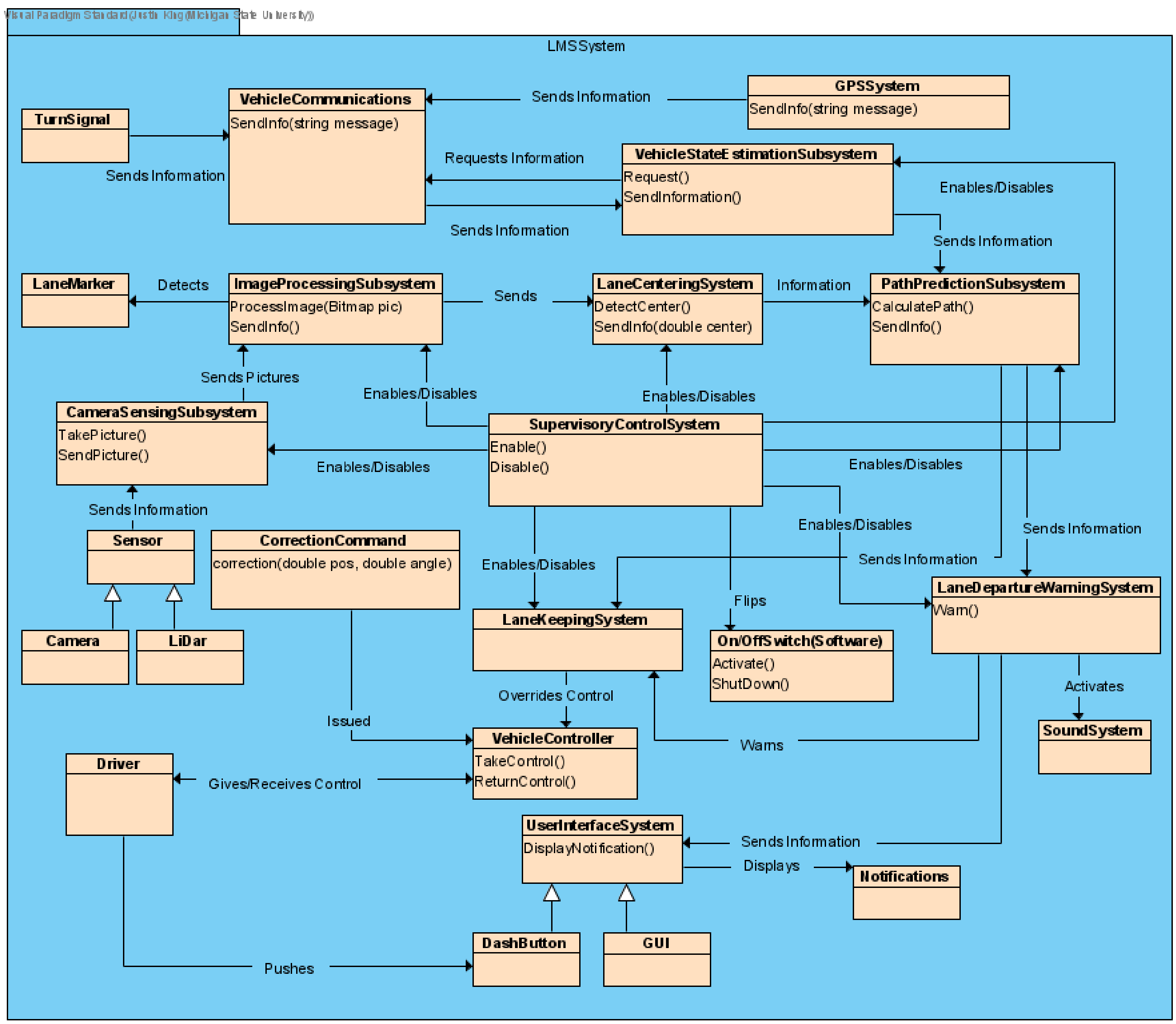


Figure 2: High-Level Domain Model for LMS

Element Name	Description
Camera	The camera is made within a set of the camera systems on the vehicle that provides the data for lane marker detection.
Attributes	
Operations	
Relationships	Camera inherits from Sensor.
UML Extensions	

Element Name	Description	
CameraSensingSub system	The camera sensing system captures images on the sides of the vehicle and sends over to the image processing unit for lane marker detection.	
Attributes		
Operations		
	TakePicture()	Uses the cameras to take a picture of the road
	SendPicture()	Sends the picture of the road to the IPS so that it can be processed and find the lane lines
Relationships	Sends pictures to the ImageProcessingSystem, can be enabled or disabled by the SCS.	
UML Extensions		

Element Name	Description	
CorrectionCommand	Correction commands are sent to the vehicle controller when the LMS (more specifically the PPS) predicts that the vehicle is performing an illegal lane departure.	
Attributes		
Operations		
	correction(double position, double	Given the position of the vehicle, where position equals 0.0 indicates that the vehicle

	angle)	is in the center of the lane, and the angle in which to turn at to correct to the center of the lane, a correction command is issued to the vehicle controller
Relationships	A correction command is issued to the vehicle controller	
UML Extensions		

Element Name	**Description**
DashButton	The dash button is a physical part of the user interface and when the driver presses the button, it turns off the LMS
Attributes	
Operations	
Relationships	Inherits from UserInterface. Is pushed by the driver.
UML Extensions	

Element Name	**Description**
Driver	The person who is driving the vehicle.
Attributes	
Operations	
Relationships	Pushes the dash button to turn the system on/off. Gives/takes over control of the vehicle from the vehicle controller.
UML Extensions	

Element Name	**Description**
GPSSystem	An in house collection of gps data about the roads that a vehicle could drive on. Is used as a supplement to the cameras and LiDAR sensors for lane management.
Attributes	

Operations		
	SendInfo(string message)	When requested, the GPSSystem acquires the road data and sends it to the VehicleCommunications class to be used.
Relationships	Sends GPS data to the VehicleCommunications class to be used later on in the VSES and PPS	
UML Extensions		

Element Name	**Description**
GUI	Graphical user interface that can display notifications/warnings, and any other pertinent data. Notifications state warnings about unintentional lane departures and when a system is activated or deactivated.
Attributes	
Operations	
Relationships	Inherits from UserInterface since it is a software based user interface.
UML Extensions	

Element Name	**Description**	
ImageProcessingSubsystem	Processes the raw images coming from the camera and identifies the lane lines	
Attributes		
Operations		
	ProcessImage (Bitmap pic)	Processes the raw image and detects the position of the most inward lane marker; i.e. the lane marker that is closest to the vehicle in the Bitmap taken by the camera.
	SendInfo()	Sends the information about the detected lane markers, or lack thereof, to the LCS.
Relationships	Detects Lane markers, receives pictures from the CSS, sends lane marker information to the LCS	
UML Extensions		

Element Name	**Description**	
LaneCenteringSystem	Calculates the center of the lane based on the lane marker information received from the IPS. Send that information to the PPS	
Attributes		
Operations		
	DetectCenter()	Uses the information received from the IPS to calculate the center of the lane.
	SendInfo(double center)	After calculating the center of the lane via DetectCenter(), send that information to the PPS.
Relationships	Receives lane marker information from the IPS, sends information about the lane center to the PPS, can be enabled or disabled by the SCS.	
UML Extensions		

Element Name	**Description**	
LaneDepartureWarningSystem	If an illegal lane departure is detected then warn the vehicle controller, activate the SoundSystem, and send that information to the UIS.	
Attributes		
Operations		
	Warn()	Send a warning to both the UIS and the LKS so that the driver can be notified and a correction command can be issued.
Relationships	Receives information from the PPS about a potential illegal lane departure, sends warning information to both the UIS and LKS, can be enabled or disabled by the SCS.	
UML Extensions		

Element Name	Description
LaneKeepingSystem	Calculates the data needed to keep the vehicle in the center of the lane.
Attributes	
Operations	
Relationships	Receives information from the PPS about where the vehicle is headed, is warned by the LDWS of a potential illegal lane departure, overrides/takes control from the vehicle controller, can be enabled or disabled by the SCS.
UML Extensions	

Element Name	Description
LaneMarker	Yellow or white painted lines or dashes on the road that show the boundaries of a lane
Attributes	
Operations	
Relationships	Is detected by the IPS
UML Extensions	

Element Name	Description
LiDAR	Sensor that detects the distance from an object.
Attributes	
Operations	
Relationships	Inherits from sensor.
UML Extensions	

Element Name	Description
Notifications	Notifications state messages that alerts the driver of a lane departure or of a malfunctioning (sub)system.
Attributes	
Operations	
Relationships	Is displayed by the UIS
UML Extensions	

Element Name	Description	
OnOffSwitch	The software ‘switch’ that turns the LMS on or off.	
Attributes		
Operations		
	Activate()	Activates the LMS when above a certain speed threshold or is put into a ‘passive mode’ until the speed threshold is achieved.
	ShutDown()	Turn the LMS off regardless of vehicle speed.
Relationships	Can be ‘flipped’/‘pressed’ by the SCS.	
UML Extensions		

Element Name	Description	
PathPredictionSystem	A software subsystem receives information from LCS and VSES to try to predict the path of the vehicle in order to detect, warn and possibly correct any potential lane violations.	
Attributes		
Operations		
	CalculatePath()	Based on the information received from the LCS and VSES, calculate the predicted path of the vehicle.

