Autonomous Delivery Robot (ADR)

System-Level Architecture

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Team Name: Team 3
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1. Introduction

1.1. Document Purpose

The purpose of this document is to provide the System-Level Architecture for the Autonomous Delivery Robot (ADR) system.

1.2. Architecture Description

This section describes the system's context-level system architecture, element-level system architecture in the form of structural and behavioral diagrams. The intent of system architecture is to define a holistic view or solution using principles, concepts, and properties logically related to and consistent with each other. The architecture framework contains collective viewpoints which address all the stakeholder's needs, and logical model templates to depict the fundamental aspects of the system. It focuses on high-level structure (context-level) in systems and system elements while addressing the architectural principles, concepts, properties, and characteristics of the system of interest (SOI).

1.3. References

1. HW 8 System-level Architecture - Template - V1, by Dr. Tony Barber, 2022.
2. HW3 Team 3 Project Proposal, by Xinyi Yang, Sidney Leigh Molnar, Manu Madhu Pillai, Mukundhan Rajendiran, 2022.
3. HW6 Team 3 Project System Concept Description – Part 2, by Manu Madhu Pillai, Sidney Leigh Molnar, Mukundhan Rajendiran, Xinyi Yang, 2022.

1.4. Document Overview

This document follows the structure specified in reference [1] and it is organized as follows:

1. Section 1 describes the purpose of this document, the architecture description, references used, and the organizational structure of the document.
    1. Subsection 1.1 defines the purpose of this document
    2. Subsection 1.2 describes the purpose of architecture, its level, and what it consists of.
    3. Subsection 1.3 lists all the references used to create the document.
    4. Subsection 1.4 defines the document's organizational overview.
2. Section 2 provides a brief description of the domain and the system in terms of their elements.
3. Section 3 describes the interfaces between the system elements and between them and the external systems.
4. Section 4 identifies the principal system capabilities and provides Use Case Diagram for the system.
5. Section 5 provides a Use Case Narrative (UCN) for each UC in the UC Diagram.
6. Section 6 provides Activity Diagrams for each UC in the UC Diagram.
7. Section 7 provides Sequence Diagrams for each Use Case in the UC Diagram.
8. Section 8 provides a State Machine diagram for the System-level and also, for the element-level subsystems.
9. Section 9 provides the Package Diagram for the System Architecture.

2. System-Level Definition Block Definition Diagram (BDD)

The section describes the system's context-level system architecture using block diagrams. The ADR system consists of Autonomous Delivery Robot Elements (ADREs), the User Interaction Element (UIE), and the Support Element (SE) conceptually. Figure 1 provides a visual representation of the conceptual architecture of the ADR system using a SysML System Block Definition Diagram (BDD). The purpose of a System Definition BDD is to show the hierarchy trees and classification trees of the ADR system. Also, it shows elements like blocks and values types and the relationships between them.

1. Autonomous Delivery Robot consists of 1) chassis and storage bins; 2) the sensor packages used to detect dynamic or static obstacles (pedestrians, vehicles etc.); 3) hardware and software for processing the sensor data; 4) hardware and software for motion control which uses the sensor data and controls the motion of the ADR (forward/backward/left/right); 5) hardware and software for telecommunication which allows the ADR to transmit data to the central server for monitoring, management,and usage for mobile application purposes. 6) QR code sticker on the body for users to scan (identify if the ADR reaches the user so it can open the storage bin).
2. User Interaction Element consists of 1) a mobile application to communicate with the central server to get the ADR live location and display it to the users; 2) user scanning the QR code on the ADR to verify the ADR has reached its destination.
3. Support Element consists of cleaning and charging the ADRs, replacing parts if needed, and maintaining the system.

The different operations performed by the sub-systems are also documented in the diagram at a contextual level.

