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 is founded upon the architecture and framework of ROS 1, with outcomes visualized through the Carla Simulator. Facilitating seamless communication between Carla and ROS Noetic, we employ the ROS bridge as our interface for data retrieval and command transmission. Functioning as a crucial intermediary, the ROS bridge facilitates integration between ROS programs and non-ROS environments.

4.2 Architectural Design

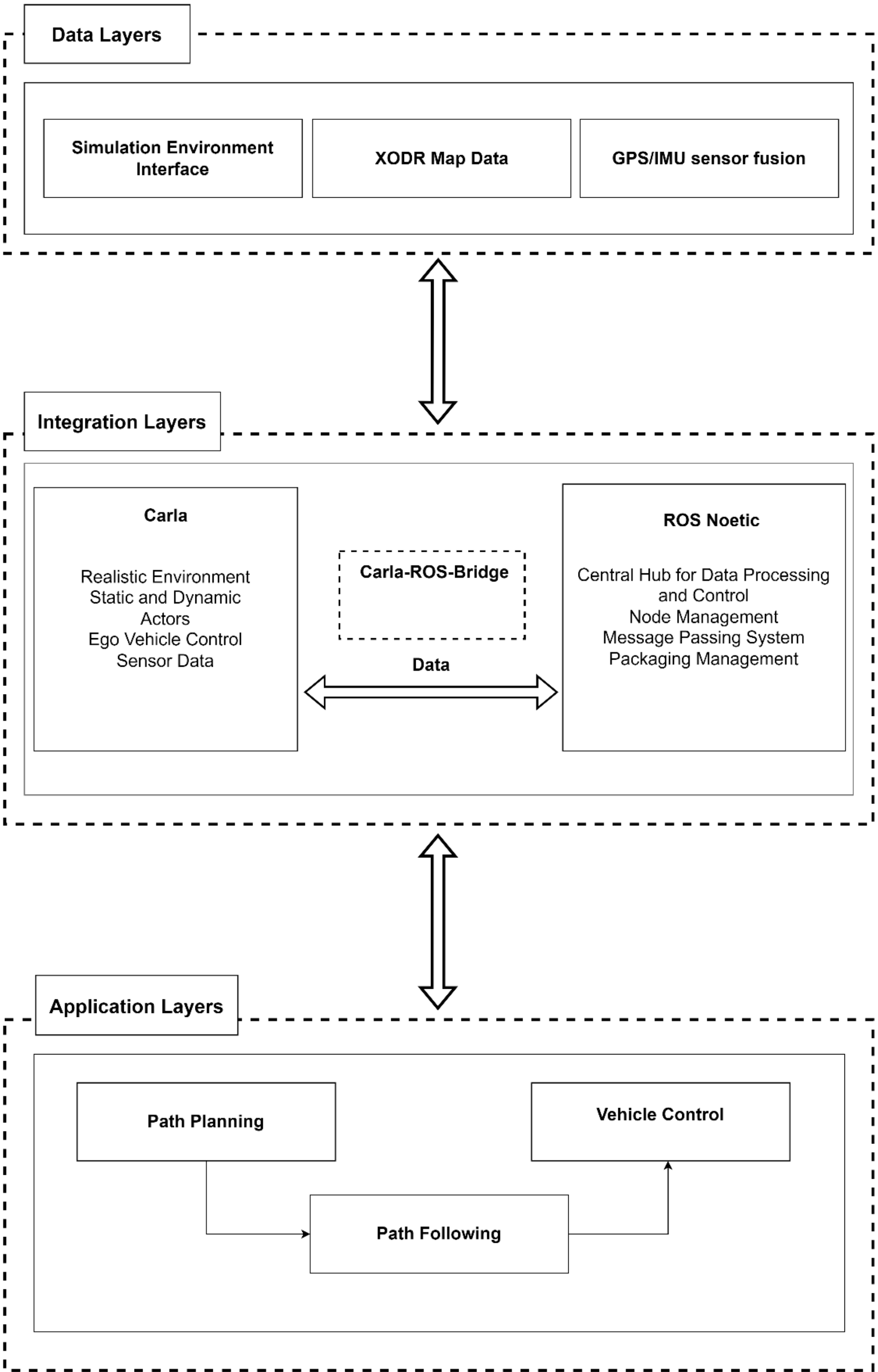

Figure 4.1 - Architecture Diagram.

4.3 Detailed Design

4.3.1 Use Case Design

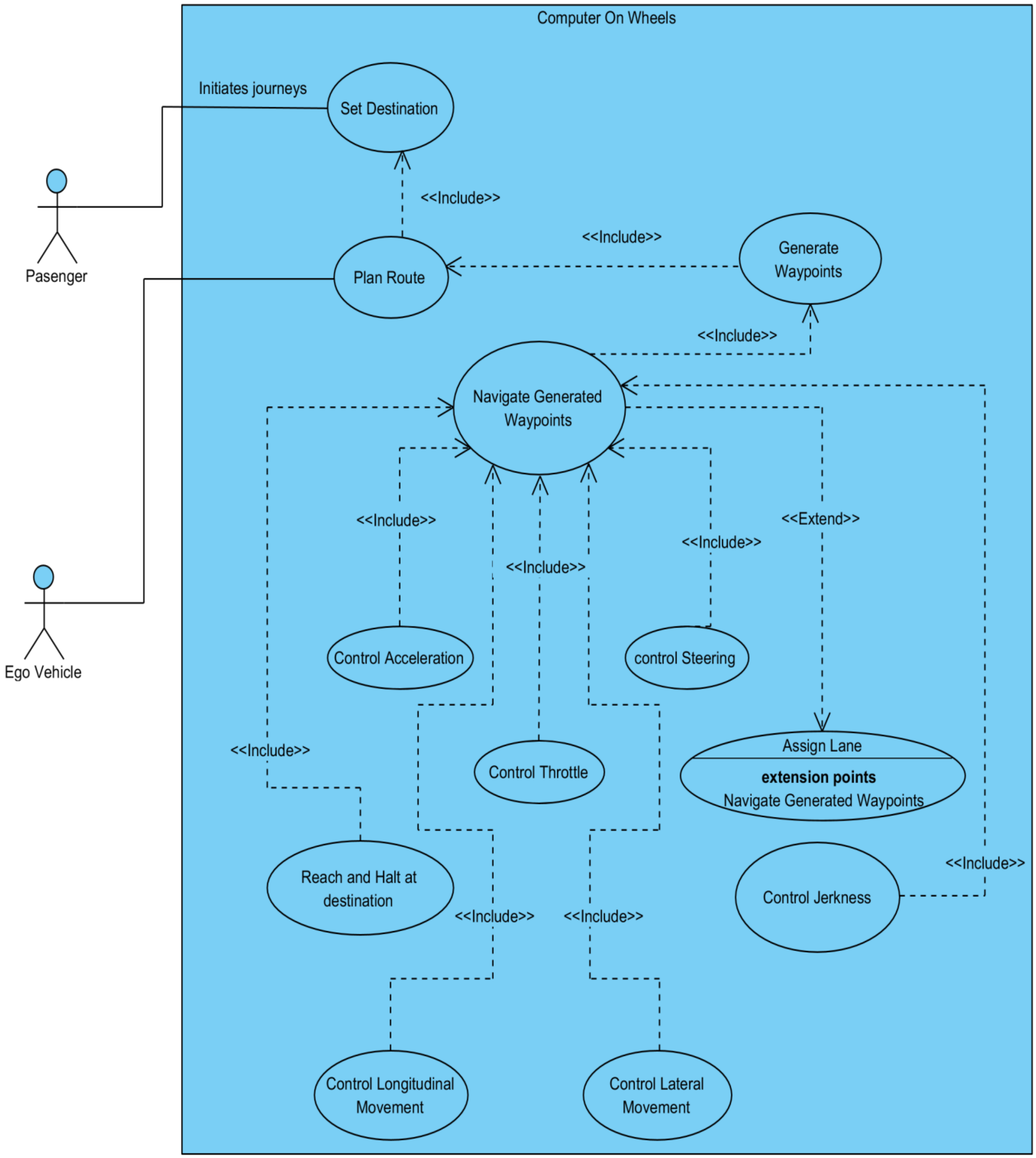

Figure 4.2 - Use-case Diagram.