	SendInfo()	Send the predicted path information to the LKS.
Relationships	Receives information from the VSES and LCS, sends predicted path information to the LKS, sends predicted path information to the LDWS, can be enabled or disabled by the SCS.	
UML Extensions		

Element Name	**Description**
Sensor	Parent class for the Camera and LiDAR subclasses.
Attributes	
Operations	
Relationships	Sends the information from the sensors to the CSS.
UML Extensions	

Element Name	**Description**
SoundSystem	The vehicle's built in sound system. This will make an audible warning for the driver should an illegal lane departure take place
Attributes	
Operations	
Relationships	Is activated by the LDWS.
UML Extensions	

Element Name	**Description**
SupervisoryControl System	Supervises the other subsystems such that at any point in time, the SCS can enable or disable any one of them.
Attributes	
Operations	

	Enable()	Enables a specific (sub)system such as the LKS.
	Disable()	Disables a specific (sub)system such as the LKS.
Relationships	Can enable or disable the CSS, IPS, LCS, PPS, VSES, LDWS, or LKS. It can also 'flip' the On/OffSwitch	
UML Extensions		

Element Name	**Description**
TurnSignal	The vehicle's built-in turn signal that signifies which direction the vehicle is about to begin turning.
Attributes	
Operations	
Relationships	Sends it's on or off status to the VehicleCommunications class.
UML Extensions	

Element Name	**Description**	
UserInterfaceSystem	Parent class for the DashButton and GUI. Able to display notifications.	
Attributes		
Operations		
	DisplayNotifications()	Creates notifications via the GUI or SoundSystem.
Relationships	Is inherited by DashButton GUI, and can display notifications.	
UML Extensions		

Element Name		Description
VehicleCommunications	Communicates with the vehicle’s shared database to retrieve information such as GPS data, turn signal status, etc.	
Attributes		
Operations		
	SendInfo(string message)	Sends the information to the VSES in the form of a string.
Relationships	Receives information from the GPSSystem and TurnSignal, is requested to find out information by the VSES, and sends information back to the VSES after finding it.	
UML Extensions		

Element Name	Description	
VehicleController	Controls the vehicle. Has control over the steering, braking, and speed.	
Attributes		
Operations		
	TakeControl()	Takes control away from the driver in order to carry out a correction command.
	ReturnControl()	Returns control to the driver after a correction command or the driver overrides the correction command.
Relationships	Is issued a correction command, gives and takes control to/away from the driver, has control taken away from it by the LKS.	
UML Extensions		

Element Name	Description	
VehicleStateEstimation System	A set of sensors that would periodically determine the speed, steering angle and road curvature	
Attributes		
Operations		
	Request()	Request that missing or ambiguous road information be retrieved by the VehicleCommunications class.
	SendInformation()	Sends the road information to the PPS.
Relationships	Can request and receive information from the VehicleCommunications class.	
UML Extensions		

4.3 Sequence Diagrams

Section 4.3 presents a series of sequence diagrams to the reader. Each sequence diagram highlights a specific scenario and goes into detail about how the system will handle the scenario. Sequence diagrams present information about the scenario through the context of the classes for the system and how those classes interact. The large boxes at the top of each column represent a specific class. The dotted lines beneath each class are the life lines of the classes; each lifeline will be connected to various other lifelines by arrows that showcase how the classes interact.

4.3.1 LMS activation Sequence

Figure 3 showcases the sequence diagram for when the system is activated by the user. The system is activated when the user (driver) activates their vehicle and turns on the LMS. When that happens, the SCS activates each of its subsystems. This will result in enable functions being called for each subsystem including the CSS, IPS, LCS, PPS, VSS, LKS, and LDWS.

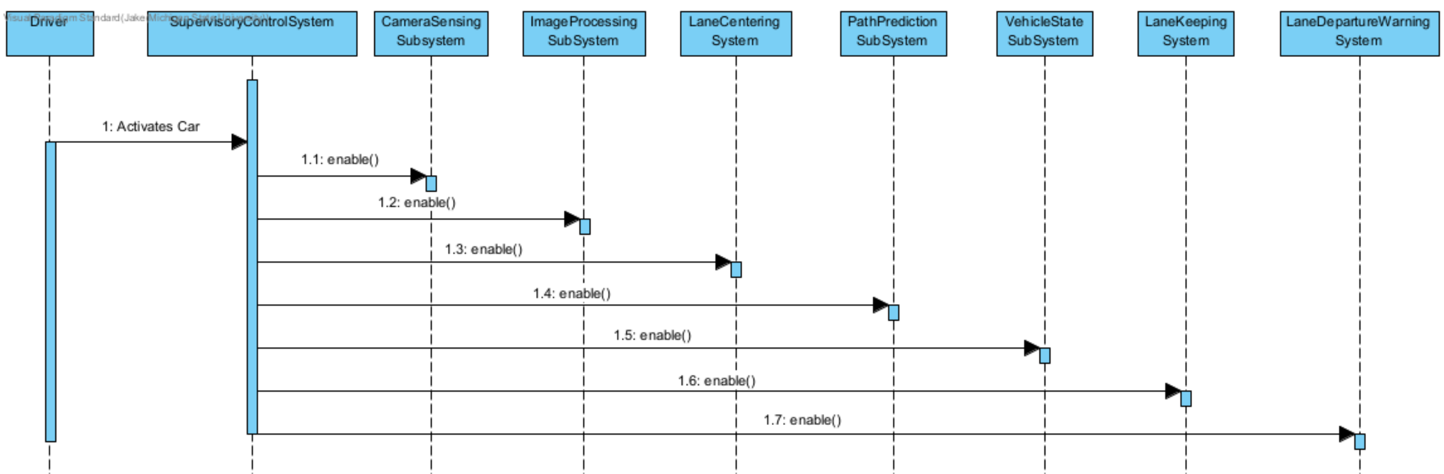


Figure 3: System Activation Sequence Diagram

4.3.2 Dash Button Turn Off LMS Sequence

Figure 4 shows the sequence diagram for when the user of the system turns the LMS off. When the user presses the power button for the LMS, the SCS will request data from the VehicleStateEstimation class which will then send that data back to the LMS. Once that data has been received, the system will call a disable function that turns the system off until the user activates it again.

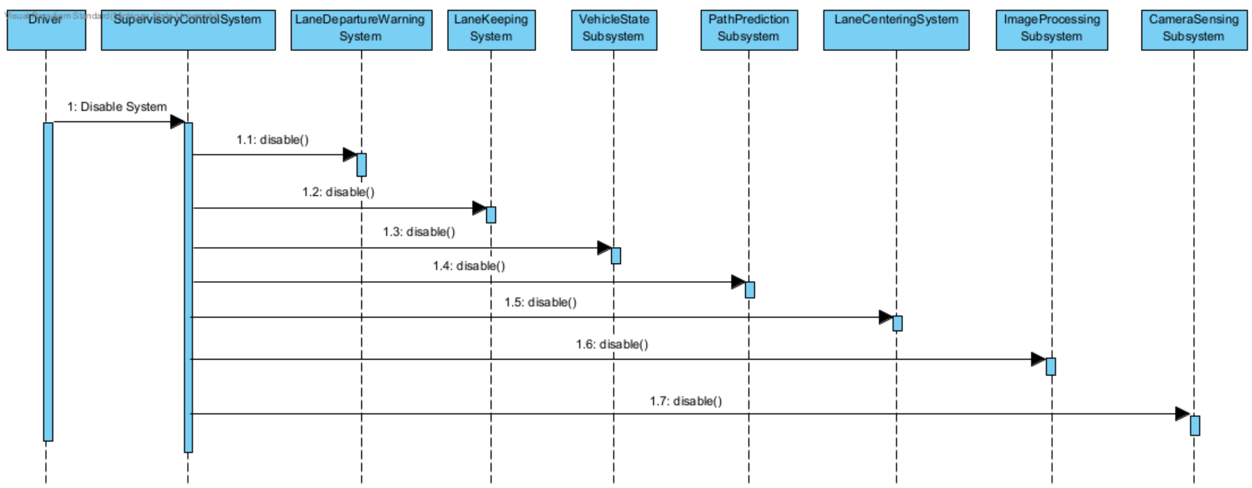


Figure 4: Off Button Sequence Diagram

4.3.3 IPS Perfect Conditions Sequence

Figure 5 shows a sequence diagram for how the system will operate when perfect conditions are present. Perfect conditions consist of clear skies, clear roads, and no obstructions. In this case, The IPS will continuously send data to the LCS every 1 second which in turn sends data to the PPS. In addition to data being sent from the LCS to the PPS, the VSES sends data about the vehicle (i.e. if the turn signals are turned on and if the vehicle speed is greater than 35 miles per hour). If the PPS calculates that an unexpected lane change is occuring, it will call upon the LKS to adjust the path of the vehicle. After the path has been adjusted, the LKS will return control back to the driver.

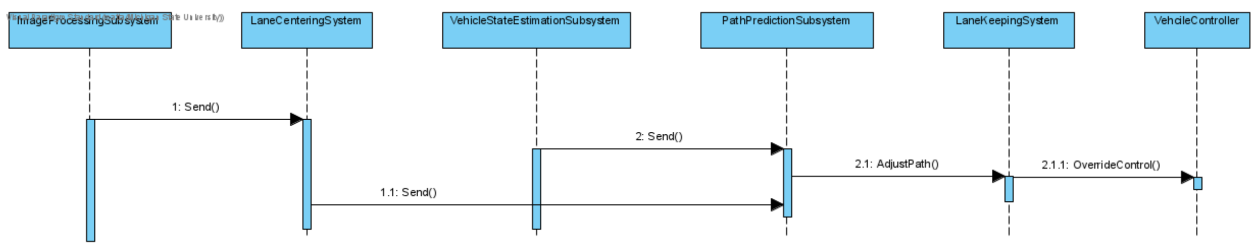


Figure 5: Perfect Condition Sequence Diagram

4.3.4 IPS Calculate Vehicle Center Sequence

Figure 6 displays the sequence diagram for the system's ability to calculate the center of the vehicle. Once the CSS is enabled by the supervisory control system, it will continuously send photos captured by the LiDAR sensors and the cameras to the IPS. The IPS processes the images sent from the cameras and sensors and finds the position of the vehicle relative to the sides of the lane. That data is then sent to the LCS which will determine if the vehicle needs to be adjusted.

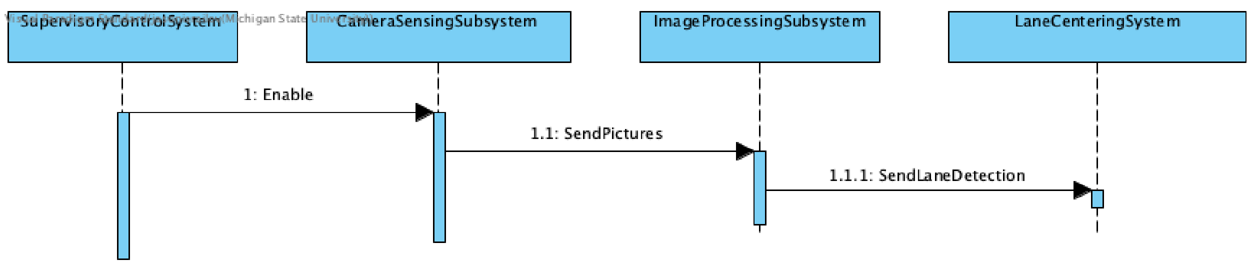


Figure 6: Calculate Vehicle Center Sequence Diagram

4.3.5 PPS Path Prediction Sequence

Figure 7 shows the sequence diagram for the system's ability to predict the path of the vehicle. The PPS utilizes data sent from both the VSES and LCS in order to predict the path of the vehicle. The VSES sends data about the state of the vehicle including whether the turn signal is on and any map data from GM servers. The LCS sends information about the calculated center of the vehicle from camera and sensor data. Using both data from the VSES and the LCS, the PPS can then calculate the path the vehicle is on track to take and determine if the LKS needs to adjust the position of the vehicle.

