Chapter 4: System Design

This chapter focuses on how we've designed our system. Design is based upon the requirements which are gathered using a variety of techniques, including interviewing domain experts and conducting documentation analysis. Our approach involves reviewing existing documentation, research papers, industry standards, and guidelines related to autonomous vehicle navigation. We won't dive into the visual parts of our software, but we'll explore how everything in the system works together

4.1 Introduction

The software system leverages the architecture of **ROS 1**, with outcomes visualized using the **Carla Simulator**. To enable seamless communication between Carla and ROS Noetic, we utilize the **ROS bridge as an interface** for data retrieval and command transmission. This bridge serves as a critical intermediary, facilitating integration between ROS programs and non-ROS environments.

4.2 Architectural Design

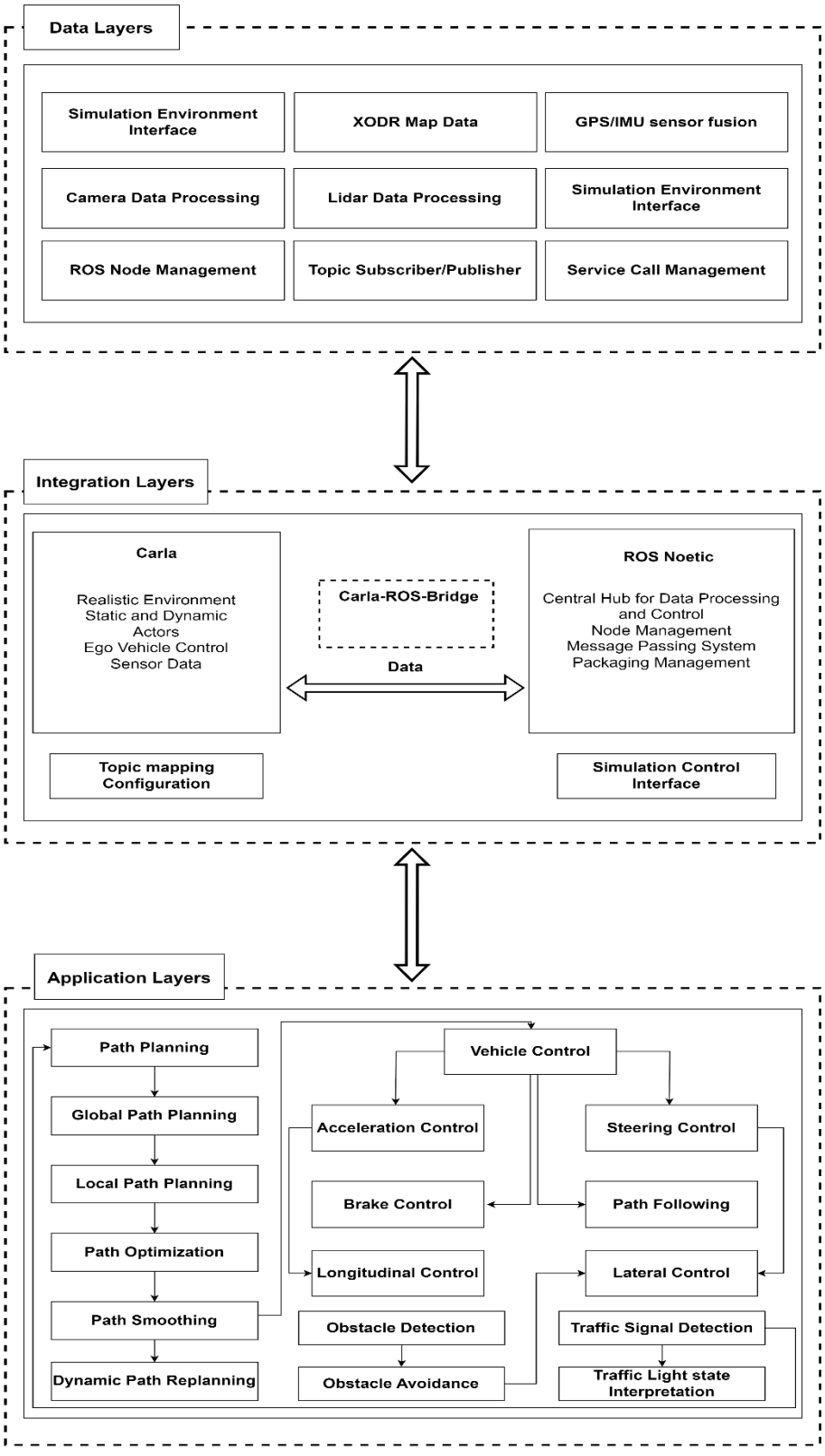

Figure 4.1: Architecture Diagram

4.3 Detailed Design

4.3.1 Use Case Design

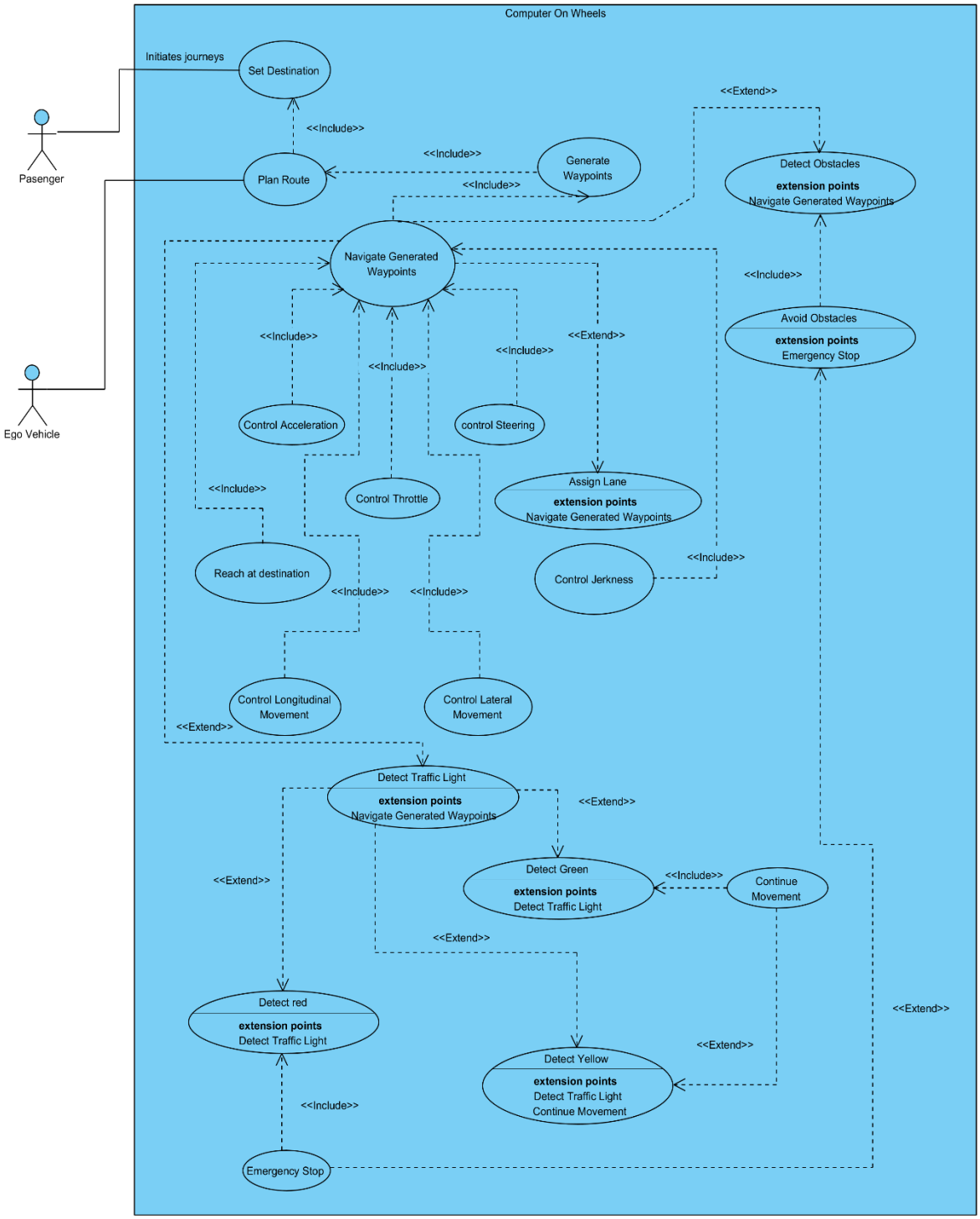

Figure 4.2: Use-case Diagram

4.3.2 Sequence Diagram

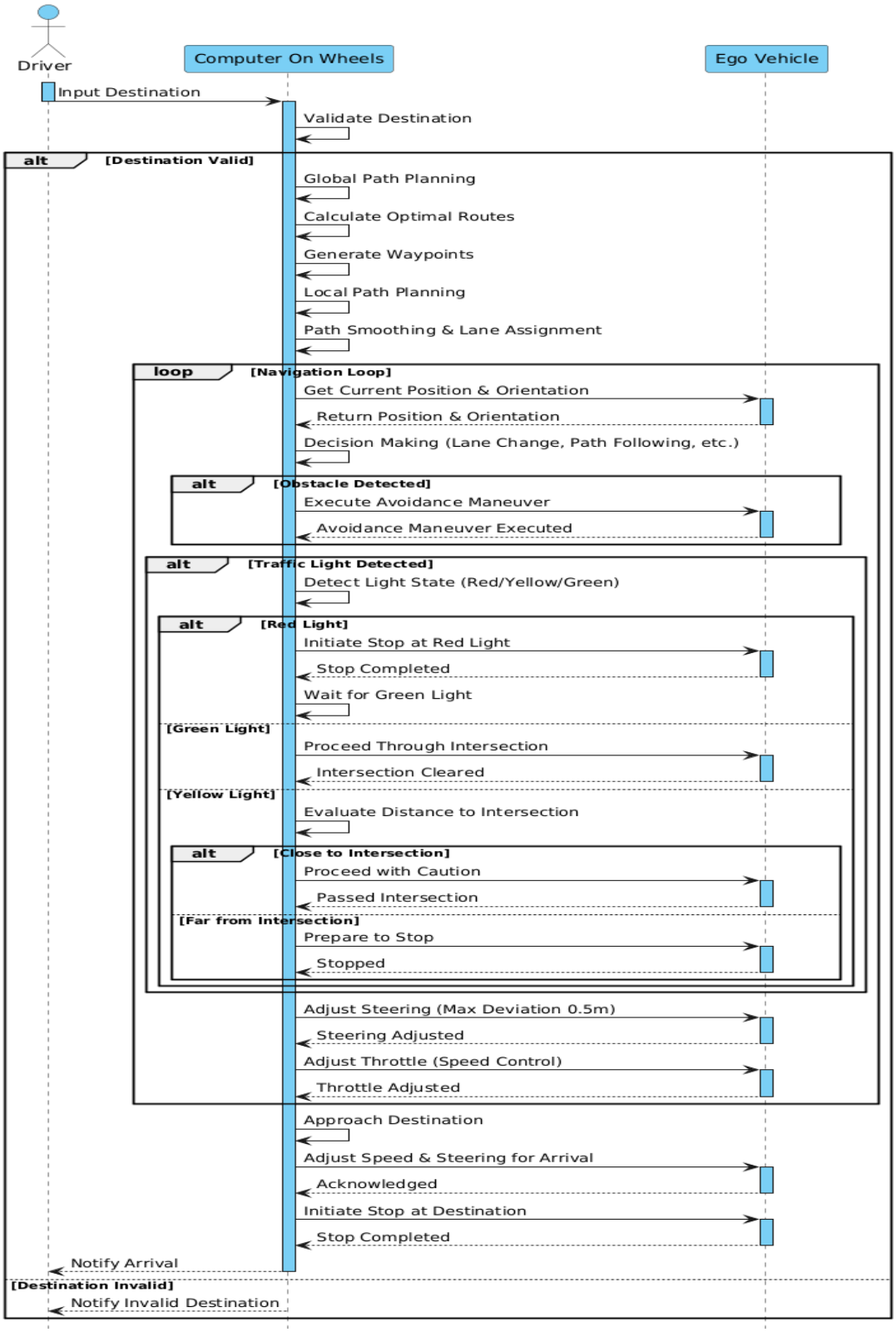

Figure 4.3: Sequence diagram

4.3.3 System State chart Diagram

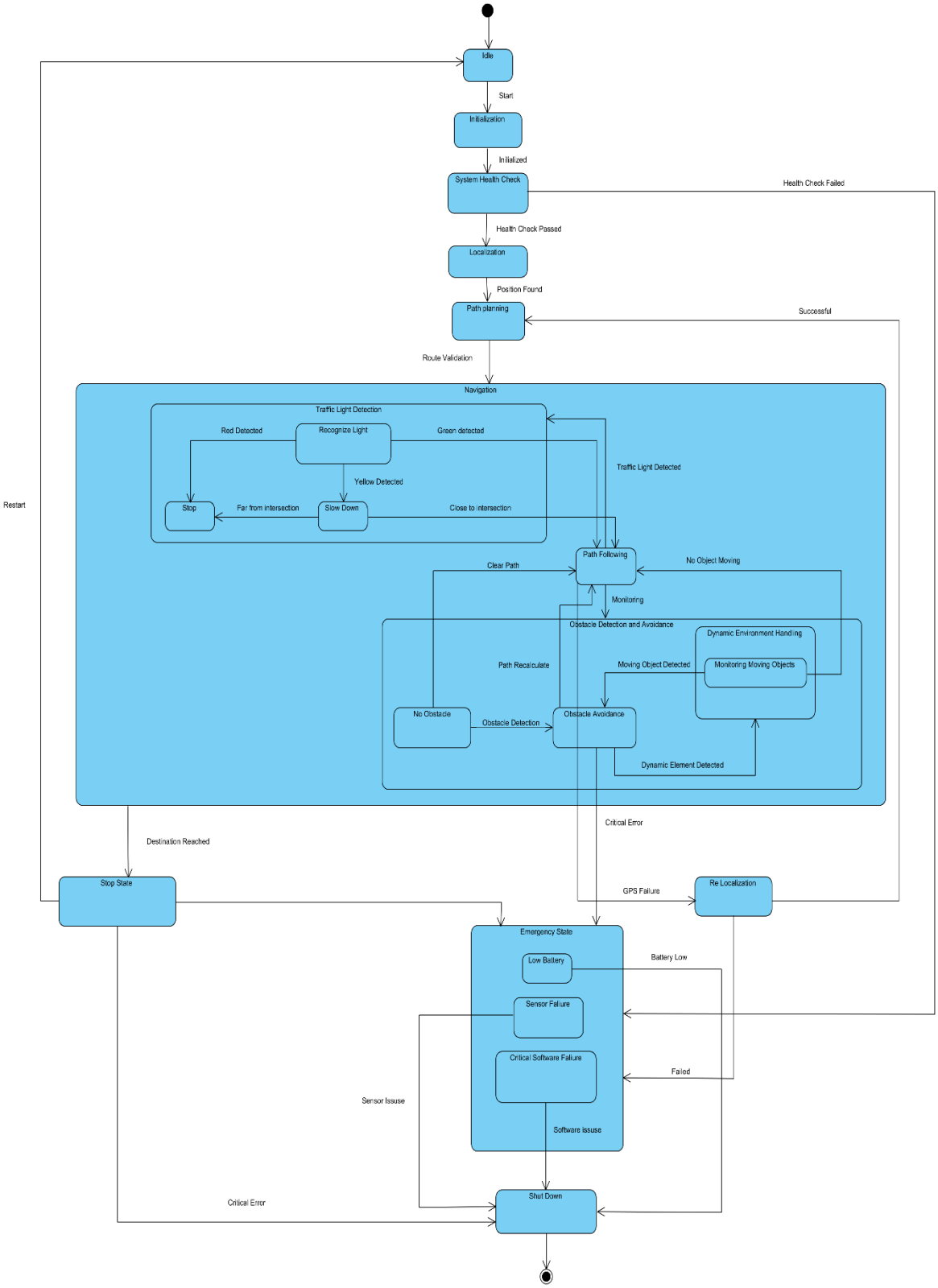

Figure 4.4: System state chart diagram