4.3.2 Detailed Use Cases

4.3.2.1 Set Destination

Use Case ID:	UC01
Use Case:	Set Destination
Actor:	Passenger
Precondition:	The Car is integrated with the system
Basic Flow:	1. Passenger launches the autonomous vehicle system. 2. Passenger selects a destination from the provided options. 3. System validates the selected destination. 4. System confirms the set destination to the passenger.
Alternative Flow:	2a. If passenger does not want to select destination from the provided options, passenger can enter the coordinates of his/her choice. 4a. If the selected destination is not available or invalid, the system prompts the passenger to select another destination from the provided options or input a custom one.
Post Condition:	The destination is successfully set in the system.

Table 4.1 - Detailed: Use-case Set Destination

4.3.2.2 Plan Route

Use Case ID:	UC02
Use Case:	Plan Route
Actor:	Ego Vehicle
Precondition:	The destination is set.
Basic Flow:	1. System receives the set destination from the passenger. 2. System retrieves the current location of the vehicle. 3. System calculates the shortest path from the current location to the destination using path planning algorithms.
Alternative Flow:	None
Post Condition:	The system successfully calculates a shortest path from the current location to the destination for the vehicle to follow.

Table 4.2 - Detailed: Use-case Plan Route

4.3.2.3 Generate Waypoints

Use Case ID:	UC03
Use Case:	Generate Waypoints
Actor:	Ego Vehicle
Precondition:	The route is planned.
Basic Flow:	1. System receives the planned route. 2. System divides the planned route into discrete waypoints 3. System assigns coordinates to each generated waypoint to define the navigation path.
Alternative Flow:	None
Post Condition:	Waypoints are successfully generated along the planned route for navigation.

Table 4.3 - Detailed Use-case: Generate Waypoints

4.3.2.4 Navigate Generated Waypoints

Use Case ID:	UC04
Use Case:	Navigate Generated Waypoints
Actor:	Ego Vehicle
Precondition:	Waypoints are generated
Basic Flow:	1. System retrieves the planned route and waypoints. 2. System allows the vehicle to follows the planned path by steering and accelerating as necessary to reach each waypoint. 3. System continuously monitors the vehicle's position and adjusts the guidance commands to keep the vehicle on the planned path. 4. The vehicle progresses along the planned path until it reaches the final destination.
Alternative Flow:	3a. If an obstacle is detected, it will avoid the obstacle using avoidance algorithm and update the guidance commands, vehicle resumes motion along the alternative route.
Post Condition:	The autonomous vehicle successfully follows the planned path, reaching the destination while ensuring safety and efficiency

Table 4.4 - Detailed Use-case: Navigate Generated Waypoints

4.3.2.5 Control Acceleration

Use Case ID:	UC05
Use Case:	Control Acceleration
Actor:	Ego Vehicle
Precondition:	The vehicle is operational and in motion.
Basic Flow:	1. System monitors the vehicle's velocity or acceleration parameters. 2. A change in acceleration is required, the system computes the necessary adjustments based on navigation requirements, traffic conditions, and vehicle dynamics. 3. System sends commands to adjust the vehicle's acceleration accordingly, using throttle control mechanisms.
Alternative Flow:	3a. If an unexpected obstacle is detected requiring sudden deceleration, the system overrides the acceleration command and initiates avoidance maneuver.
Post Condition:	The vehicle's acceleration is controlled as per navigation and operational requirements.

Table 4.5 – Detailed Use-case: Control Acceleration

4.3.2.6 Control Throttle

Use Case ID:	UC06
Use Case:	Control Throttle
Actor:	Ego Vehicle
Precondition:	The vehicle is operational and in motion.
Basic Flow:	1. System monitors the vehicle's speed and throttle position. 2. A change in throttle position is required, the system computes the necessary adjustments based on navigation requirements, traffic conditions, and vehicle dynamics. 3. System adjusts the throttle position accordingly, regulating the engine's power output.
Alternative Flow:	None
Post Condition:	The vehicle's throttle position is controlled as per navigation and operational requirements.

Table 4.6 - Detailed Use-case: Control Throttle

4.3.2.7 Control Steering

Use Case ID:	UC07
Use Case:	Control Steering
Actor:	Ego Vehicle
Precondition:	The vehicle is operational and in motion.
Basic Flow:	1. System continuously monitors the vehicle's position, orientation, and intended path. 2. Based on navigation instructions and environmental factors, the system computes the required steering angle adjustments. 3. System adjusts the steering angle accordingly.
Alternative Flow:	None
Post Condition:	The vehicle's steering angle is controlled as per navigation and operational requirements.

Table 4.7 - Detailed Use-case: Control Steering

4.3.2.8 Assign Lane

Use Case ID:	UC08
Use Case:	Assign Lane
Actor:	Ego Vehicle
Precondition:	The autonomous vehicle is driving on a multi-lane road.
Basic Flow:	1. System identifies the need for a lane change 2. System evaluates the surrounding conditions 3. System determines the optimal timing and trajectory for the lane change to minimize disruption to traffic flow. 4. System executes the lane change maneuver by steering the vehicle smoothly into the target lane while maintaining safe distance from other vehicles.
Alternative Flow:	2a. If the system detects an obstruction or unsafe condition in the target lane during the lane change maneuver: • System aborts the lane change maneuver. • System re-evaluates the surrounding traffic conditions. • System selects an alternative lane change strategy
Post Condition:	The autonomous vehicle successfully changes lanes while ensuring safety and minimizing disruption to traffic flow.

Table 4.8 - Detailed Use-case: Assign Lane

4.3.2.9 Control Longitudinal Movement

Use Case ID:	UC09
Use Case:	Control Longitudinal Movement
Actor:	Ego Vehicle
Precondition	Vehicle is in motion
Basic Flow	1. System monitors the vehicle's speed. 2. System monitors the distance to vehicles and objects ahead. 3. System adjusts throttle to maintain desired speed. 4. System applies brakes to maintain safe following distance. 5. System continuously monitors and adjusts as needed.
Alternative Flow	None
Post Condition	Vehicle maintains desired speed and safe distance from other objects.

Table 4.9 - Detailed Use-case: Control Longitudinal Movement

4.3.2.10 Control Lateral Movement

Use Case ID:	UC10
Use Case:	Control Lateral Movement
Actor:	Ego Vehicle
Precondition	Vehicle is in motion; path or lane is defined.
Basic Flow	1. System monitors the vehicle's lateral position. 2. System detects deviations from the intended lane. 3. System adjusts steering to maintain lane position. 4. System continuously monitors and adjusts as needed.
Alternative Flow	2. If an obstacle detected while deviating or changing lane position: 2.1. System performs avoidance maneuver. 2.2. System re-evaluates the lane and path. 2.3. System resumes lateral control once clear.
Post Condition	Vehicle maintains correct lateral position within its lane.

Table 4.10 - Detailed Use-case: Control Lateral Movement

4.3.2.11 Control jerkiness

Use Case ID:	UC11
Use Case:	Control jerkiness
Actor:	Ego Vehicle
Precondition	Vehicle is in motion; speed and path are defined.
Basic Flow	1. System monitors the vehicle's acceleration and deceleration patterns. 2. System smooths throttle and braking inputs to minimize jerky movements. 3. System adjusts steering inputs to provide smooth directional changes. 4. System continuously monitors and adjusts to maintain a smooth ride.
Alternative Flow	None
Post Condition	Vehicle maintains a smooth ride with minimal jerkiness during acceleration, deceleration, and directional changes.

Table 4.11 - Detailed Use-case: Control Jerkiness

4.3.2.12 Reach and Halt at Destination

Use Case ID:	UC12
Use Case:	Reach and Halt at Destination
Actor:	Ego Vehicle
Precondition	Vehicle is near the destination; final approach path is defined.
Basic Flow	1. System identifies the final approach path. 2. System gradually decelerates the vehicle. 3. System maneuvers the vehicle to align with the designated stopping point. 4. System brings the vehicle to a complete stop at the destination.
Alternative Flow	1. If the designated stopping point is obstructed: 1.1. System identifies near stopping point. 1.2. System re-evaluates the approach path. 1.3. System brings the vehicle to a complete stop at the new location.
Post Condition	Vehicle has stopped at the destination.