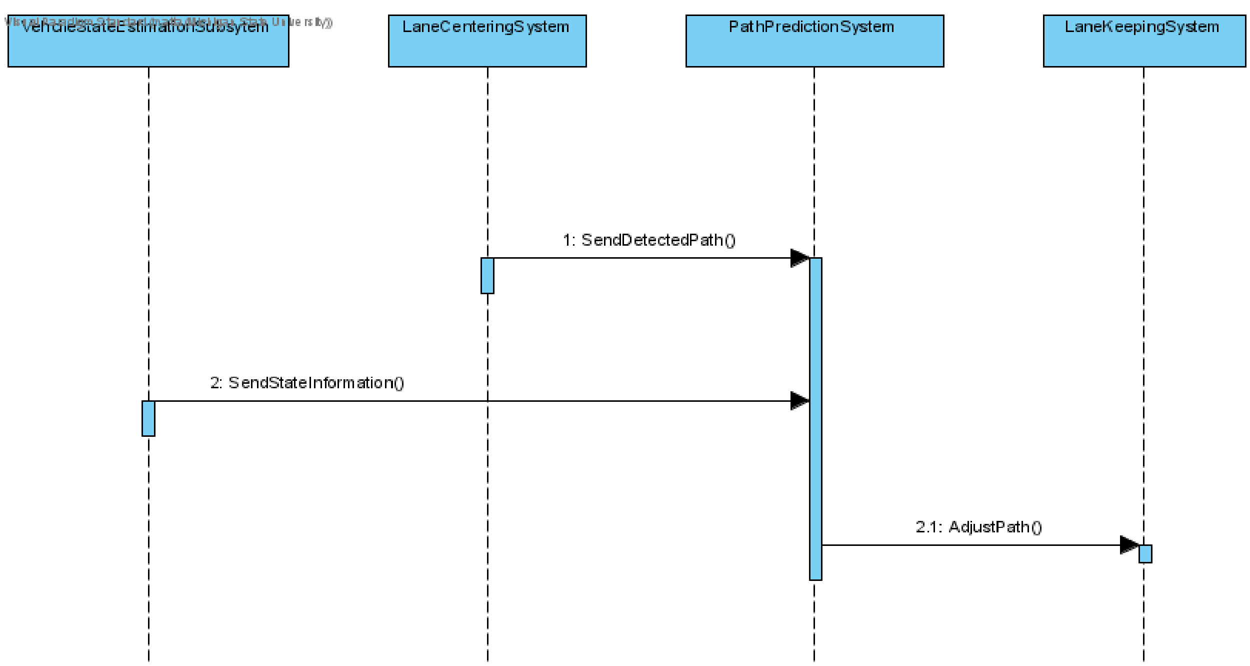


Figure 7: Path Prediction Sequence Diagram

4.3.6 LKS Return Driver Control Sequence

Figure 8 shows the system's behavior for returning control of the vehicle back to the driver after the LKS corrects the position of the vehicle. As the PPS continuously calculates the path of the vehicle it will let the LKS know if the vehicle has returned to its center position in the lane. Once the isCarCenter() function flags the vehicle as being in the center of the lane, the LKS will call a series of disable functions. The disable functions will remove control of the vehicle from the system and stop the lane correction.

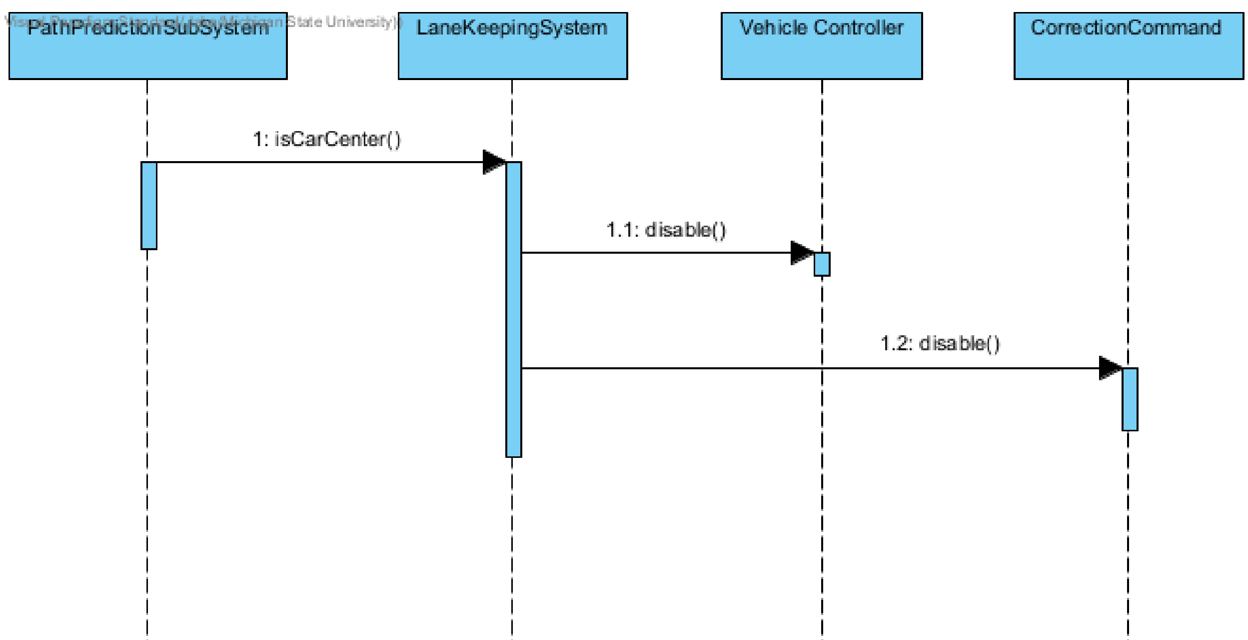


Figure 8: Return Driver Control Sequence Diagram

4.3.7 PPS Illegal Departure Sequence

Figure 9 shows the classes involved and the functions called for when the vehicle undergoes an unexpected lane change. This sequence starts with the PPS calculating the predicted path of the vehicle and determining that the vehicle is no longer within the center of the lane. It does this using data from the LCS and the VSES. Once the PPS determines this, it will call upon functions that flag the LDWS and LKS to activate. The LDWS will issue a warning to the driver that they have moved out of the lane, and the LKS will take over control of the vehicle to readjust its position.

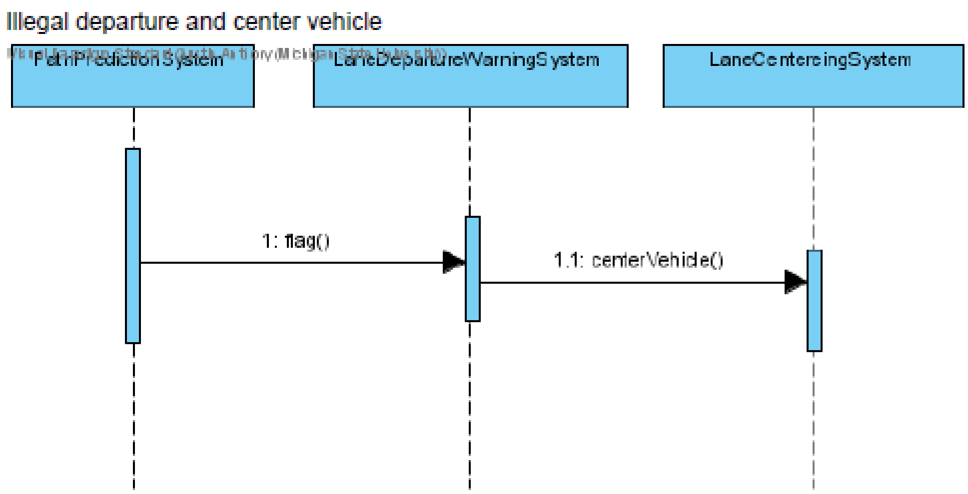


Figure 9: Illegal Departure Sequence Diagram

4.3.8 VSES Data retrieval Sequence

Figure 10 shows the sequence of classes and called functions for the system's ability to retrieve data for the GM servers and other systems of the vehicle. The VSES continuously requests data by calling a requestData() function on the Vehicle Communication class. The Vehicle Communication class then in turn requests data from the other systems of the vehicle (namely the turn signal) as well as the internal GM servers. In turn, the data from the servers and the vehicle systems is sent back to the Vehicle Communication class and finally sent back to the VSES. This data retrieval sequence operates as a loop as a constant stream of data is needed to accurately operate the LMS.