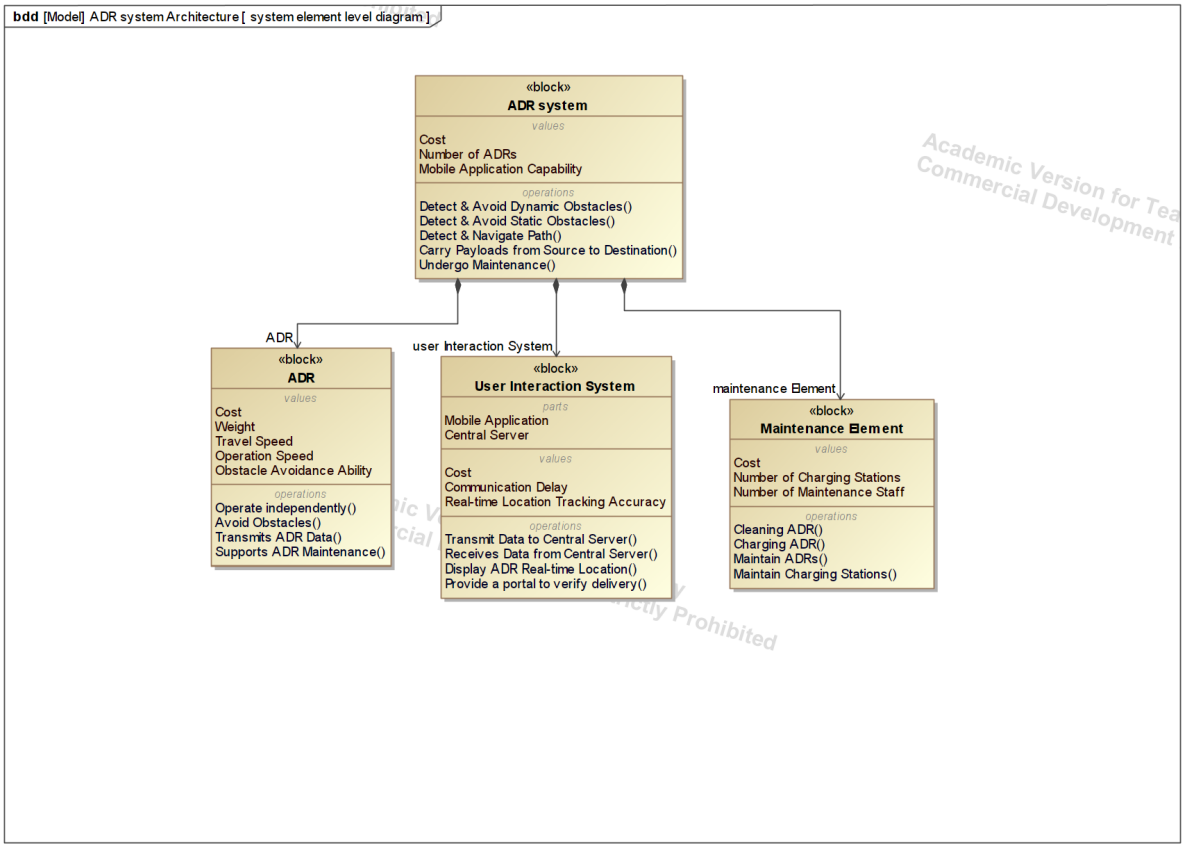

Figure 1: ADR Conceptual Architecture (BDD)

3. System-Level Internal Block Diagram (IBD) and Interface Flow Block Definition Diagram (BDD)

This section details about the interfaces between the system elements and between them and the external systems. **Figure 2** indicates the nature of the interfaces between the SOI and its environment (users and external systems). **Figure 3** provides the Interface Flow Block Diagram that defines the information and items that flow over the interfaces indicated in **Figure 2** - AMR System Context Internal Block Diagram.