Table 4.12 - Detailed Use-case: Reach and Halt at Destination

4.3.3 Activity Diagrams

4.3.3.1 Set Destination:

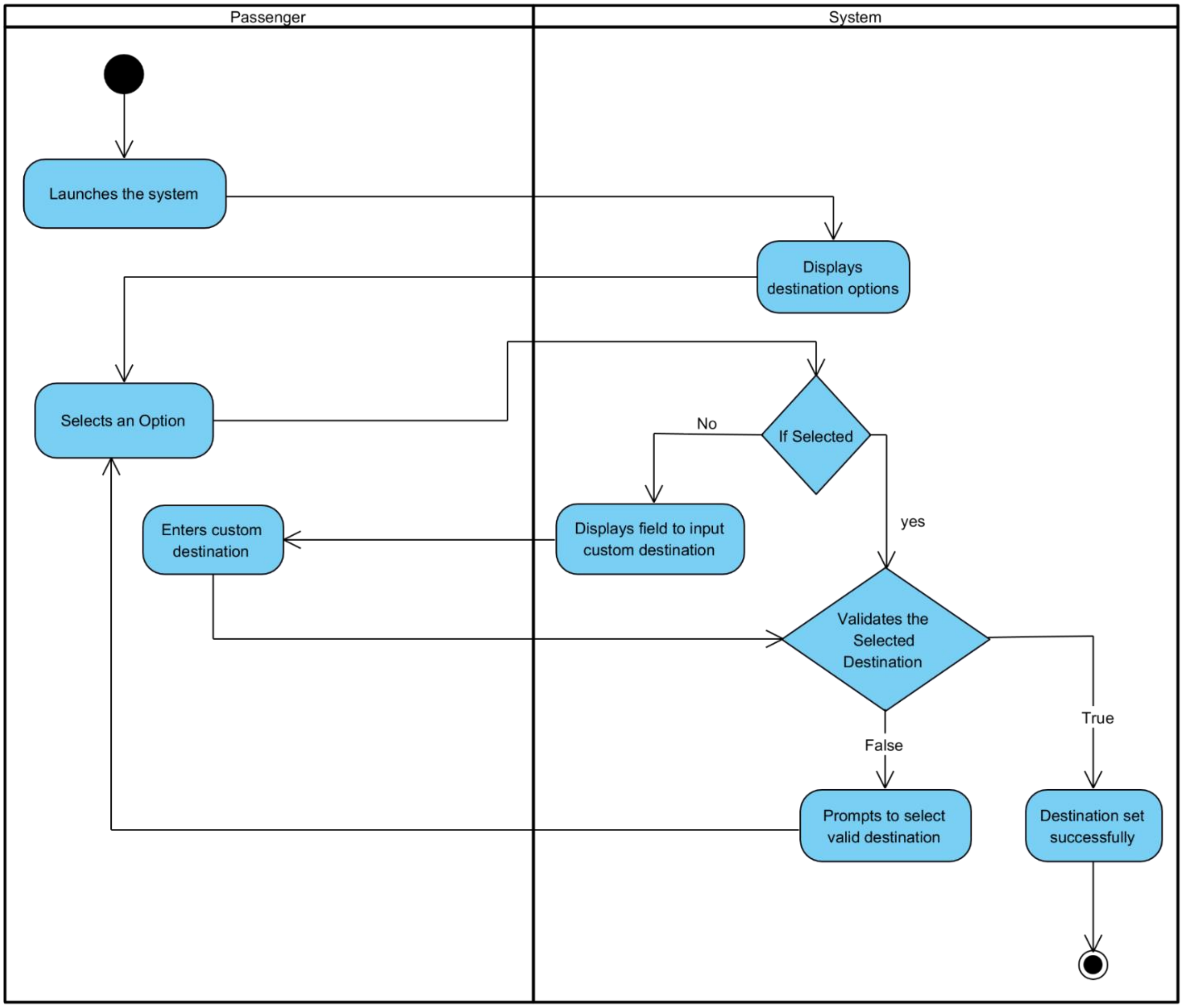

Fig 4.3.3.1 – Set Destination

4.3.3.2 Plan Route:

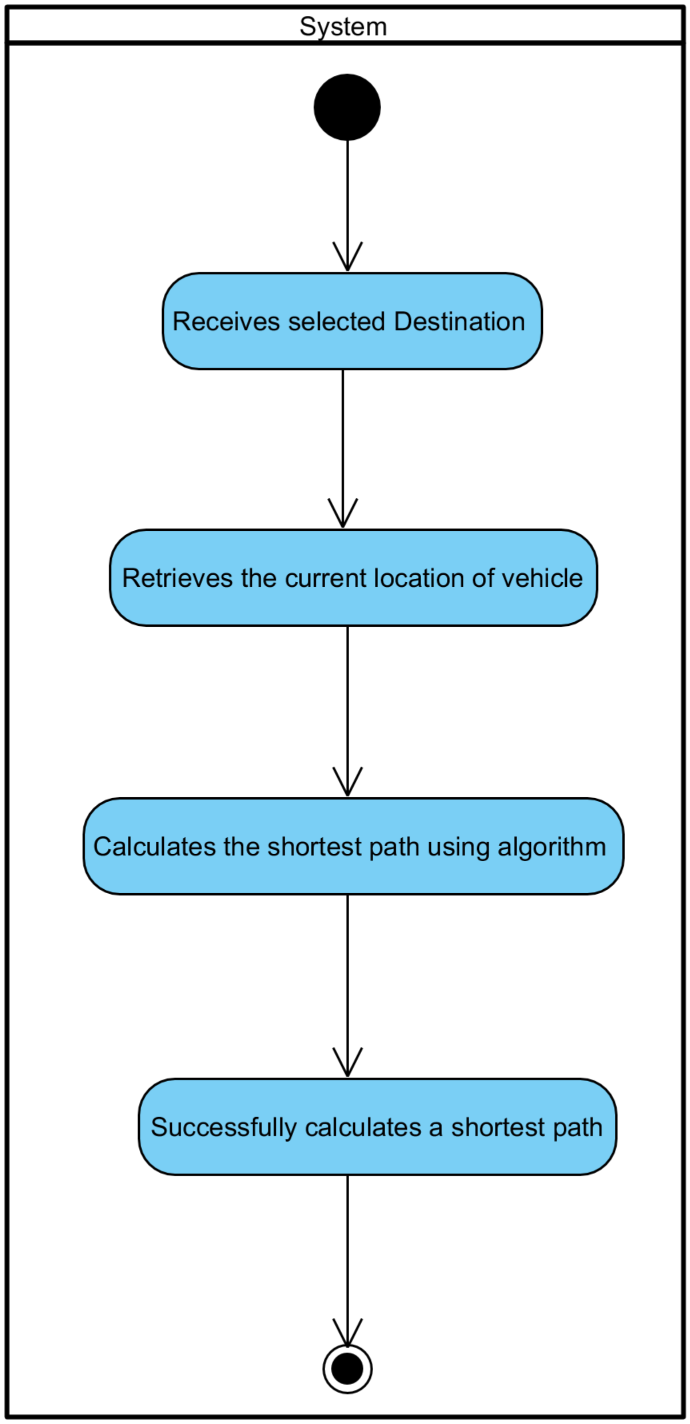

Fig 4.3.3.2 – Plan Route

4.3.3.3 Generate Waypoints:

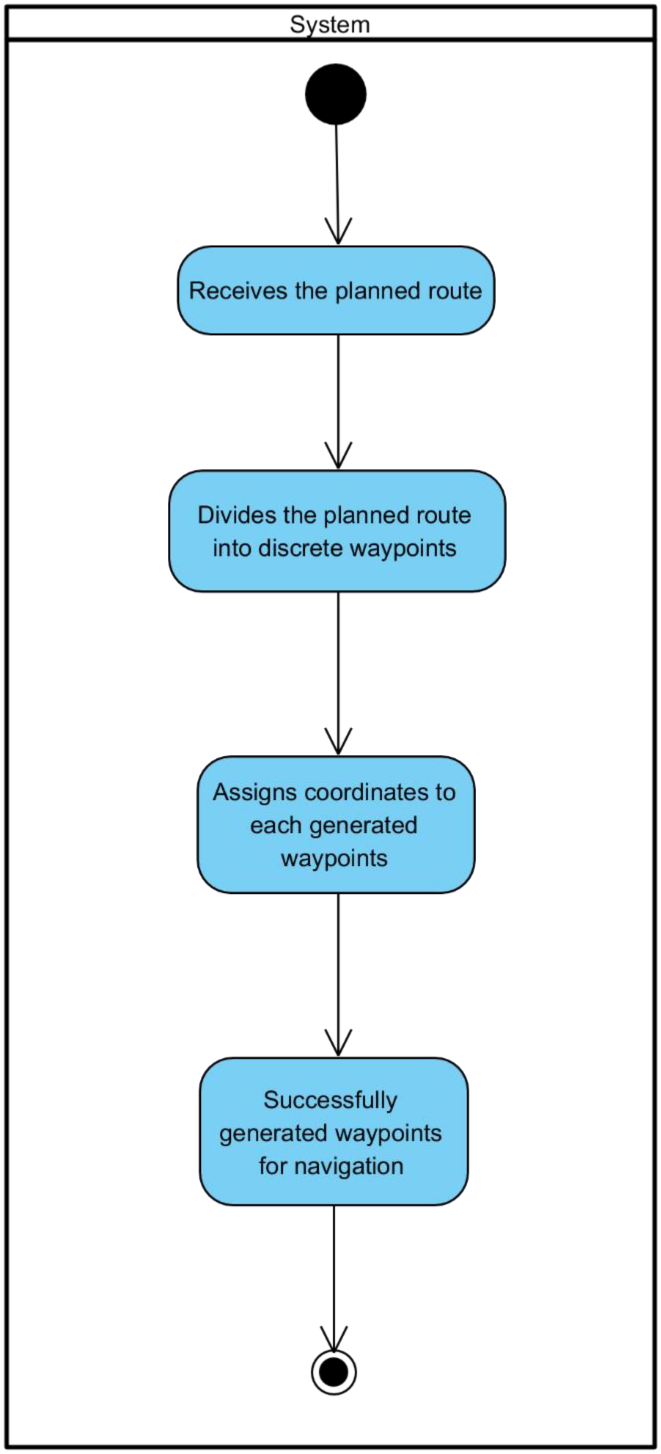

Fig 4.3.3.3 – Generate Waypoints

4.3.3.4 Navigate Generated Waypoints:

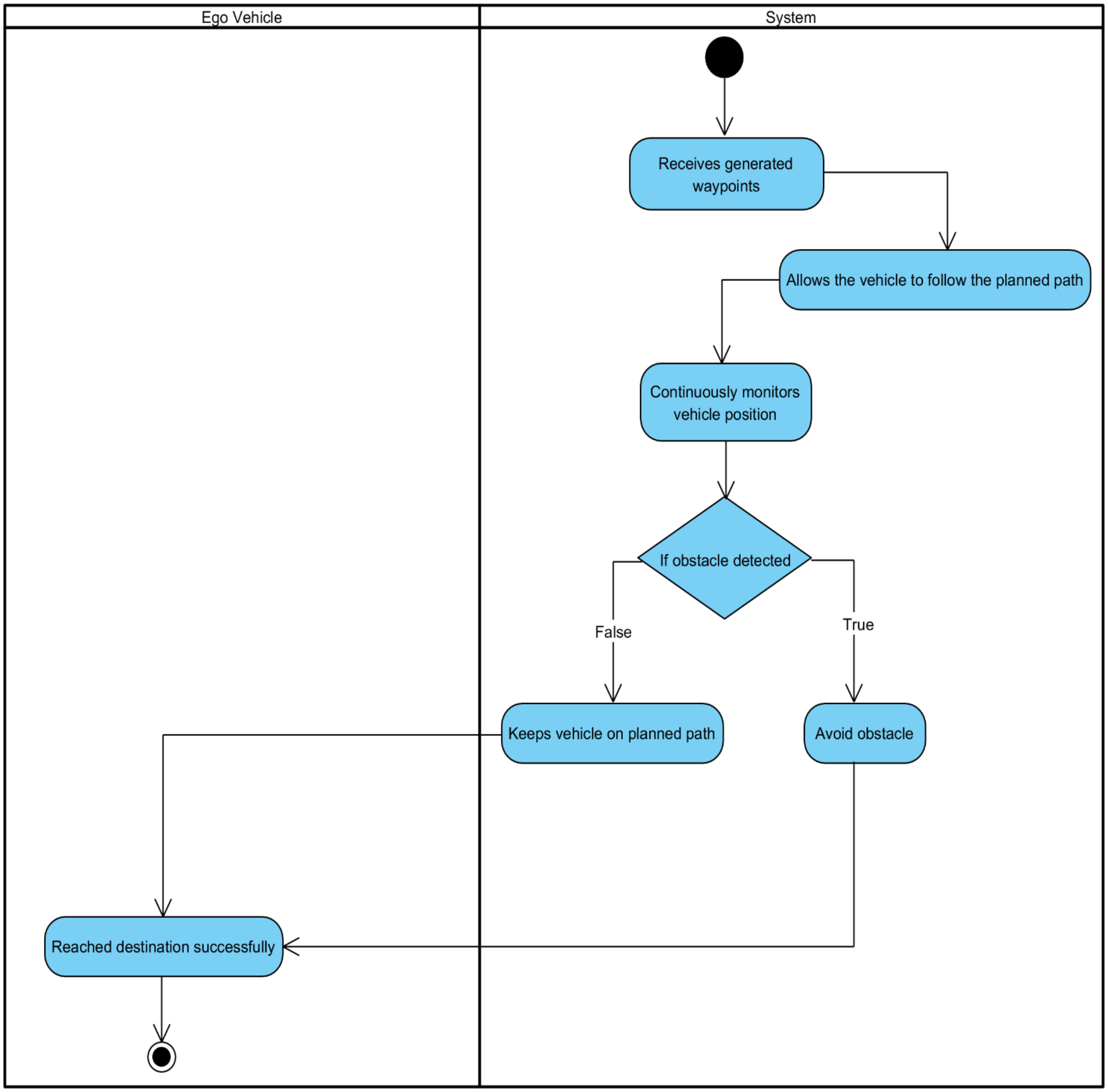

Fig 4.3.3.4 – Navigate Generated Waypoints

4.3.3.5 Control Acceleration:

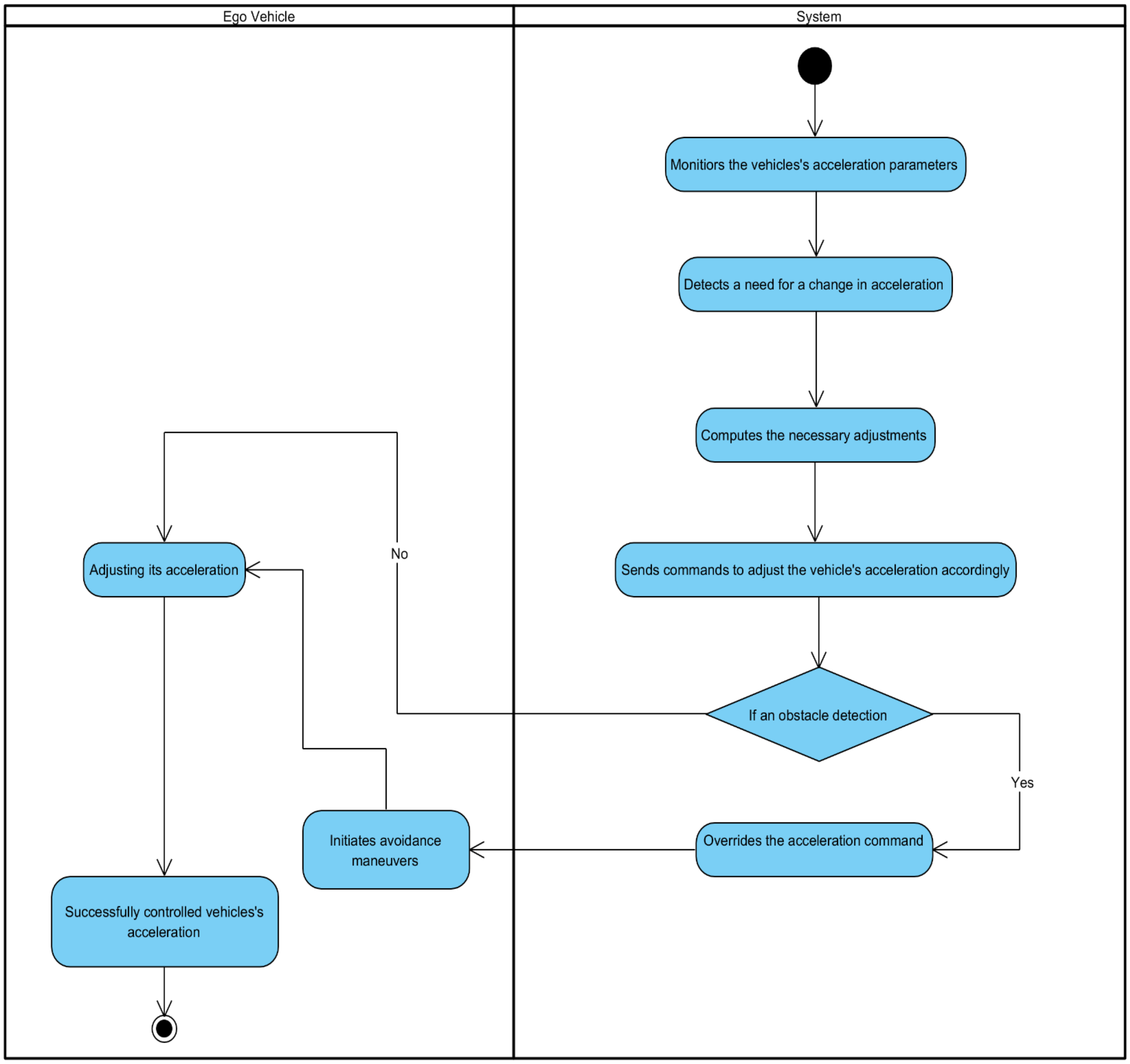