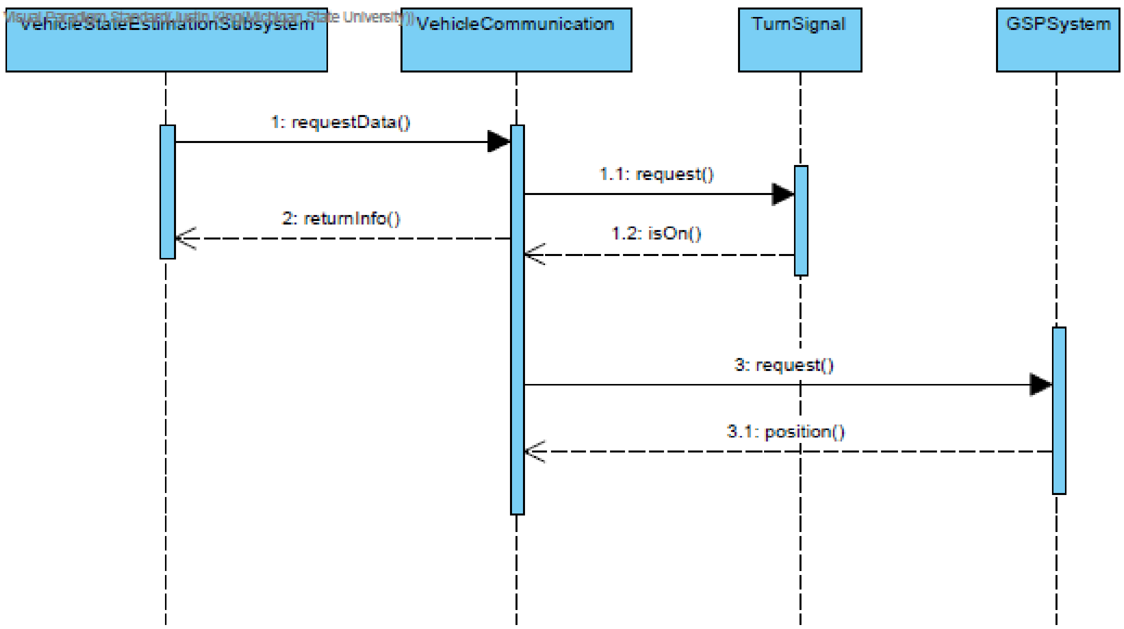


Figure 10: Data Retrieval Sequence Diagram

4.3.9 UIS Warning State Sequence

Figure 11 shows the sequence diagram for how the LMS issues a warning to the user that an unexpected lane change is occurring. Once the PPS detects the illegal lane change, it will flag both the LKS and the LDWS. The LDWS then activates its various warning signal devices. The LDWS utilizes a sound system alert that gives off an audio warning signal and works with the user interface for the system to display a graphical, visual warning to the user. The LDWS will also be activated for various other warnings including a lack of reliable data. The LDWS creates a graphical warning specific to the situation so the user knows exactly what has occurred.

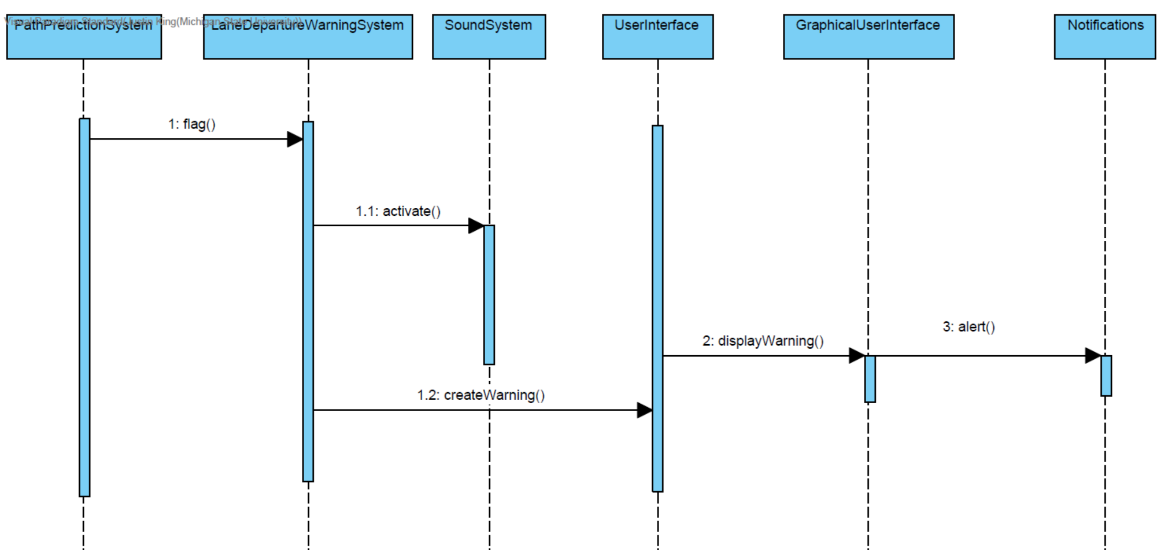


Figure 11: Warning State Sequence Data

4.3.10 VSES Ambiguous Data Sequence

Figure 12 shows the sequence diagram for what occurs when the system requests data from the VSES and the data received is ambiguous. Ambiguous data means data that can not be used to develop an accurate representation of the current state of the vehicle. This means that the VSES was either unable to communicate with the other systems in the vehicle or it was unable to gain useful information from the GM servers. If the data received is ambiguous, the supervisory control system will first flag the LDWS to display a warning message to the user and then disable itself until the data it is receiving is no longer ambiguous.

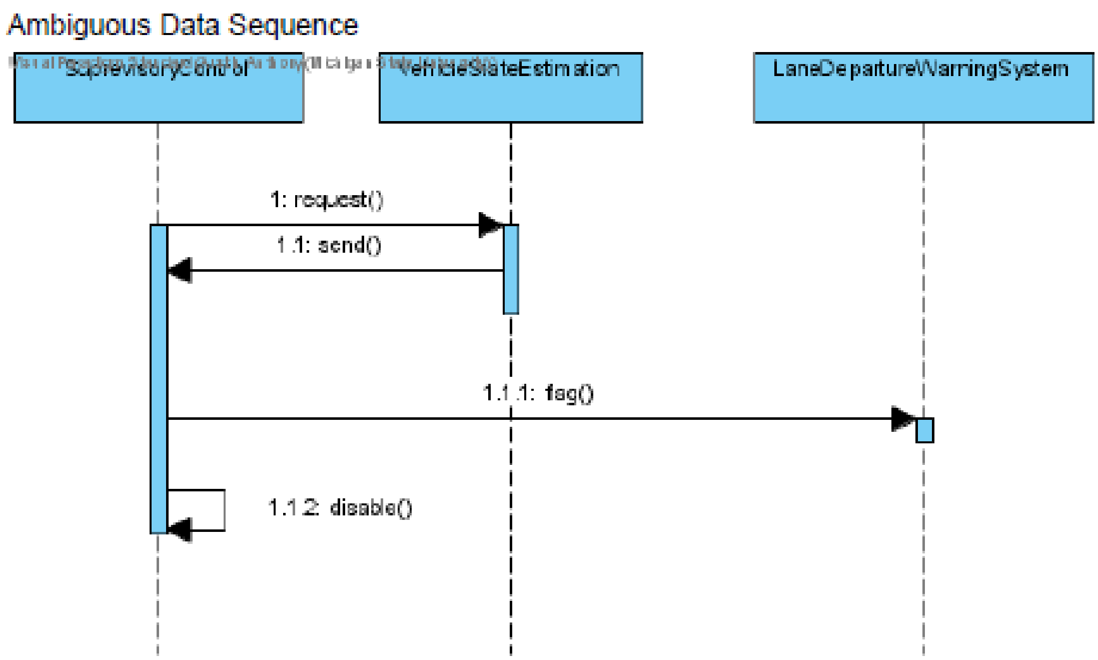


Figure 12: Ambiguous Data Sequence Diagram

4.4 State Diagrams

Section 4.4 details the dynamic behaviors of classes and how the state changes and transitions per use case. In the diagrams, the previous state is denoted by the black circle with an arrow attaching to a state. A state is denoted by the blue rectangle in the diagram. The black arrows are transitions that denote a change in state.

4.4.1 LMS System Activation

Figure 13 shows that the LMS System will only activate when the vehicle has been activated and must exceed the speed threshold. Once these two conditions are met, the Supervisory Control System will run diagnostics on all subsystems. If no errors are found, then the Supervisory Control System will enable all subsystems of the LMS. Following this, the LMS system will be in an idle state.

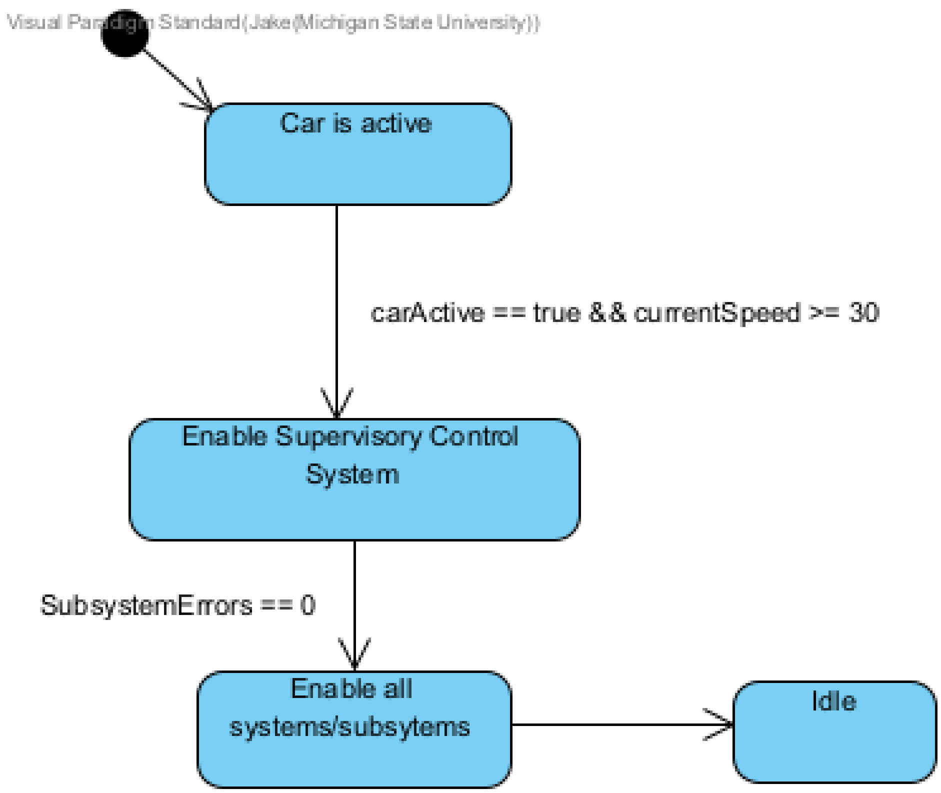


Figure 13: System Activation State Diagram

4.4.2 System Shutdown

Figure 14 depicts the two methods of shutting down the LMS system. One method is while the system is active, the driver may disengage the system by pressing the LMS power button located on the dashboard. The other method shown is an automatic shutdown when the GPS data and sensory data from the vehicle's Camera Sensing Subsystem is inadequate. This will disable the LMS system for the safety of the driver.