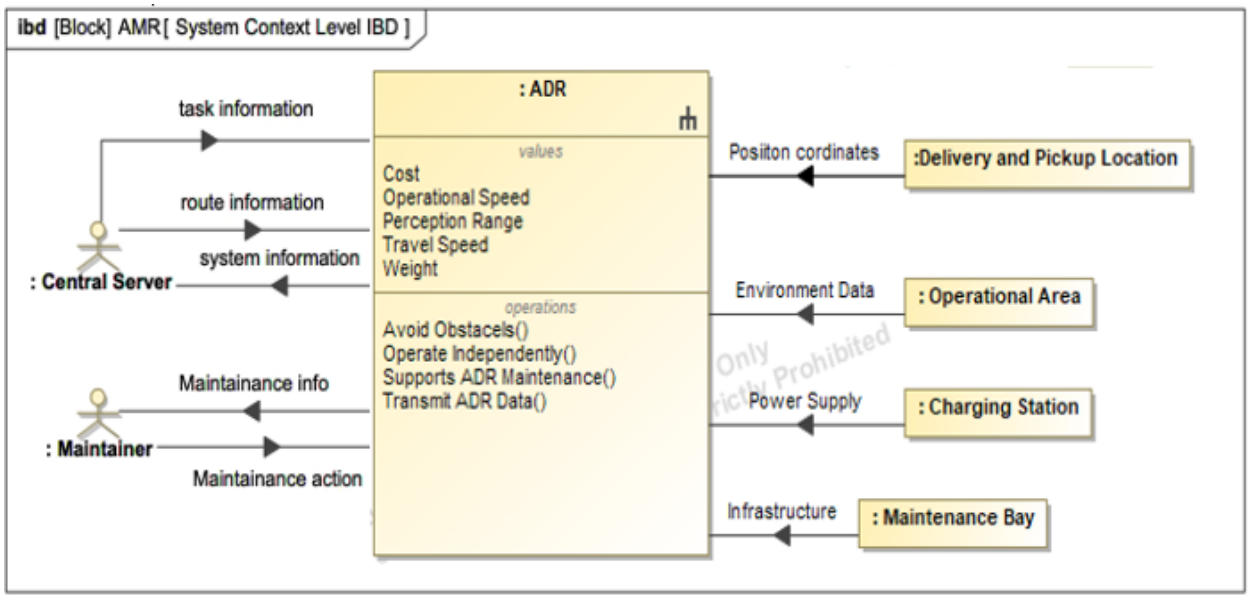

Figure 2: ADR Context Level IBD

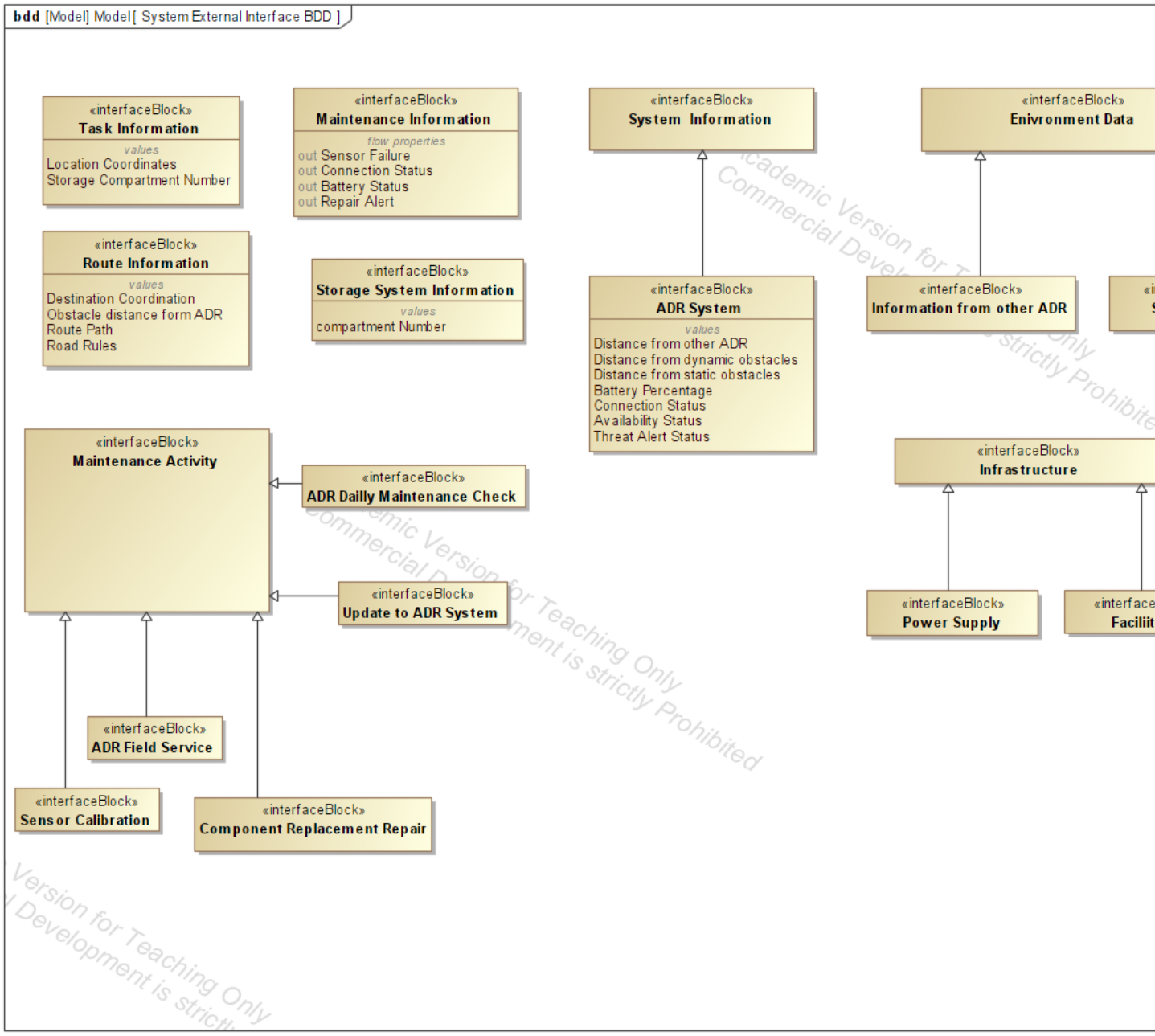

Figure 3: ADR System External Interface BDD

The System-Level IBD in Figure 4 shows how the elements interact with each other to provide the system-level capability. It shows information, material, and energy flows between system elements and external users and external systems. The Internal Interface (II) BDD in Figure 5 defines the data and other interfaces between the system and the external elements. These blocks are used to define the information and material flow in Figure 4 IBD.