4.3.3.1 Path planning state chart diagram

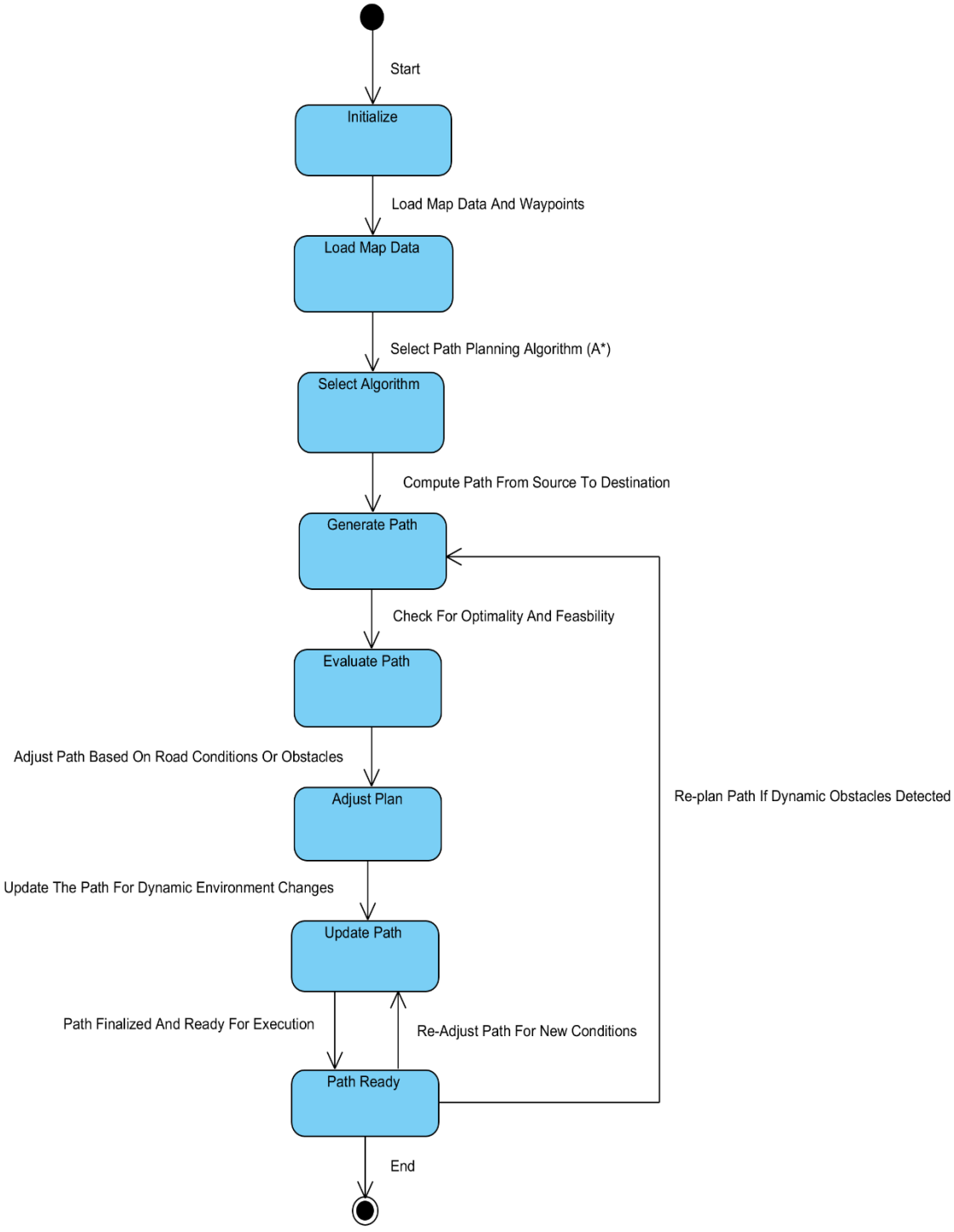

Figure 4.5: Path Planning State Chart diagram

4.3.3.2 Path following state chart diagram

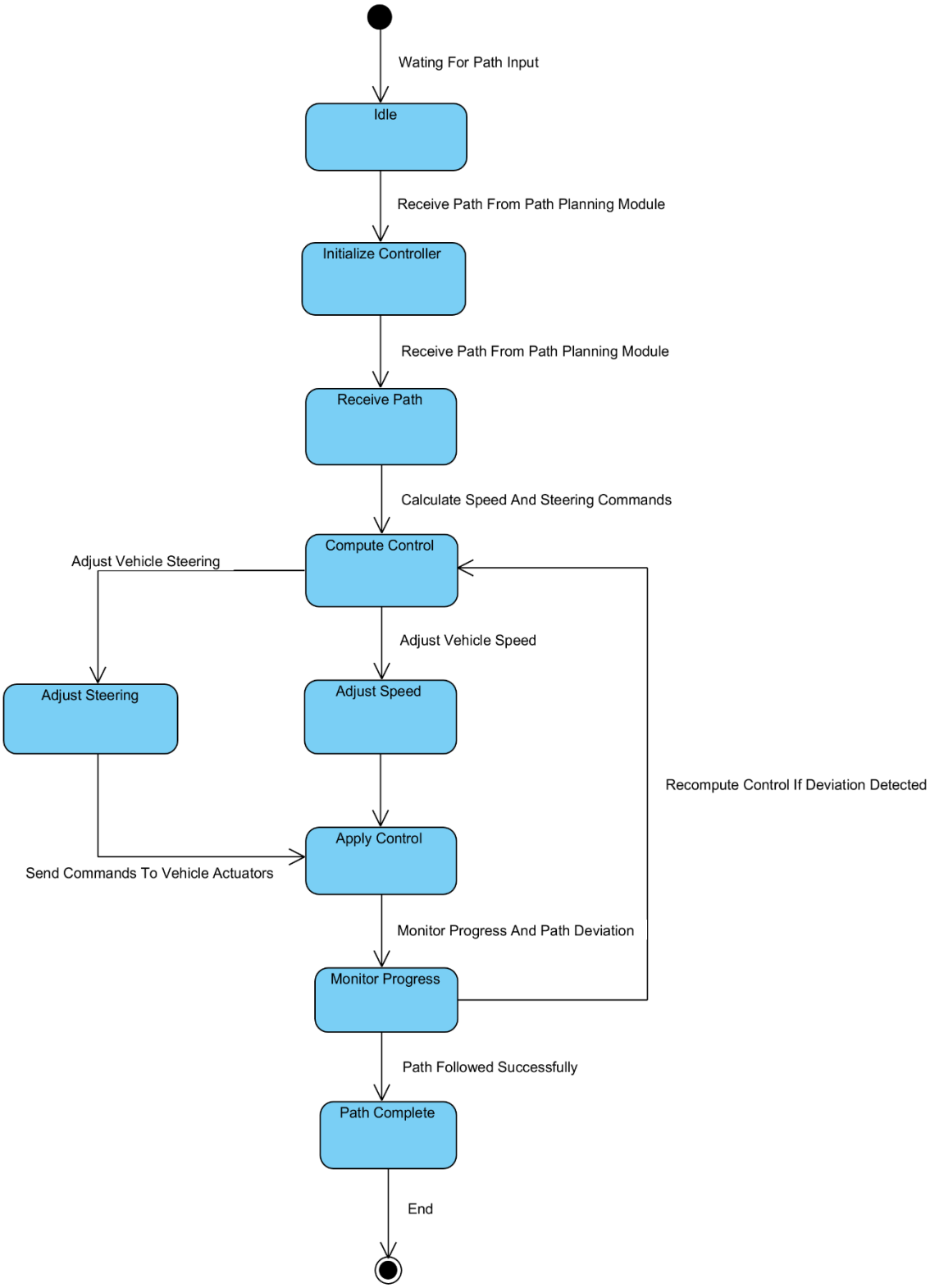

Figure 4.6: Path Following State Chart diagram

4.3.3.3 Vehicle control state chart diagram

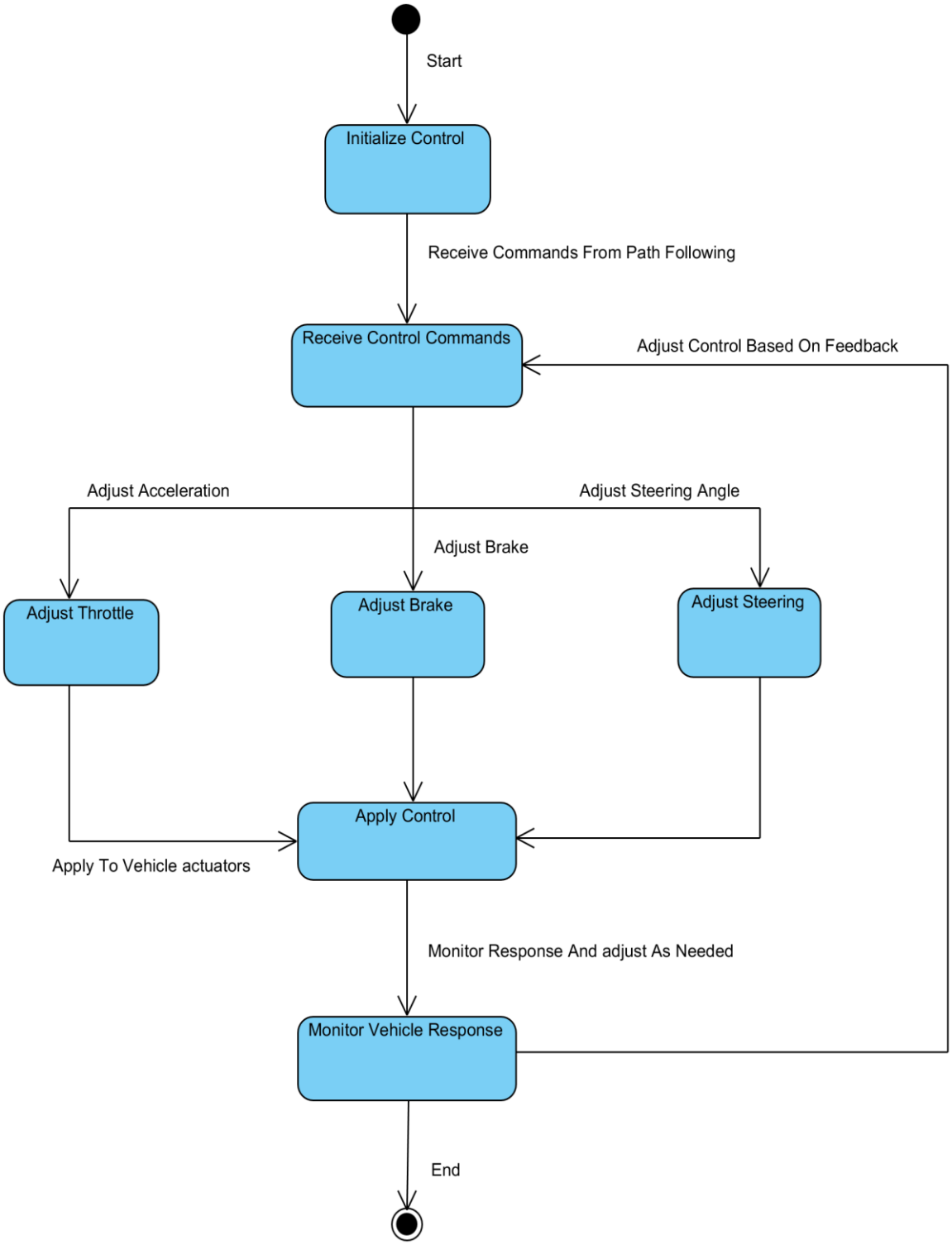

Figure 4.7: Vehicle Control State Chart diagram

4.3.3.4 Localization state chart diagram