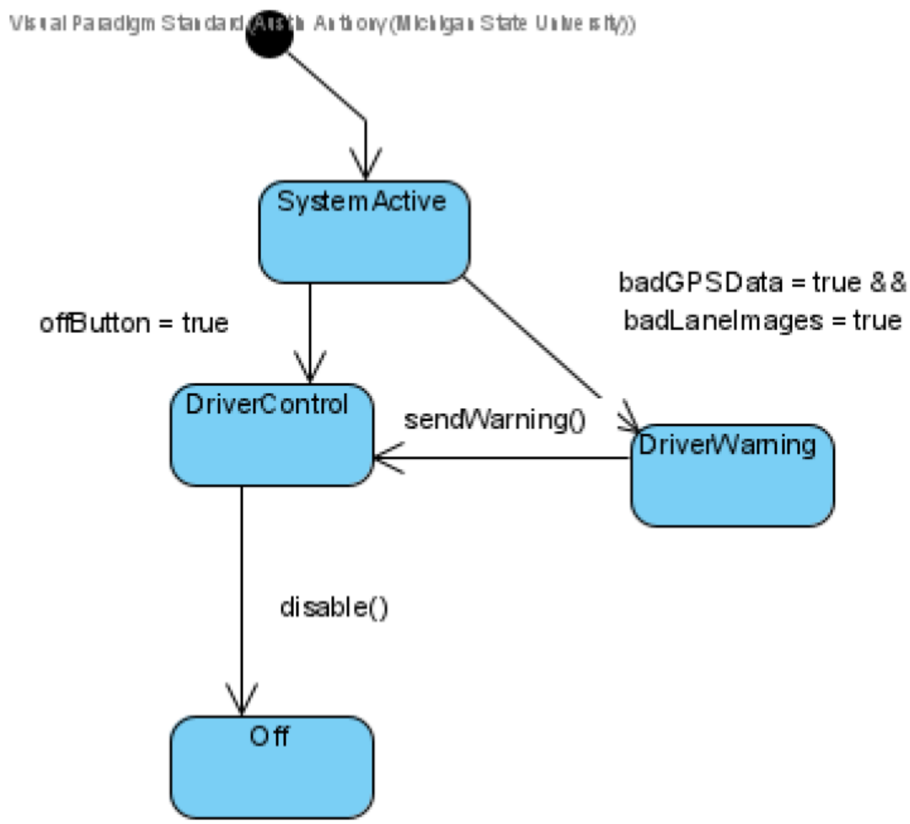


Figure 14: Off Button State Diagram

4.4.3 PPS Perfection Condition

Figure 15 depicts what the LMS system will do given perfect conditions to compensate for an illegal lane departure. When the camera detects a shift from the lane's center. It sends information to the PPS to determine if the current course away from the center is leading to a lane departure. If this is true, then the system will continue to calculate the path trajectory as well as send a warning message to the LDWS, as well as begin to override the drivers steering control via the LKS. Once the vehicle is brought back to the lane's center, then steering controls are returned to the driver.

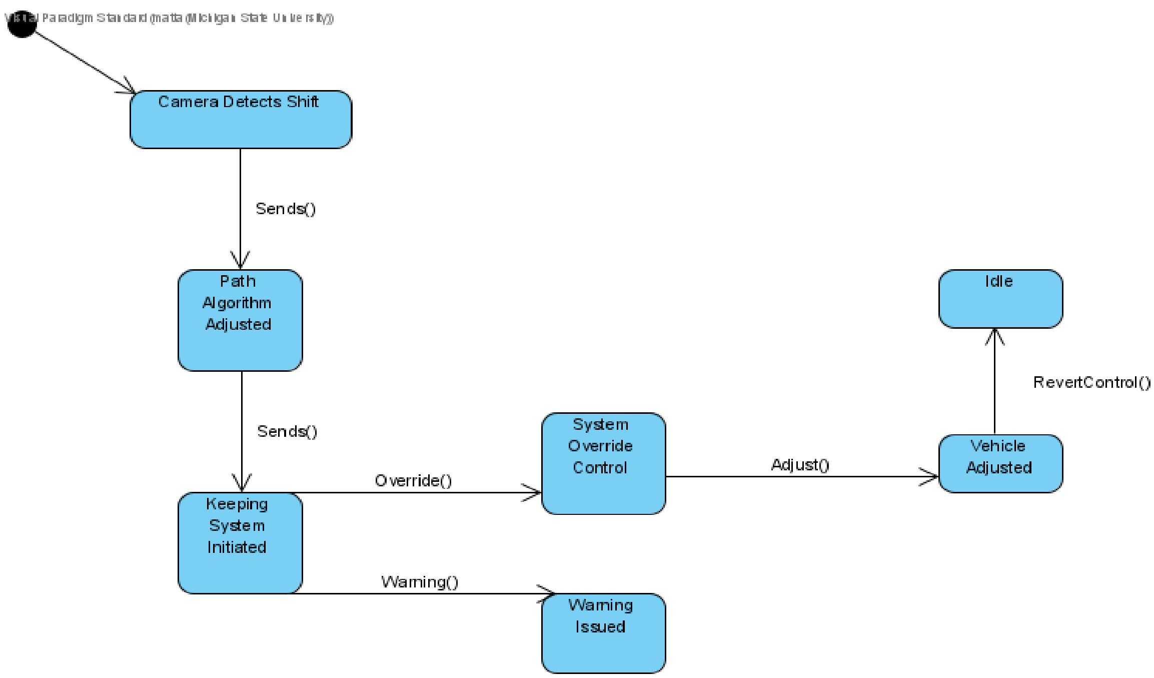


Figure 15: Perfection Condition State Diagram

4.4.4 IPS Calculate Vehicle Center

Figure 16 shows the logic behind calculating the centering of the vehicle. If the system is in the active state, meaning all subsystems are working, then the IPS will relay all information that is gathered from all available sensors to the LCS. Here the information from the IPS will be used to calculate where the center of the lane relative to the vehicle is located.

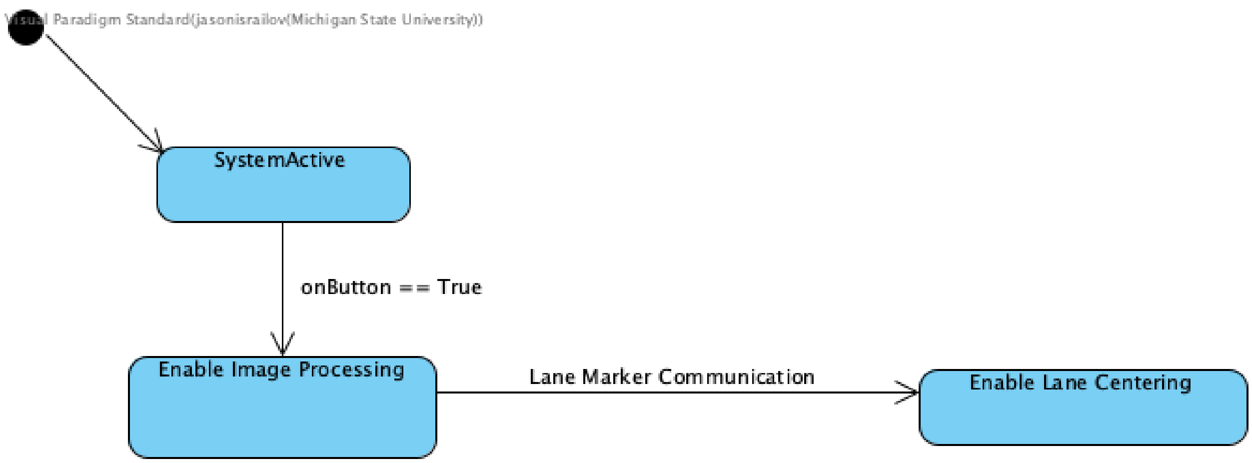


Figure 16: Calculate Vehicle Center State Diagram

4.4.5 PPS Path Prediction

Figure 17 displays the process of calculating the future path of the vehicle. The camera data from the IPS is either sent continuously or requested to the PPS. Here the information is used to determine if the vehicle will remain in the center of the lane given the current course of if the changes in the road ahead will change the center position of the vehicle. This path prediction is running and calculating continuously as conditions on the road change. It also will state the new center of the lane once a legal lane change occurs.

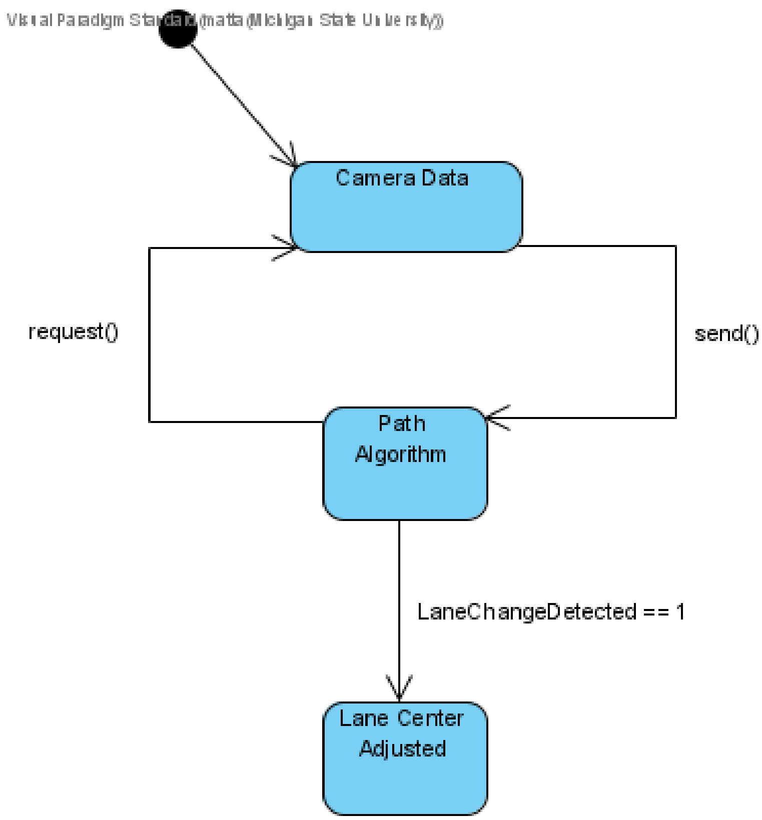


Figure 17: Prediction State Diagram

4.4.6 LKS Return Driver Control

Figure 18 depicts the conditions needed to safely return steering control back to the driver of the vehicle. After a steering correction is complete, the vehicle must be in line with the new lane center position calculated by the Lane Centering System. This position must be sent to the Vehicle State Estimation Subsystem to override the previous lane center. When the vehicle is confirmed to be in the new center of the lane, then the Lane Keeping System will be disabled, this will return control of the vehicle back to the driver. The warning alerting the driver of the lane departure as well as the LKS being active will be disabled after centering the vehicle.