Fig 4.3.3.5 – Control Acceleration

4.3.3.6 Control Throttle:

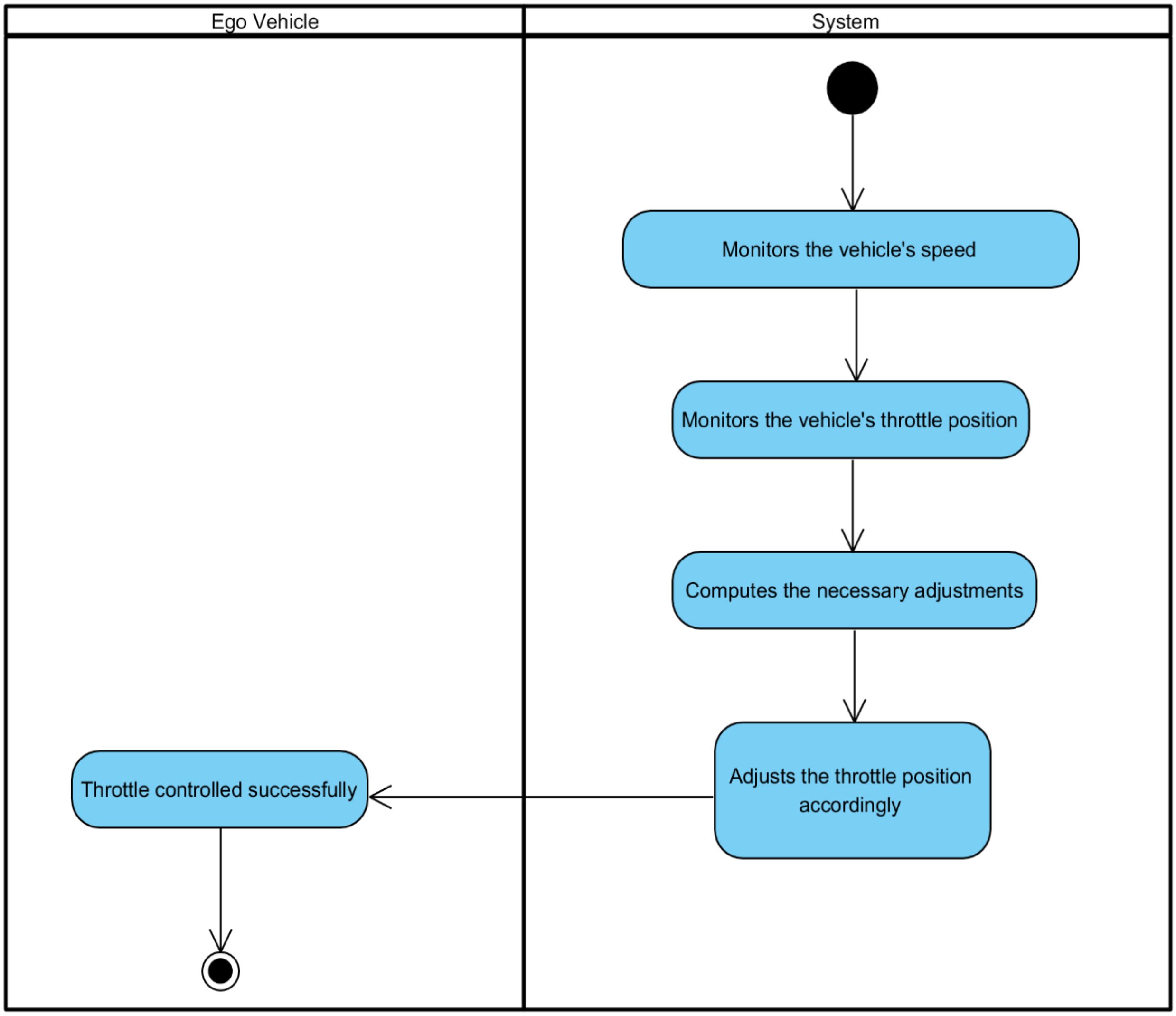

Fig 4.3.3.6 – Control Throttle

4.3.3.7 Control Steering:

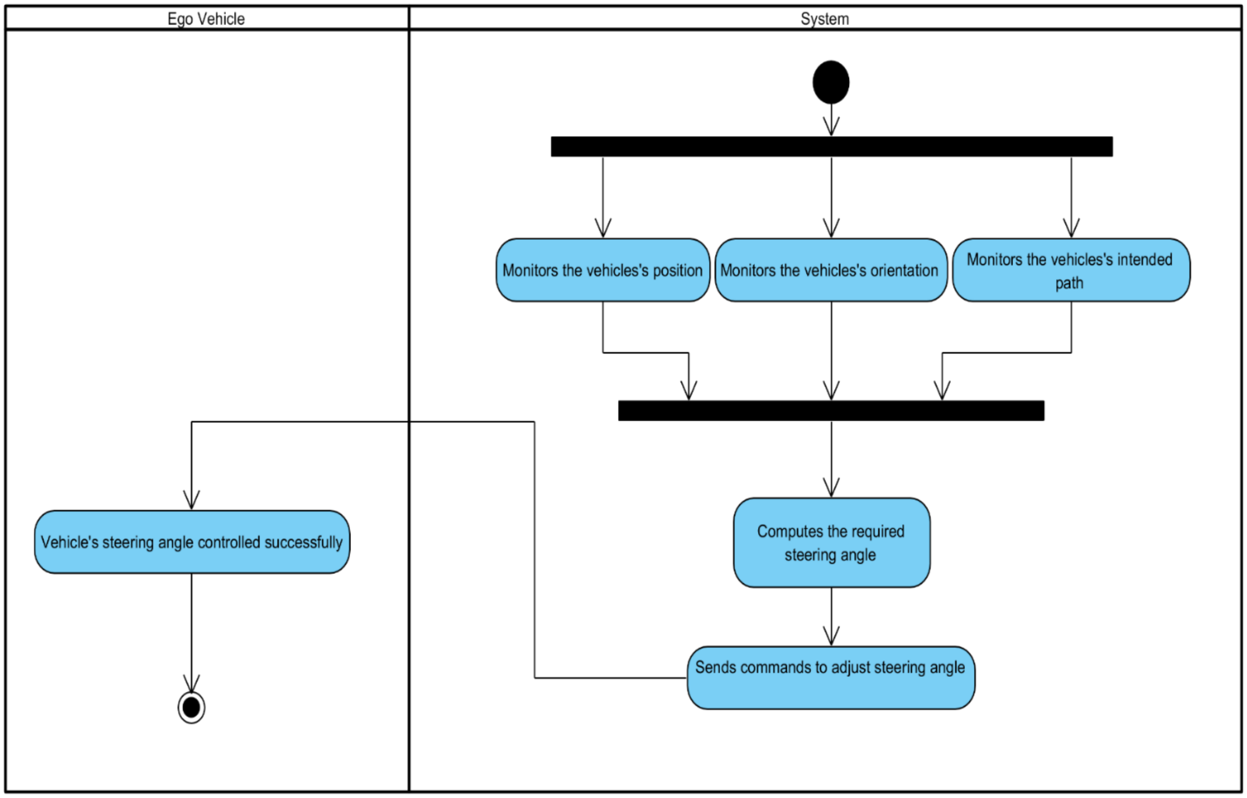

Fig 4.3.3.7 – Control Steering

4.3.3.8 Assign Lane:

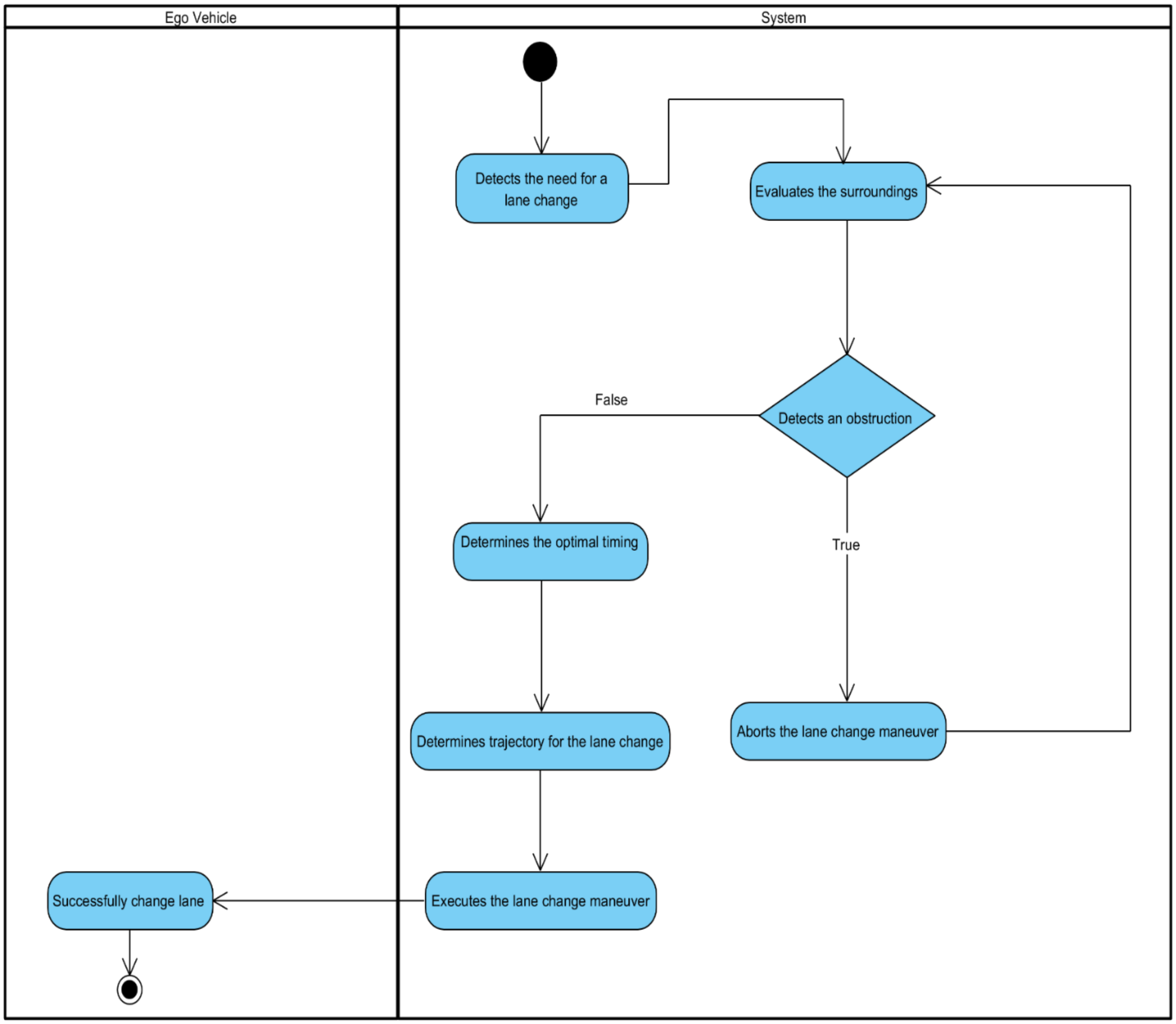

Fig 4.3.3.8 – Assign Lane

4.3.3.9 Control Longitudinal Movement:

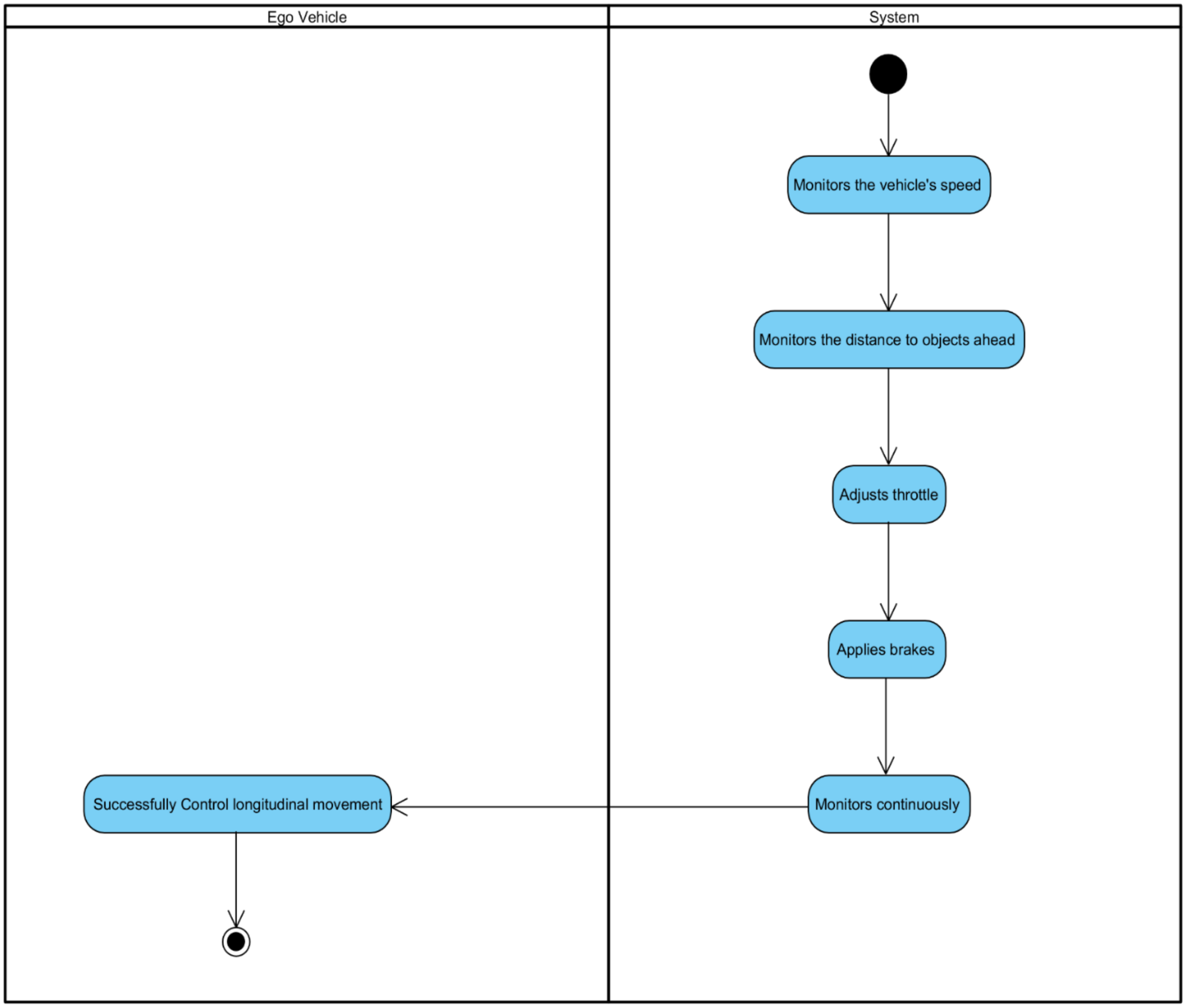

Fig 4.3.3.9 – Control Longitudinal Movement

4.3.3.10 Control Lateral Movement:

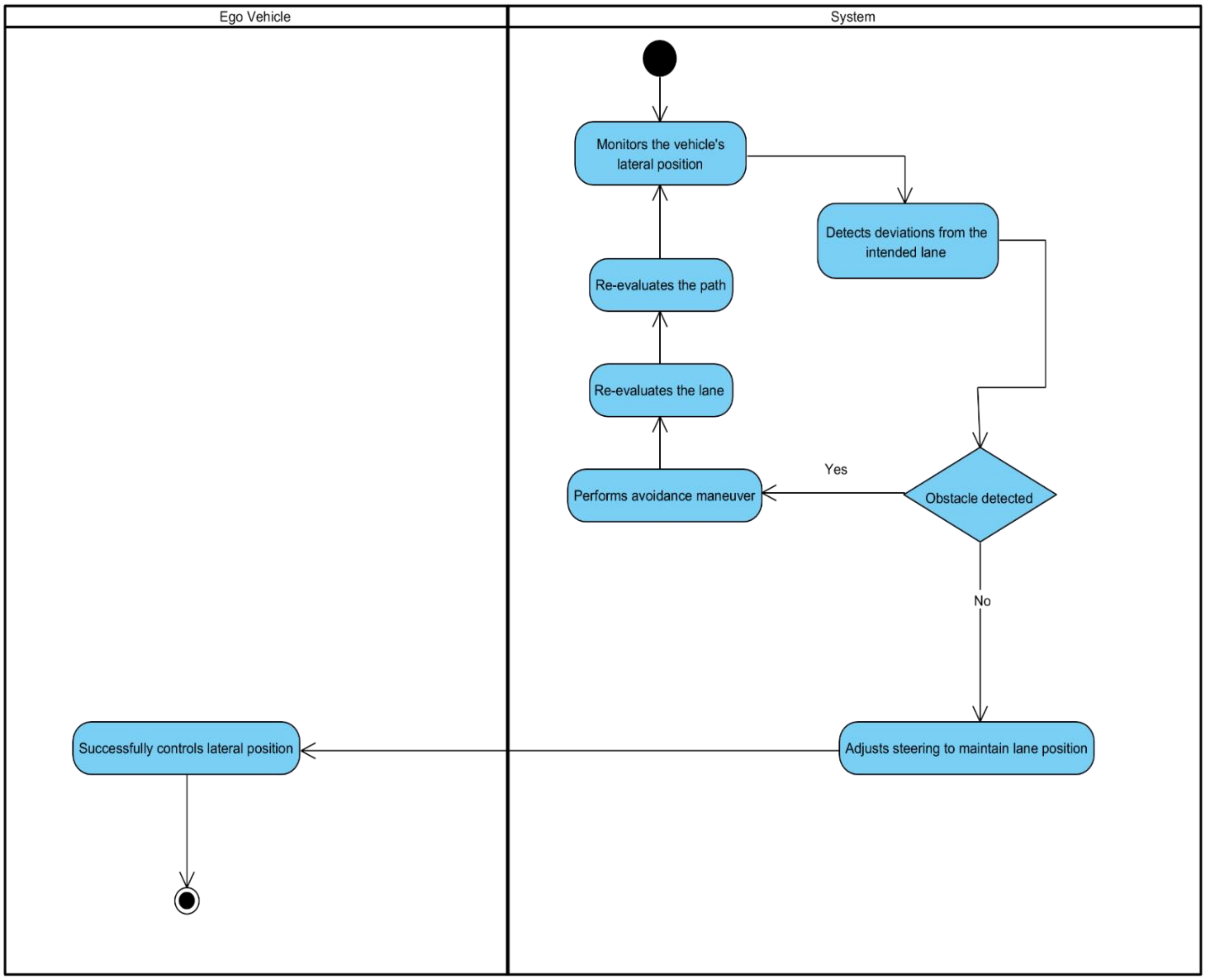

Fig 4.3.3.10 – Control Lateral Movement