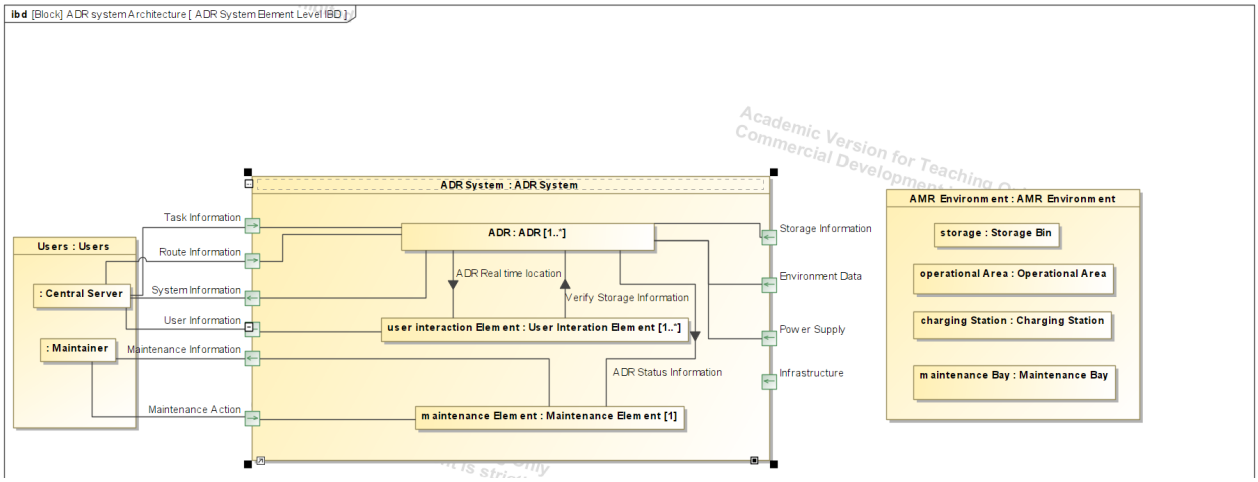

Figure 4: ADR System Element-Level Interface Flow IBD

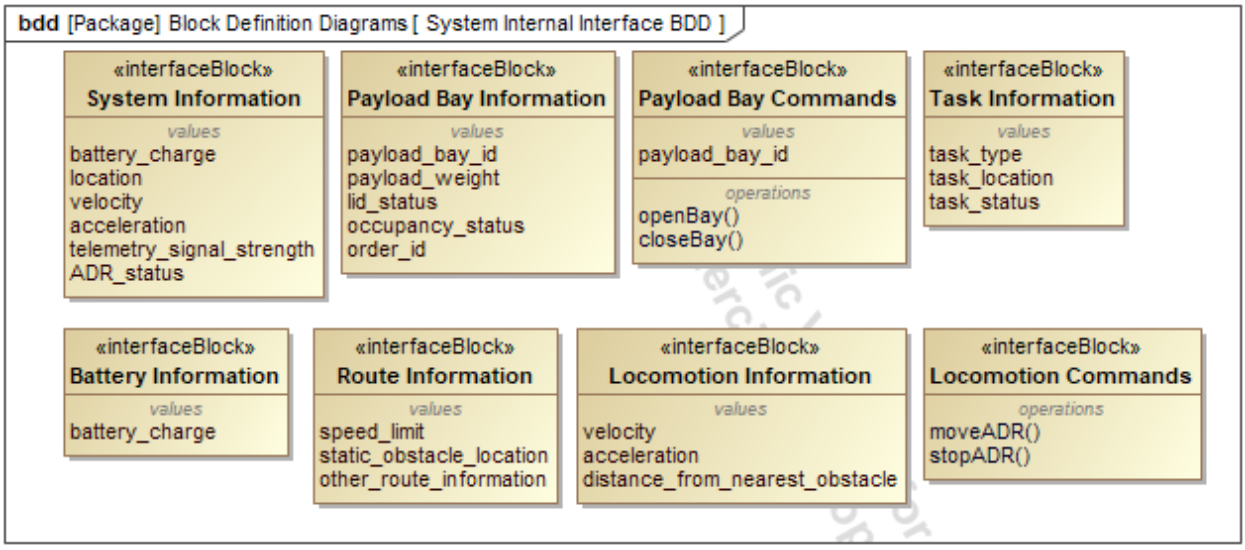

Figure 5: ADR System Internal Interface BDD

4. System-Level Use Case Diagrams

This section identifies and describes the principal high-level use cases for the ADR system. A SysML Use Case Diagram (UCD) is described in Figure 6 to define and view the use cases and actors that derive from the system, and the relationship between them. Also, it provides a high-level description of the system functionality in terms of how users and external systems use the system to achieve their goals.

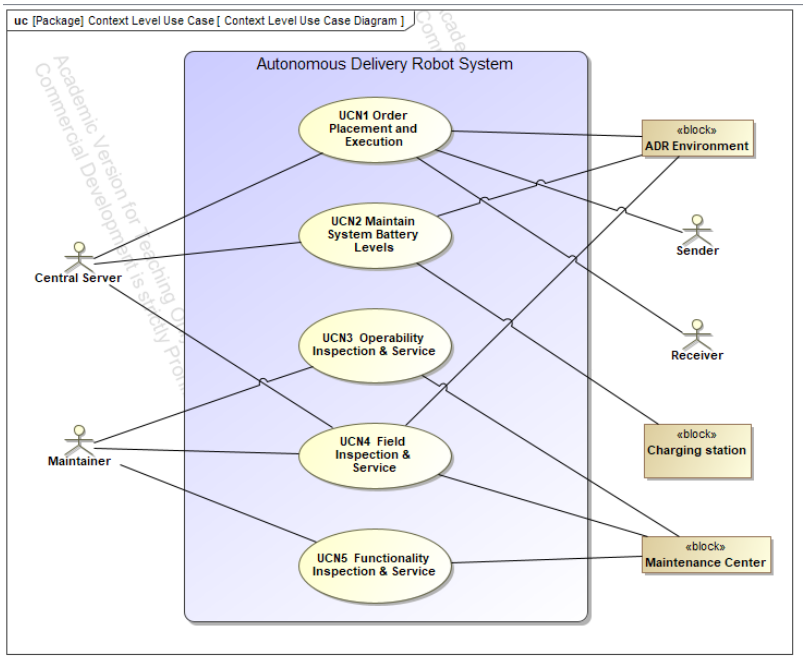

Figure 6: ADR Context Level Use Case Diagram

Figure 6 describes a SysML Context-Level Use Case Diagram (UCD) that indicates the most important top-level user goals and system capabilities. Also, it shows the use cases (UC) within the scope of the system and the actors in the environment with which each use case is associated. The “primary” actors are identified as the Central Server and the Maintainer, who activate the use case. This Use Case Diagram (UCD) is used to generate Activity diagrams, Sequence diagrams, and State Machine diagrams in the next sections.

5. System-Level Use Case Narratives