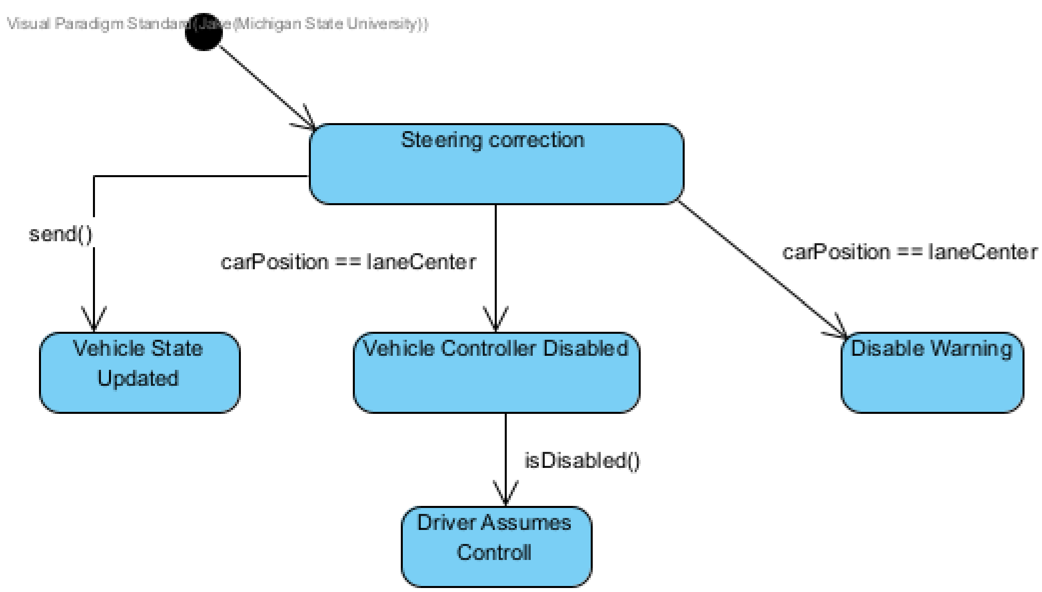


Figure 18: Return Driver Control State Diagram

4.4.7 LKS Illegal Departure of Vehicle

Figure 19 shows how the vehicle changes state upon detecting an illegal lane departure. The system is in its idle state if no departures are detected. An illegal departure is detected when the Lane Centering System is active and the Path Prediction system detects the vehicle to be drifting from the vehicle center without any indication with the turn signal. Once it drifts close to the lane's edge, the Lane Keeping System will begin a corrective command to get the vehicle back to the center of the lane. Once this is complete, the system will be in the idle state.

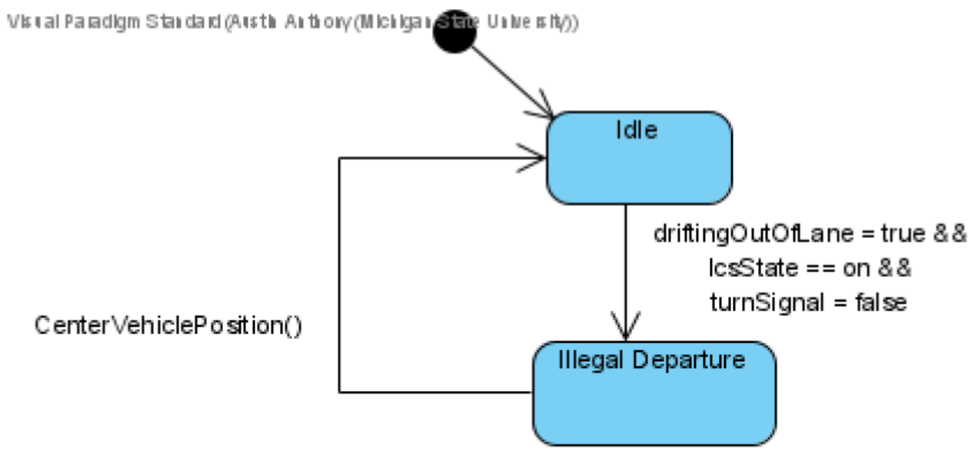


Figure 19: Illegal Departure of Vehicle State Diagram

4.4.8 VSES Data Retrieval

Figure 20 shows the process of gathering data from the General Motors Server such as GPS information, and other GM vehicle features needed to operate the LMS system such as turn signal activation. The Vehicle State Estimation Subsystem requests information from vehicle communications. This information is then sent and stored in the Vehicle State Estimation Subsystem until it is overridden by new incoming data.

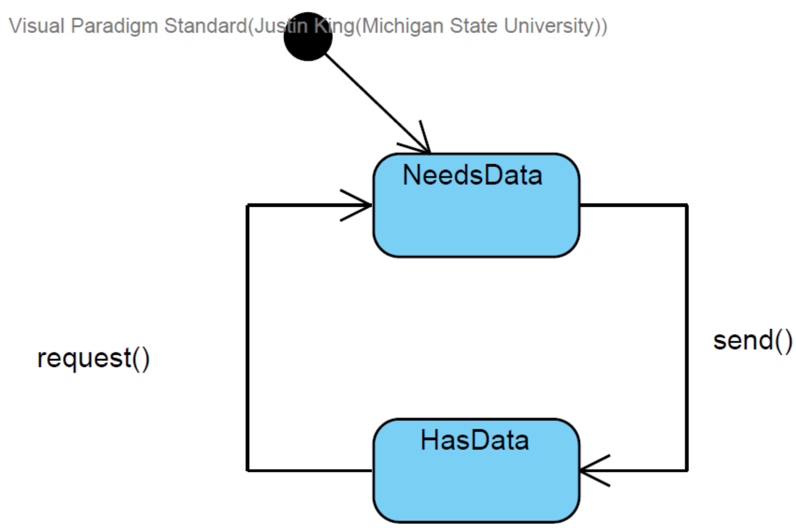


Figure 20: Data Retrieval State Diagram

4.4.9 UIS Warning State

Figure 21 shows what occurs in the Lane Departure Warning System to alert the driver of a lane departure and the activation of the LKS. Upon a detected illegal departure by the Path Prediction Subsystem, a warning is to be issued by the LDWS, this is done by playing an audible sound through the audio system in the vehicle and sending a visual alert to the graphic user interface. After both the audio and visual alerts are given and the corrective action by the LKS is completed, both warnings will cease.

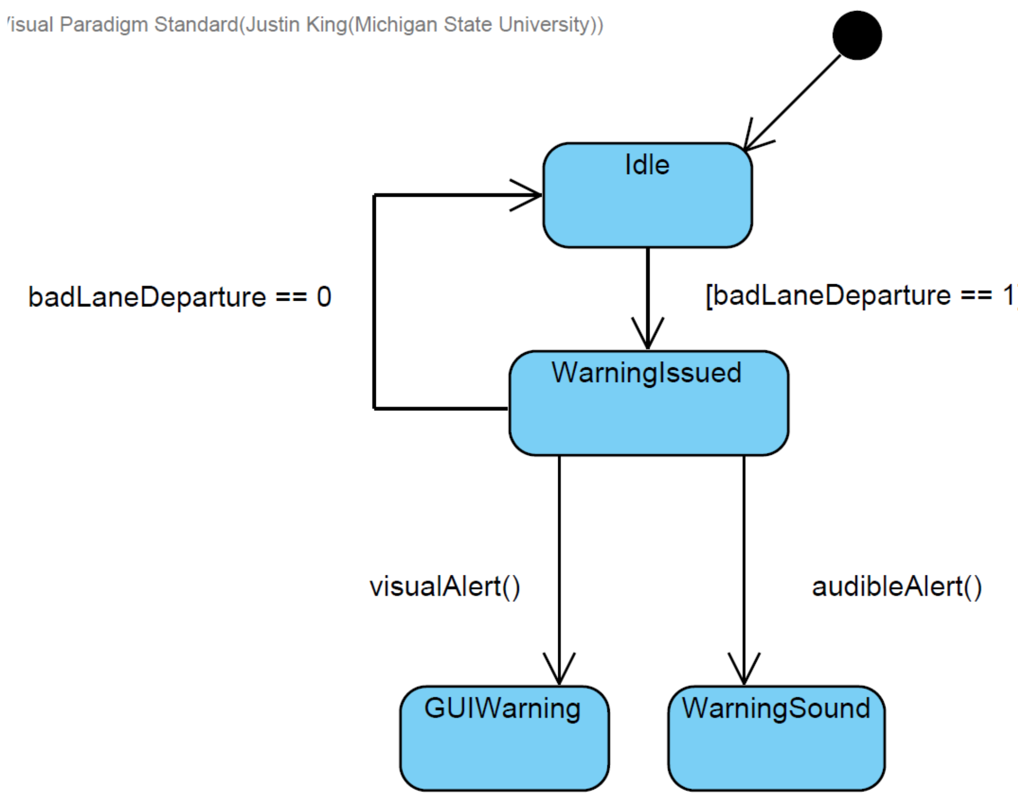


Figure 21: Warning State Diagram

5 Prototype

The intention of this section is to illustrate the LMS prototype and scenarios. The prototype was developed using animation software with images and shapes to outline the prototype's real life scenarios. Below are the example scenarios for the prototype as well as a description for how to run the prototype. While the example scenario animations do not provide a fully accurate representation of how the system will operate in real life and are not used in the development process for the system, they serve to provide the customer with an opportunity to view how the development team envisions the actions of the system. Included with the sample scenarios are instructions on how to view and run the prototypes.

5.1 How to Run Prototype

The prototype for the LMS is accessible for public use through any standard web browser at the following website https://cse.msu.edu/~periala3/prototypeHome.html . The previous link takes the user to the home-page for the prototype section. On that page, there are various links to each scenario with a prototype showcasing how the system will react to that scenario. The prototypes were created using an animation software, so when the link to a specific scenario is clicked, the animation will automatically play for the viewer. The animations do not require further user input and will continue to play on a loop so the viewer can continuously watch the scenario. There are no extensions needed, no constraints, and the scenarios will play on any operating system.