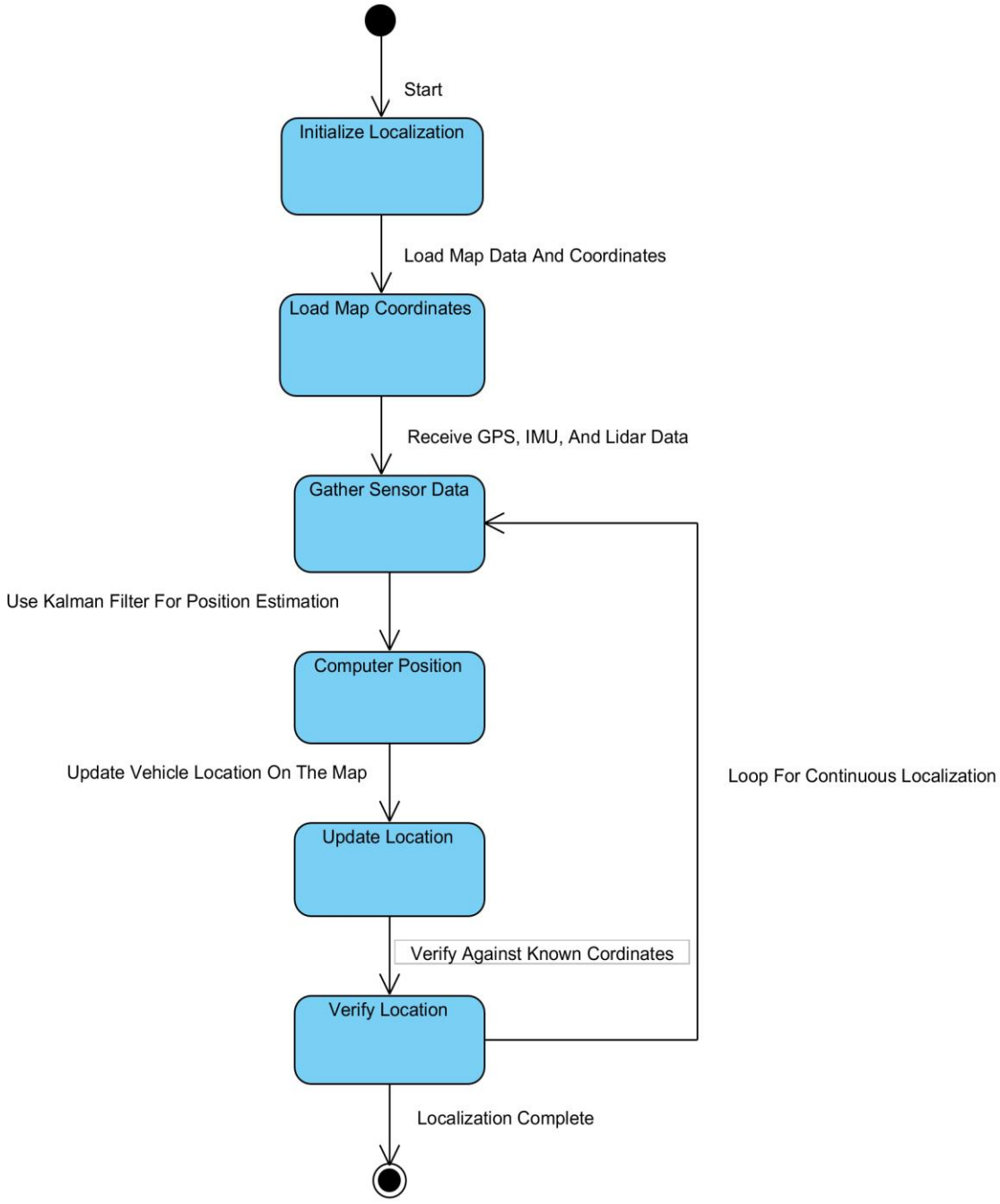

Figure 4.8: Localization State Chart diagram

4.3.3.5 Perception state chart diagram

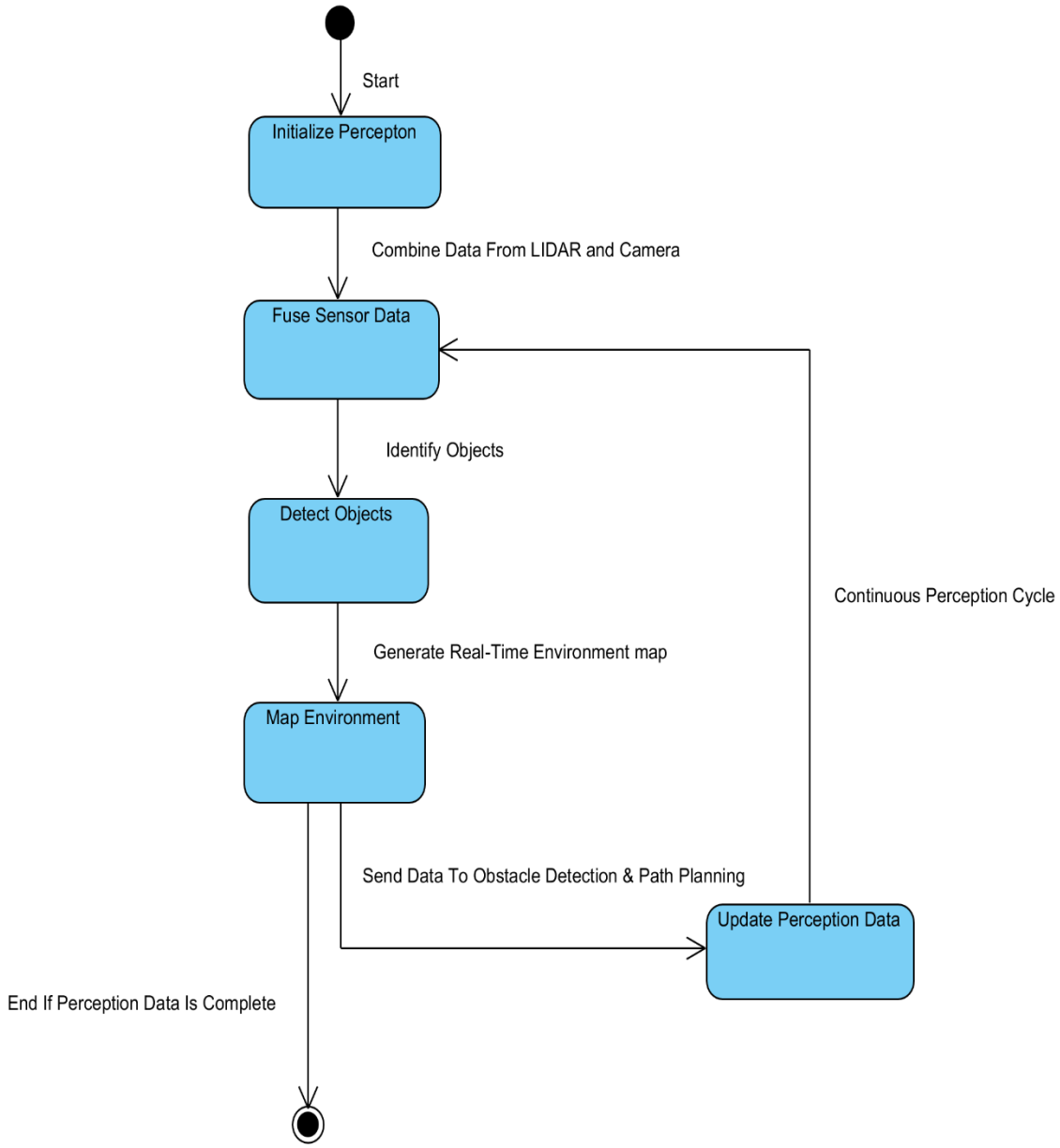

Figure 4.9: Perception State Chart diagram

4.3.3.6 Obstacle detection and avoidance state chart diagram

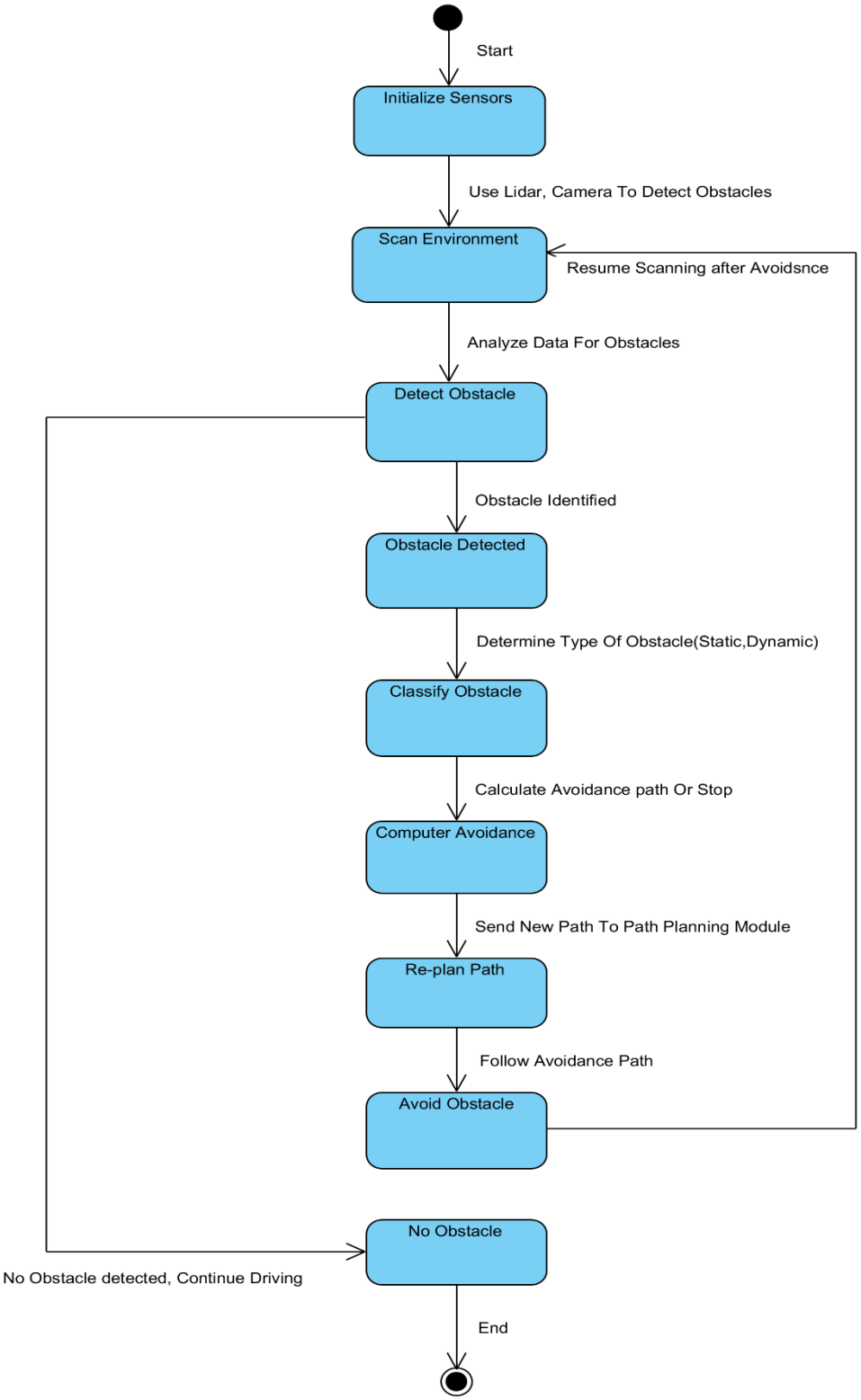

Figure 4.10: Obstacle Detection and avoidance State Chart diagram

4.3.3.7 Error handling and recovery state chart diagram