4.3.3.11 Control Jerkiness:

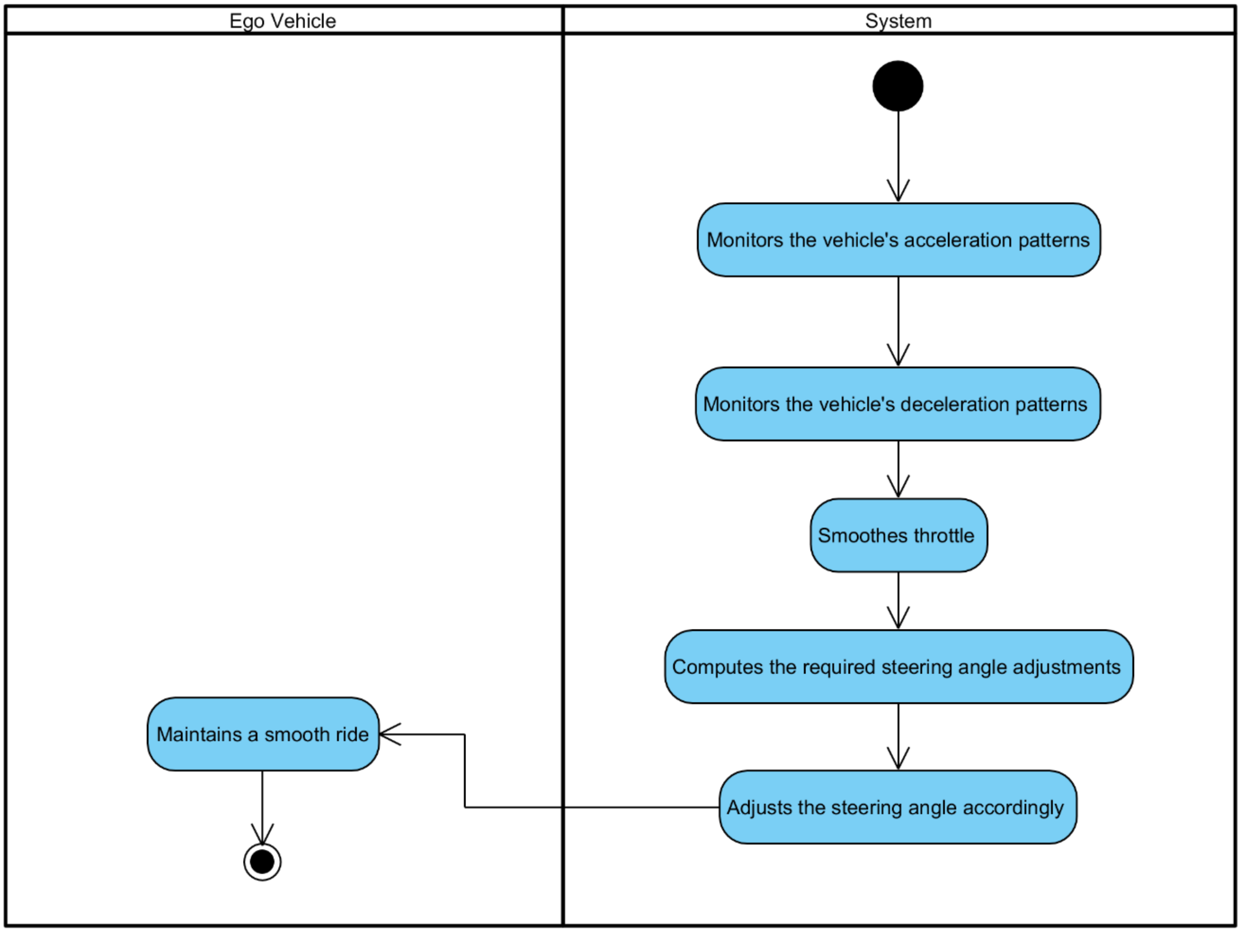

Fig 4.3.3.11 – Control Jerkiness

4.3.3.12 Reach & Halt at Destination:

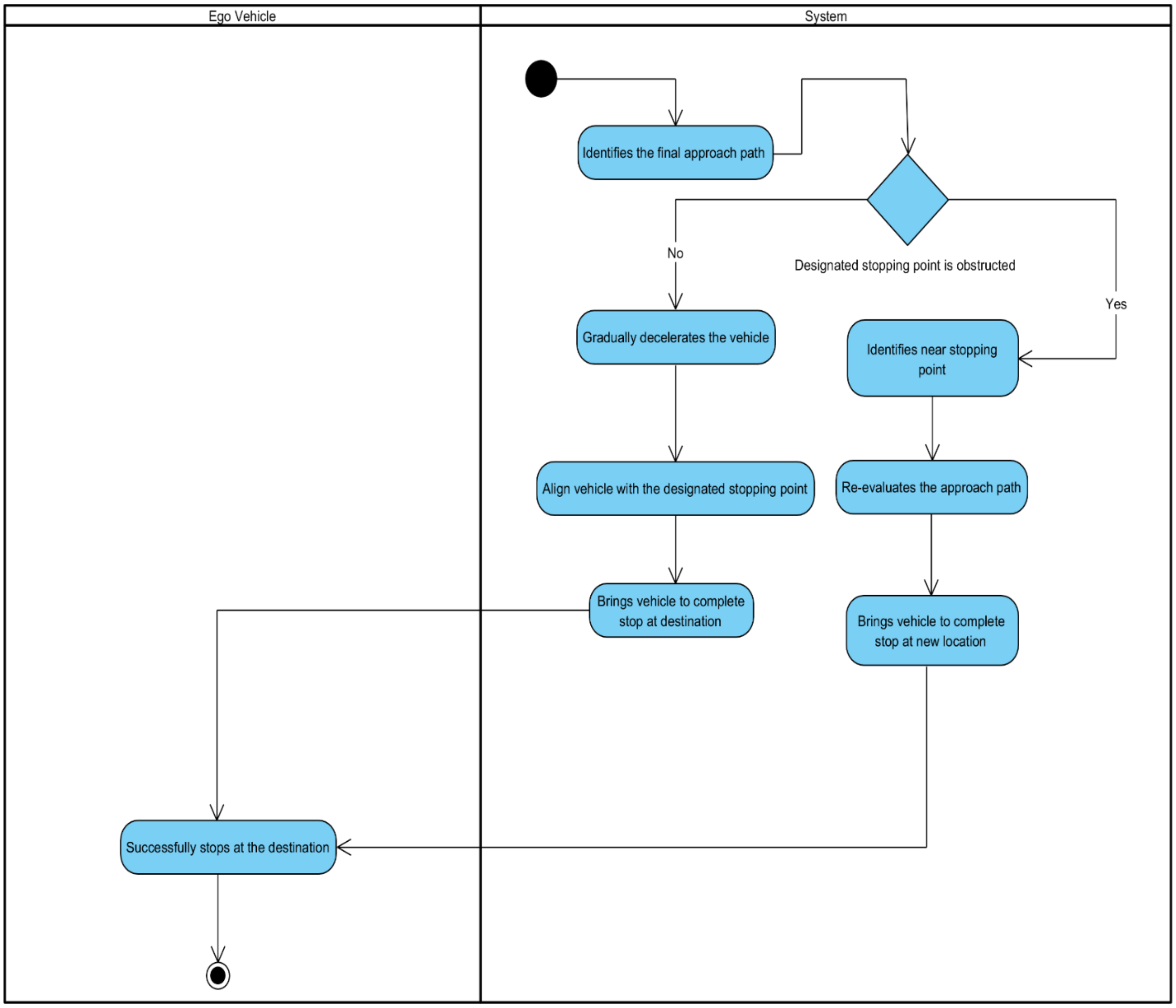

Fig 4.3.3.12 – Reach & Halt at Destination

4.3.4 Sequence Diagram

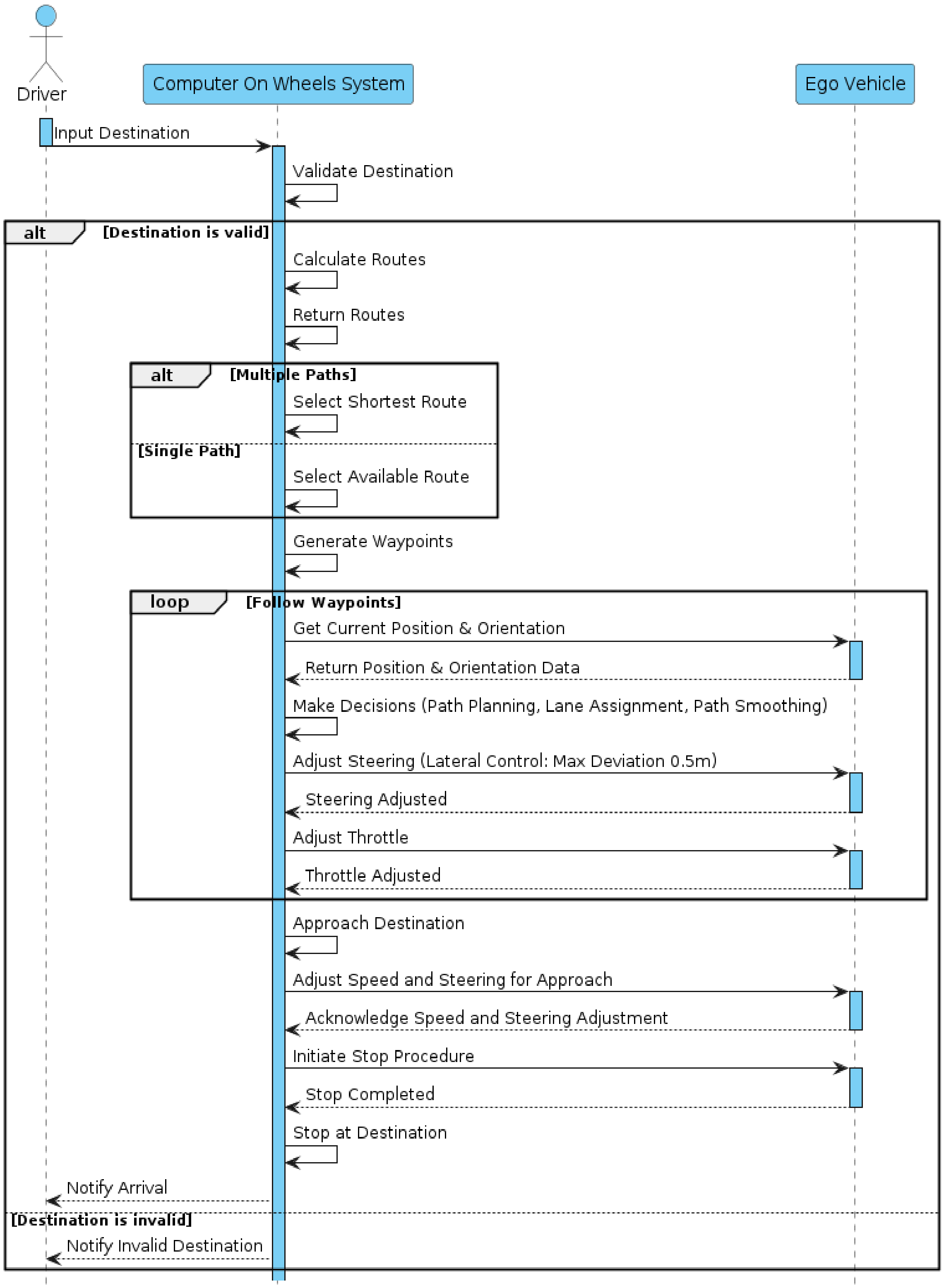

Figure 4.3.4.1 - Sequence diagram

4.4 SQA activity: Defect Detection

4.4.1 Set Destination (UC001)

Equivalence Class Partitioning (ECP):

- **Valid Classes**:
  - The destination is selected from the provided options.
  - The destination is entered manually and is valid.