5.2 Sample Scenarios

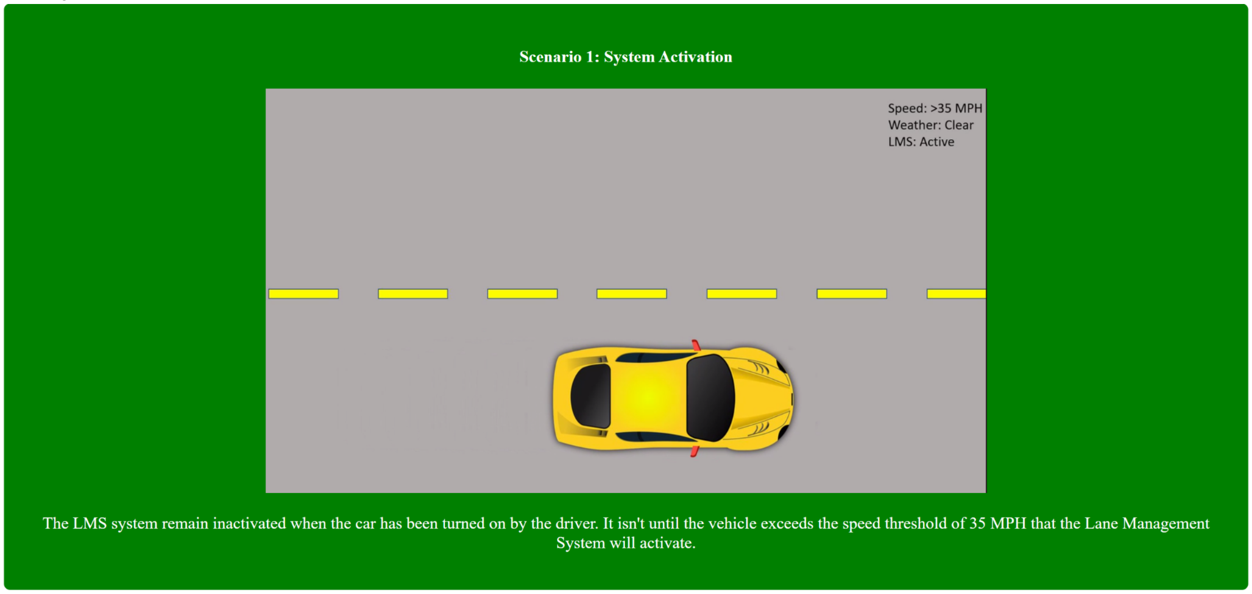
The following section showcases three sets of scenarios of the LMS prototype: Ideal Scenarios, Non Ideal but Manageable Scenarios, and Unmanageable Scenarios. A screen capture illustrating each prototype is shown along with a description of what the prototype showcases.. To view the animated gif image of each scenario, navigate to our website at https://cse.msu.edu/~periala3/prototypeHome.html.

5.2.1 Ideal Scenarios

The "Ideal Scenarios" section demonstrates ideal weather and road conditions. Ideal weather and road conditions consist of factors that do not impact the performance of the LMS. Examples include clear skies, no precipitation, no road obstructions, no curves in road, lane markings on both sides of the road, and dry roads.

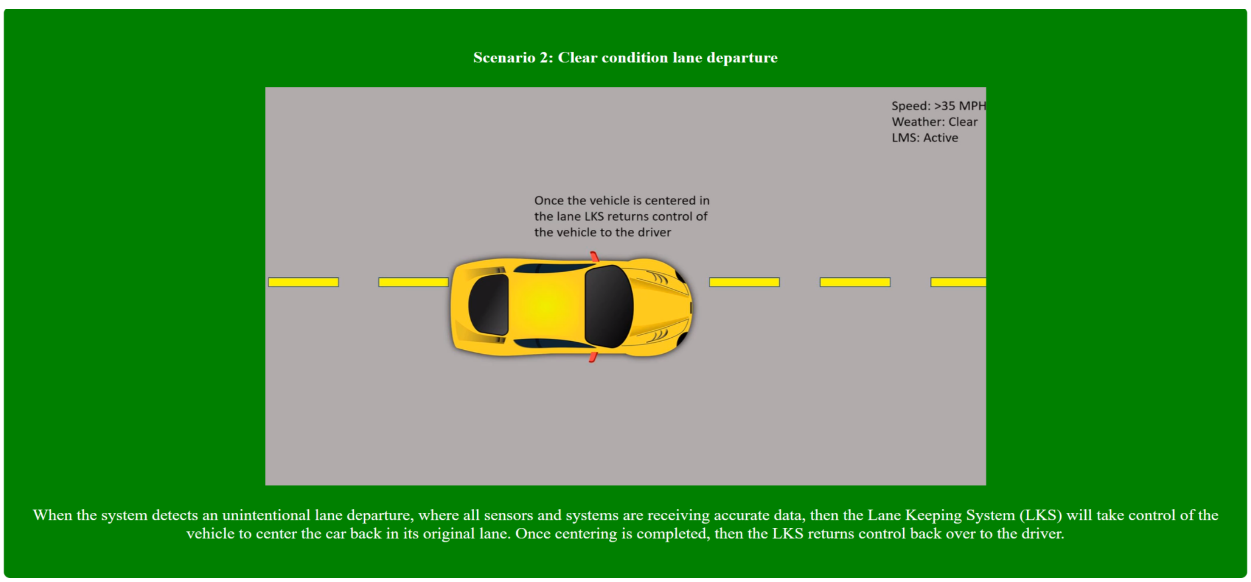
System Active

The “System Active” scenario describes how the LMS will operate when the user is driving at a speed of above 35 miles per hour, on a clear road (no obstructions or curves), and with clear skies. The vehicle remains in the center of the lane for the duration of the scenario; this is meant to show how the system remains active even though there is no need for warnings or adjustments.



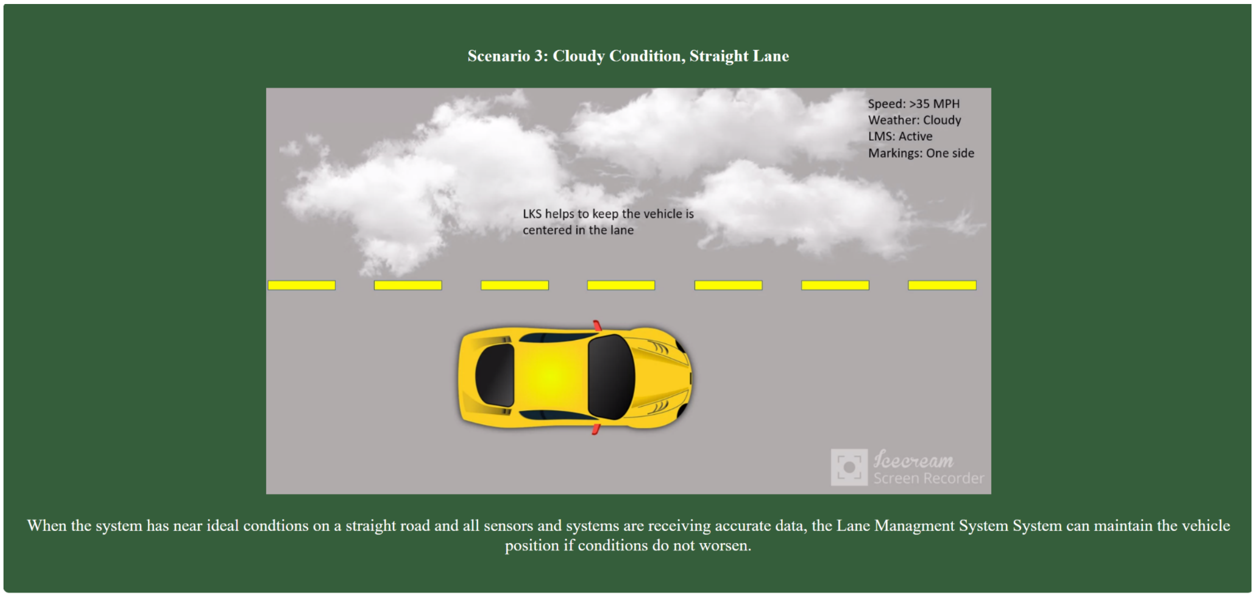
Clear Condition Lane Departure

The “Clear Condition Lane Departure” scenario is a continuation of the previous “System Active” scenario, however, the vehicle makes an unintended lane change. The same perfect conditions apply (clear skies, clear roads, no obstructions), so the system is able to perfectly identify the lane change occurring and takes over control of the vehicle. Once the system corrects the position of the vehicle back to the center of its original lane, then it reverts control back to the user.



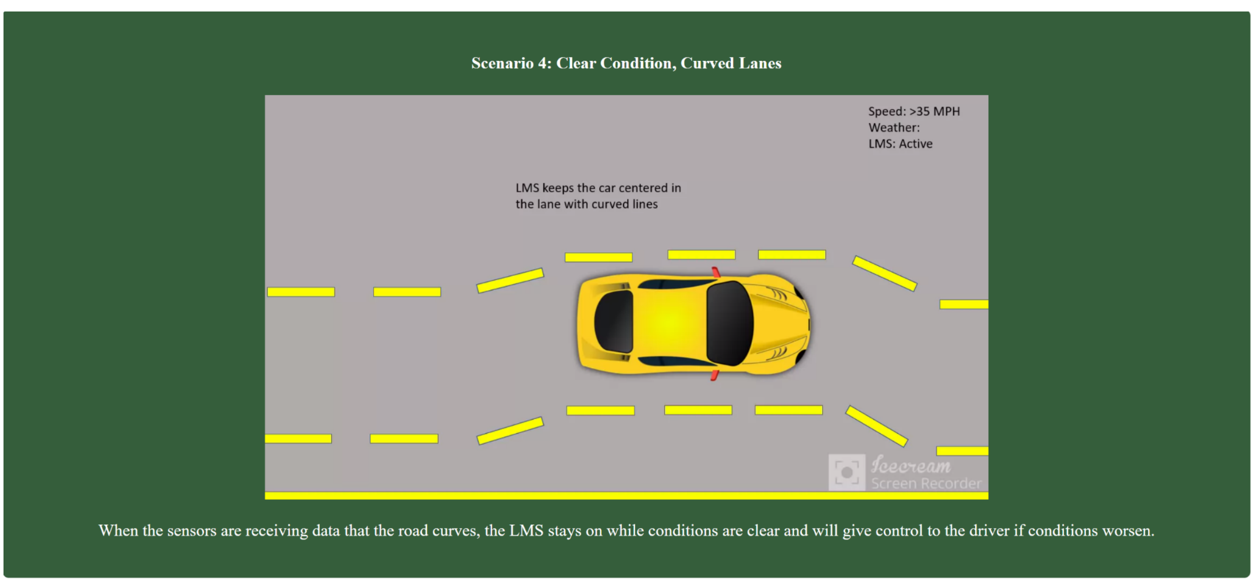
Cloudy Conditions, Straight Lane

Similarly to how the LMS will operate when there are clear skies, cloudy conditions do not have an affect on the functionality of the system. Cloudy conditions are considered to be ideal conditions as they do not affect the ability of the sensors to detect the lane markings of the road. LMS will remain active and operate accordingly.