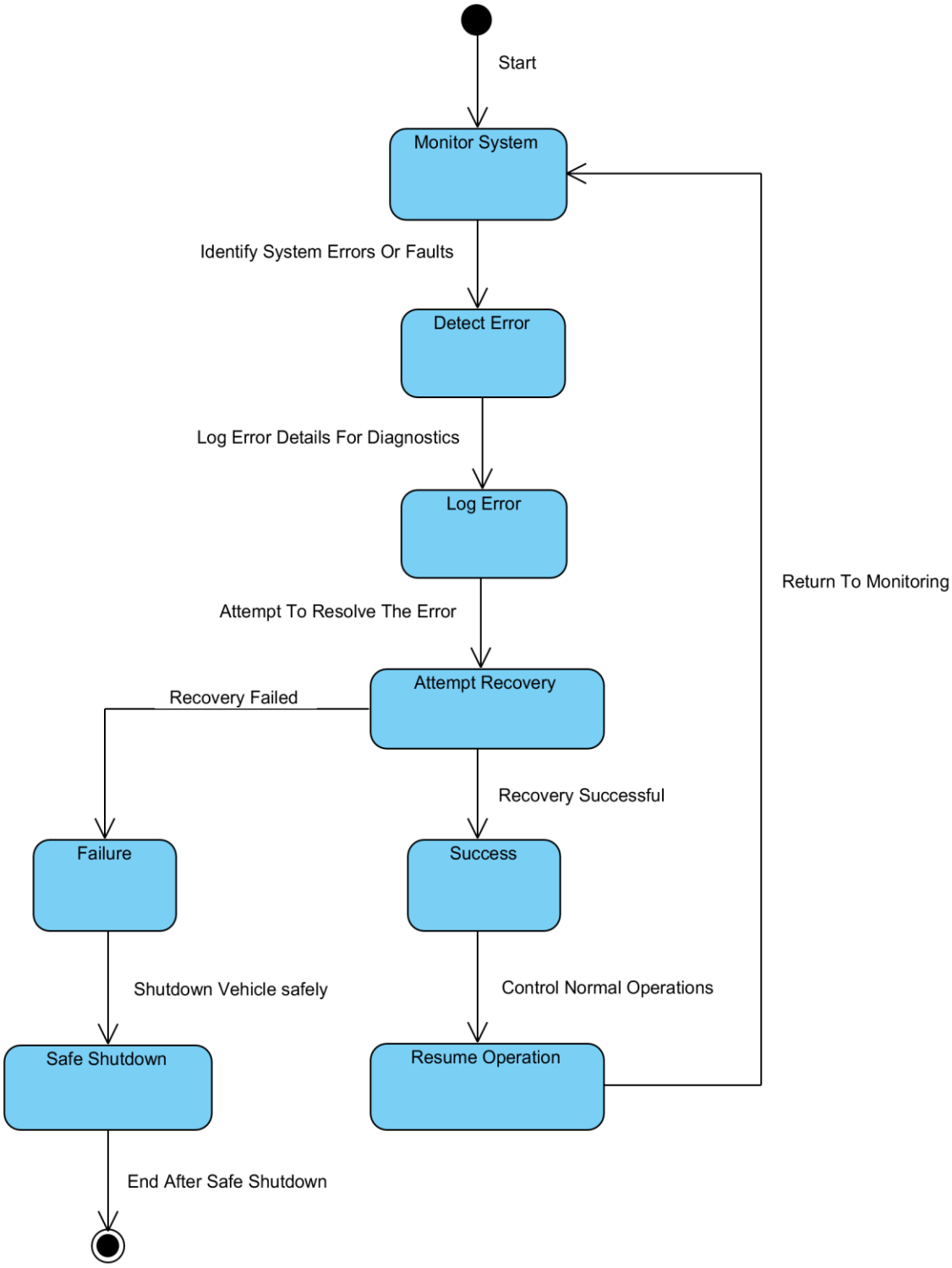

Figure 4.11: Error Handling and Recovery State Chart diagram

4.3.3.8 Traffic light detection state chart diagram

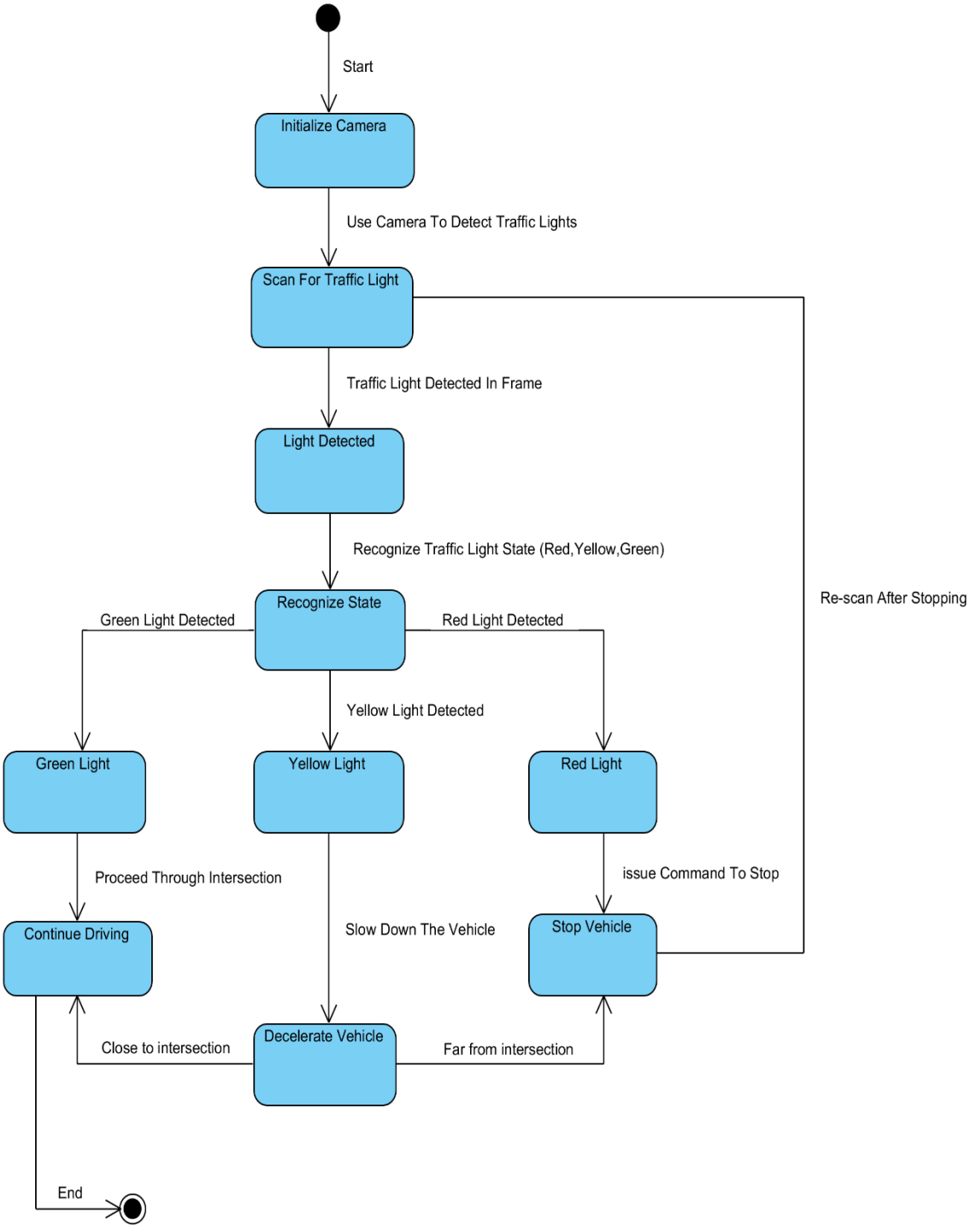

Figure 4.12: Traffic Light Detection State Chart diagram

4.3.3.9 Simulation integration state chart diagram

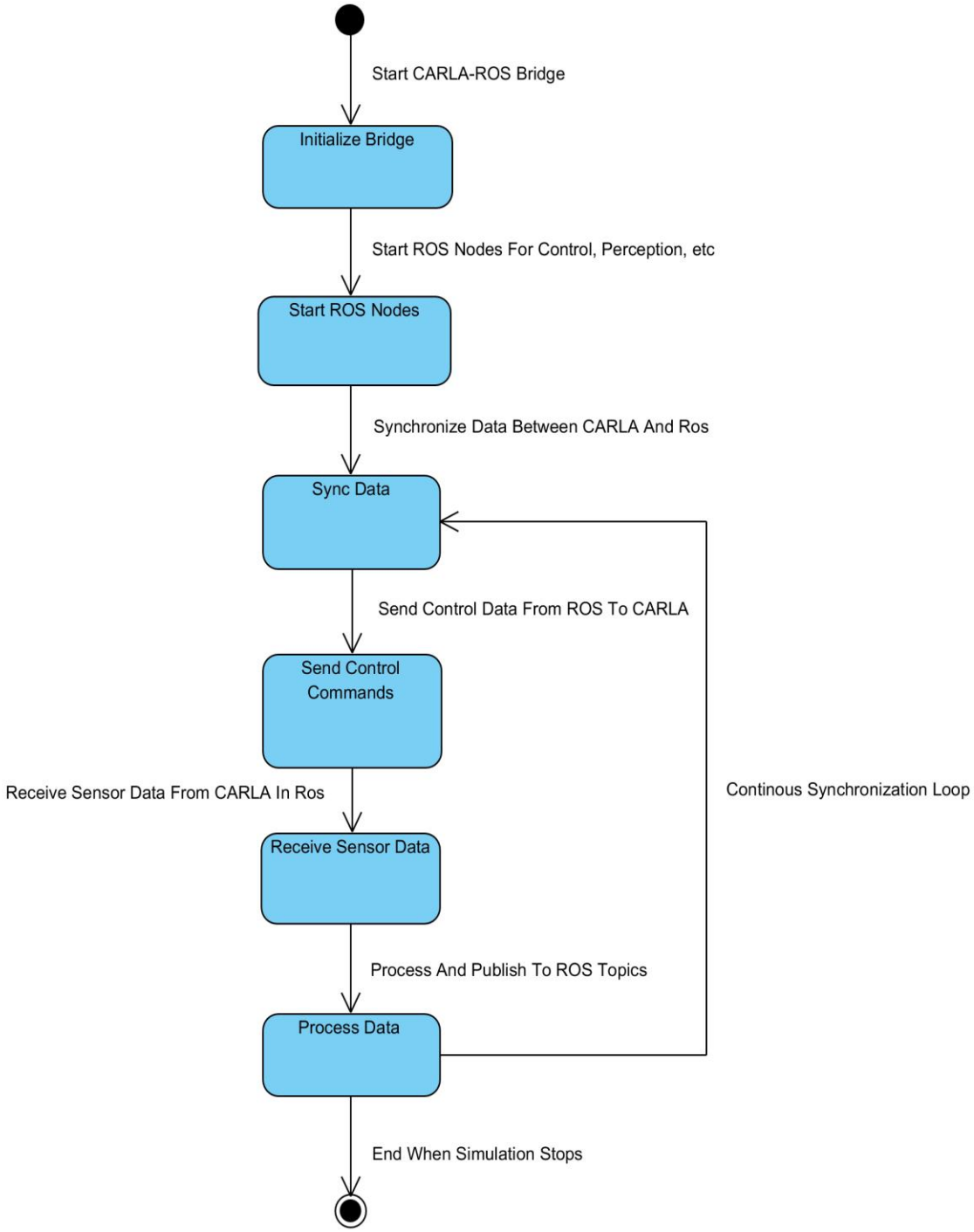

Figure 4.13: Simulation Integration State Chart diagram

4.4 SQA activity: State-Based Defect Detection Scenarios

4.4.1 Path Planning

Equivalence Class Partitioning (ECP):

- **Valid Classes**:
  - The destination is selected from the provided options.
  - The destination is entered manually and is valid (x is integer, y is integer).
- **Invalid Classes**:
  - The destination is selected but is not available (e.g., out of service area).
  - The destination coordinates are entered manually but are invalid (e.g., incorrect format, non-existent location).