- **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:

Scenario	Input Type	Input Value	ECP	Expected Output
Out of service area coordinates	Entered coordinates	"80.000000, -170.000000"	None	**Error**: Vehicle tries to go to the entered Coordinates, even if they are in any building

4.4.2 Control Acceleration (UC005)

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:

Test Case	Input Value	ECP	Expected Output
Abnormal Velocity Parameters	Velocity = 200 km/h	None	Unexpected Error
Negative Velocity Parameters	Velocity = -20 km/h	None	Unexpected Error

4.4.3 Control Throttle (UC006)

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:

Test Case	Input Value	ECP	Expected Output
Negative Speed	Speed = -10 km/h	None	Unexpected Error
Negative Throttle Position	Throttle = -20%	None	Unexpected Error

4.4.4 Control Steering (UC007)

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:

Test Case	Input Value	ECP	Expected Output
Abnormal Orientation	roll of -220°, pitch of 120°	None	Unexpected Error
Position out of bounds	-100°, 120°	None	Unexpected Error
Abnormal Steering Angle	-45°, 40°	None	Unexpected Error

4.4.5 Control Longitudinal Movement (UC009)

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:

Test Case	Input Value	ECP	Expected Output
Abnormal Steering Angle	-45°, 40°	None	Unexpected Error
Unsafe distance	0	None	Unexpected Error
Braking force	152%	None	Unexpected Error
Abnormal Speed	-15.2	None	Unexpected Error

4.4.6 Control Lateral Movement (UC10)

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:

Test Case	Input Value	ECP	Expected Output
Abnormal Lateral Position	-2.0 meters	None	Unexpected Error
Excessive Steering Adjustment	-45.23°	None	Unexpected Error