Clear conditions, Curved Lanes

The “Clear conditions, Curved Lanes” scenario showcases how the LMS will operate when ideal conditions (clear skies, no obstructions, and clear roads) are present but the curvature of the lane changes. Because there are ideal conditions, there is no effect on the system’s ability to identify the changes in the lane. Using the camera and the LiDAR sensors, the LMS detects the new center of the lane and adjusts the vehicle accordingly.

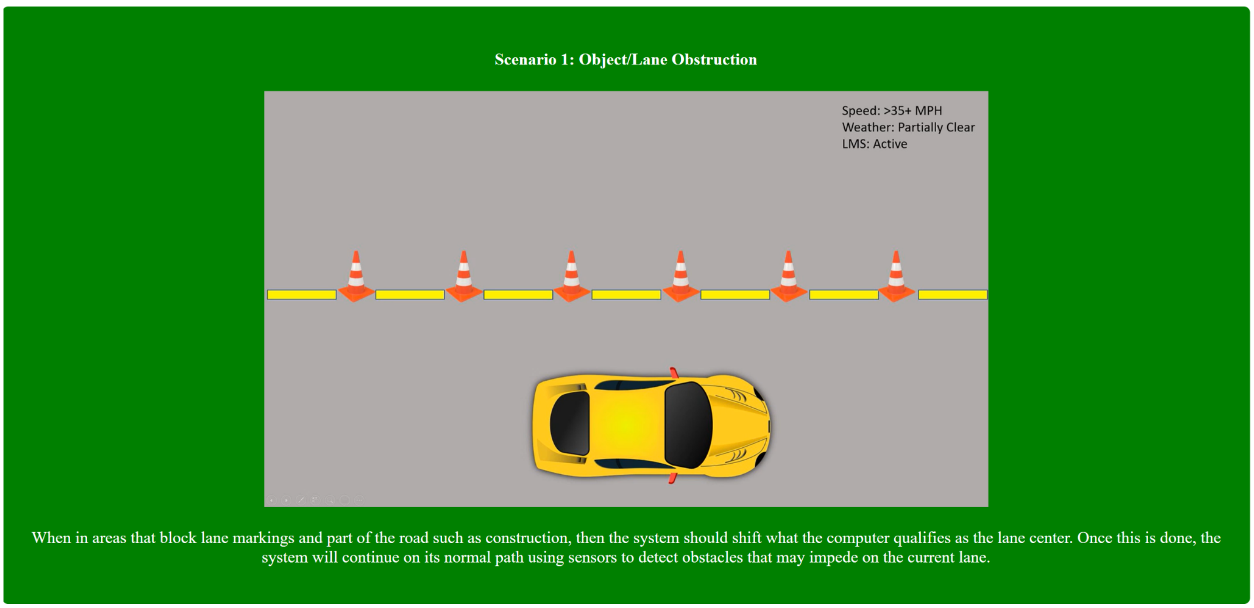


5.2.2 Non Ideal but Manageable Scenarios

This scenario section titled "Non Ideal but Manageable Scenarios" showcases how the LMS will operate in cases where the conditions the system faces are not perfect but do not extend far enough for the system to face shutdown. The purpose of these scenarios is to show the limitations of the LMS and the various constraints it can withstand.

Object/Lane Obstruction

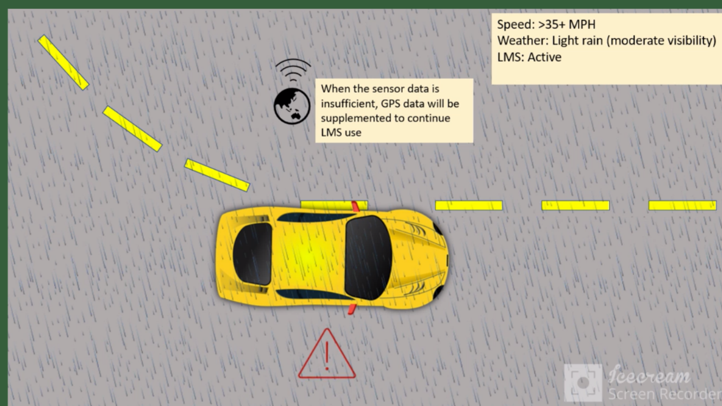
The scenario "Object/Lane Obstruction" shown in the following figure describes the vehicle as it is driving over 35 miles per hour, with mostly cloudy conditions, and with obstacles (traffic cones) being placed alongside the lane markings on the left side of the vehicle. The prototype showcases the system operating correctly as the cameras in conjunction with the LiDAR sensors are still able to identify the lane markings on the sides of the road.



Light Weather

The “Light Weather” scenario showcases how the LMS will react when the conditions of the weather result in the camera sensors not being able to provide sufficient data. In this scenario the rain is heavy enough to block the view of the sensors, but the LMS is still able to operate. This is because the LMS is able to supplement the lack of sensor data with the available GPS data from the GM servers.

Scenario 1: Light Weather

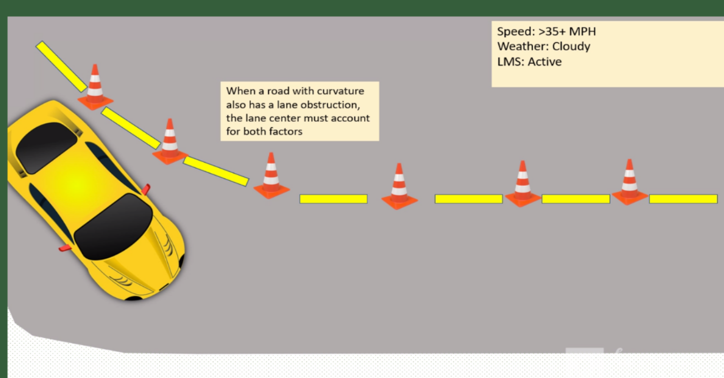


When the vehicle is in weather conditions that can hinder the abilities of one of the sensors, the system can supplement the lack of data for GPS data if it is available. This will allow the system to continue operating as intend with insufficient sensor data

Lane Curvature with Lane Obstruction

In situations where a curvature in the lane exists the LMS utilizes both the camera sensors and the LiDAR sensors to calculate the center of the lane with the PPS. However, road obstacles and obstructions are common and the system must account for them. The following scenario shows how the system will react when calculating a new center of the lane while obstacles exist in the middle of the road. These obstacles, however, do not cover the entirety of the lane markings and thus allow for the sensors to accurately detect the markings and make the proper adjustments.

Scenario 3: Curvature with Object/Lane Obstruction



When a road with curvature also has a lane obstruction, the calculated lane center must account for both the future curve of the road as well as the object impeding on the lane. â€‹

5.2.3 Unmanageable Scenarios

"Unmanageable Scenarios" consist of cases where the conditions that the LMS is facing at the time of operation break the constraints of the system and prevent it from operating properly. These conditions create a situation where if the LMS were to continue operating and take over control of the vehicle, an unsafe situation would be presented to the user. Examples of conditions that would create an unmanageable scenario would be slippery roads due to rain, ice, or snow, large obstructions in the road, and severe weather conditions. The following scenarios showcase how the system will operate in these circumstances.

Insufficient data due to inclement weather

In this scenario, the driver of the vehicle is attempting to use the LMS in inclement weather. While the vehicle is driving at a speed of greater than 35 miles per hour and there are no obstacles on the road, the heavy rainfall prevents the LiDAR sensors and the cameras from accurately determining the center position of the lane and the position of the vehicle relative to the lane markings. Because of this, the system can not identify lane changes. The lack of camera and sensor data conjoined with no map data on the current road results in the LMS entering passive mode until sufficient road data is available. The figure below showcases how the system will operate in this scenario.

Scenario 1: Insufficent data due to inclement weather

If the system receives insufficient data from the sensor and GPS due to inclement weather, then the system will shut off due to safety concerns so that the driver will have continuous full control until conditions are deemed safe again.

Snowing; Unable to Read Lane Markings

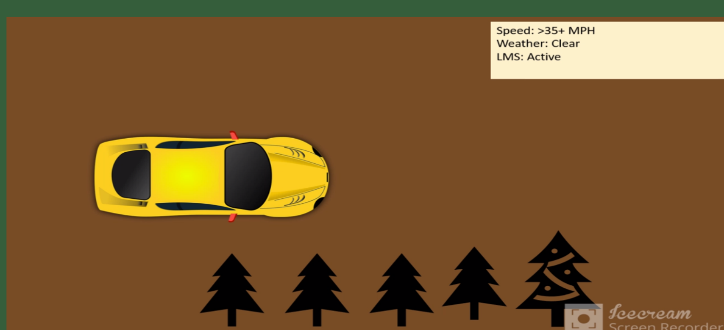
In situations where the driver of the vehicle is attempting to utilize the LMS while there are heavy snowing conditions, the LMS forces itself to enter passive mode until the conditions cease. Snow covered roads provide for potentially dangerous conditions if the LMS were to take over control of the vehicle. First off, snow weakens the traction between a vehicle's tires and the road, and if the LMS were to make an adjustment that the driver was not prepared for, then the driver risks losing control of the vehicle. Additionally, the snow makes it extremely difficult to detect the lane markings of the road.

Scenario 2: Snowing, unable to read lanes

When the vehicle is in an environment with snow on the road that is covering the lane markers, the LMS, if on, should relinquish control back to the driver.

Dirt Road

Dirt roads environments provide conditions that result in the LMS not being able to operate. The reasoning for this is, dirt roads do not have any lane markings which removes the system's ability to calculate the positioning of the vehicle. Whenever the system detects the vehicle operating on a dirt road, if active, the system will enter passive mode until a road with markings is reached.



Scenario 3: Dirt Road

When the vehicle is in an environment with a dirt road, if the LMS is active it will relinquish control back to the driver

6 References

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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.