Scenarios and Test Case:

Table 4.1: State-Based TC1

Scenario	Input Value	ECP	Expected Output
Out of service area coordinates	x = 80.000000 y = 170.000000	Invalid	**Error**: Vehicle tries to go to the entered Coordinates, even if they are in any building

4.4.2 Path Following

Equivalence Class Partitioning (ECP):

- **Valid Classes**:
  - The vehicle's velocity and acceleration parameters are within normal operational ranges. i.e. <120 km/h
- **Invalid Classes**:
  - The vehicle's velocity or acceleration parameters are abnormal or invalid. i.e. = 120km/h

Scenarios and Test Cases:

Table 4.2: State-Based TC2

Test Case	Input Value	ECP	Expected Output
Abnormal Velocity Parameters	Velocity = 200 km/h	Invalid	Unexpected Error
Negative Velocity Parameters	Velocity = -20 km/h	Invalid	Unexpected Error

4.4.3 Vehicle Control

Equivalence Class Partitioning (ECP):

- **Valid Classes:**
  - The vehicle's speed is within the normal operational range (i.e. 0 km/h to maximum speed limit).
  - The throttle position is within the normal operational range (i.e. 0% to 100%).
- **Invalid Classes:**
  - The vehicle's speed parameters are abnormal or invalid (i.e. speed exceeding maximum permissible limit).
  - The throttle position is abnormal or invalid (i.e. throttle position exceeding 100%).

Scenarios and Test Cases:

Table 4.3: State-Based TC3

Test Case	Input Value	ECP	Expected Output
Negative Speed	Speed = -10 km/h	Invalid	Unexpected Error
Negative Throttle Position	Throttle = -20%	Invalid	Unexpected Error

4.4.4 Vehicle Control

Equivalence Class Partitioning (ECP):

- **Valid Classes:**

  Normal Steering: Steering angle within operational range

  - -90° to 90° latitude, -180° to 180° longitude

- **Invalid Classes:**

  Abnormal Steering: Steering angle outside operational range (< -30° or > +30°)

Scenarios and Test Cases:

Table 4.4: State-Based TC4

Test Case	Input Value	ECP	Expected Output
Abnormal Orientation	Roll = -220° Pitch = of 120°	Invalid	Unexpected Error
Abnormal Steering Angle	Range = -45°, 40°	Invalid	Unexpected Error

4.4.5 Vehicle Control

Equivalence Class Partitioning (ECP):

- **Valid Classes:**

  - Speed: 0 km/h ≤ Speed ≤ 120 km/h
  - Distance: 2 meters ≤ Distance ≤100 meters
  - Throttle Adjustment: 0 % ≤ Throttle ≤ 80 %
  - Brake Application: 0 % ≤ Braking Force ≤ 100 %

- **Invalid Classes:**

  - Speed: > 120 km/h
  - Distance: Distance >100 meters
  - Throttle Adjustment: < 0 % or Throttle > 80 %

- Brake Application: < 0 % or Braking Force > 100 %

Scenarios and Test Cases:

Table 4.5: State-Based TC5

Test Case	Input Value	ECP	Expected Output
Abnormal Steering Angle	Range = -45°, 40°	Invalid	Unexpected Error
Unsafe distance	Distance = 0	Invalid	Unexpected Error
Braking force	Force = 152%	Invalid	Unexpected Error
Abnormal Speed	Speed = -15.2	Invalid	Unexpected Error

4.4.6 Vehicle Control

Equivalence Class Partitioning (ECP):

- **Valid Classes:**
  - Lateral Position: -1.0 meters ≤ Lateral Position ≤ 1.0 meters
  - Steering Adjustment: -30° ≤ Steering Angle ≤30°
- **Invalid Classes:**
  - Lateral Position: Lateral Position > 1.0 meters
  - Steering Adjustment: Steering Angle > 30°

Scenarios and Test Cases:

Table 4.6: State-Based TC6

Test Case	Input Value	ECP	Expected Output

Abnormal Lateral Position	Lateral Position = -2.0 meters	Invalid	Unexpected Error
Excessive Steering Adjustment	Angle = -45.23°	Invalid	Unexpected Error

4.4.7 Localization Module Test Cases

Equivalence Class Partitioning (ECP):

- **Valid Classes:**
  - Sensor data (GPS, IMU, LIDAR) within acceptable ranges.
  - GPS accuracy ≤ 5 meters.
  - IMU data drift ≤ 2 degrees.
  - LIDAR scan range ≥ 50 meters.
- **Invalid Classes:**
  - Sensor data outside acceptable ranges.
  - GPS accuracy > 5 meters.
  - IMU data drift > 2 degrees.
  - LIDAR scan range < 50 meters.

Scenarios and Test Cases:

Table 4.7: State-Based TC7

Scenario	Input Value	ECP	Expected Output
GPS Signal Loss	GPS Accuracy = 15 meters	Invalid	Transition to Error State: "Localization

			Error"
GPS Signal Loss	GPS Status = No signal	Invalid	Unexpected Error
IMU Drift	IMU Drift = 1.5 degrees	Valid	Transition to Update Location
LIDAR Scan Range Too Short	LIDAR Range = 30 meters	Invalid	Transition to Error State: "LIDAR Range Error"
Accurate Localization	GPS Accuracy = 3 meters IMU Drift = 1 degree	Valid	Transition to VerifyLocation

4.4.8 Obstacle Detection and Avoidance Module Test Cases

Equivalence Class Partitioning (ECP):

- **Valid Classes:**
  - Obstacle detected within sensor range.
  - LIDAR detection distance ≤ 100 meters.
  - Obstacle size ≥ 0.5 meters.
  - Obstacle-free zone.
  - No objects detected within 100 meters.
- **Invalid Classes:**
  - Sensor fails to detect within expected range.
  - LIDAR detection distance > 100 meters for a detected obstacle.
  - Obstacle size < 0.5 meters considered noise.

Scenarios and Test Cases:

Table 4.8: State-Based TC8

Scenario	Input Value	ECP	Expected Output
No Obstacle Detected	LIDAR Detection	Invalid	Transition to No

	Distance = 150 meters		Obstacle state
LIDAR Sensor Failure	LIDAR Status = No data received	Invalid	Unexpected Error
Valid Obstacle Detected	LIDAR Detection Distance = 50 meters	Valid	Transition to Classify Obstacle
Dynamic Obstacle Within Range	LIDAR Detection Distance = 80 meters	Valid	Transition to Compute Avoidance

4.4.9 Traffic Light Detection Module Test Cases

Equivalence Class Partitioning (ECP):

- **Valid Classes:**
  - Traffic light detected and state correctly identified.
  - Distance to traffic light ≤ 50 meters.
  - Recognition confidence ≥ 80%.
- **Invalid Classes:**
  - Traffic light detection errors or low recognition confidence.
  - Distance to traffic light > 50 meters.
  - Recognition confidence < 80%.

Scenarios and Test Cases:

Table 4.9: State-Based TC9

Scenario	Input Value	ECP	Expected Output
Traffic Light Not Detected	Detection Distance = 60 meters	Invalid	Continue scanning in ScanForTrafficLight state

Traffic Light Detected, High Confidence	Recognition Confidence = 90%	Valid	Transition to Recognize State
Camera Failure	Camera Status = No data received	Invalid	Unexpected Error
Low Confidence in Recognition	Recognition Confidence = 70%	Invalid	Re-scan for traffic light state
Traffic Light at Threshold	Detection Distance = 50 meters	Valid	Proceed with state recognition (Red/Yellow/Green)