A Use Case Narrative (UCN) is a structured narrative showing what the system must do to respond to a specific event. An expanded use case narrative is documented for every use case corresponding to an external event which captures the sequence of messages from an actor to the system as well as the system’s response to each message. The narrative also reveals the structure and content of the messages.

5.1. Use Case Narrative: UCN1 - Order Placement and Execution

Introductory Information:

Use Case ID: 1

Use Case Name: Order Placement and Execution

Configuration Control Information:

Version:1.0

Date:10/14/2022

Team Name: Team 3
Author: Manu Madhu Pillai
Level: System and Element Level
Primary Actor(s):

1. Central Server

Supporting Actor(s):

1. Sender
2. Receiver

Precondition(s): Central Server is fully operational and connected to all the ADRs in the operating area. At least one ADR is available to commence the task.
Post-condition(s):
Minimum Condition(s):

1. ADR is able to receive Order location, Customer Location and routes from the Central Server.
2. ADR is able to avoid collisions with the surroundings.

Success Condition(s):

1. ADR reaches the order location and the package is placed in the payload bay.
2. ADR successfully reaches the customer location and opens the payload bay when the QR code is scanned and authenticated.

Trigger: The central server asks ADR to complete an order.

Main Success Scenario:

1. The central server receives an order.
2. The central server sends the pickup location to the nearest available ADR.
3. The ADR navigates to the order location.
4. The package is placed in the payload bay of ADR.
5. The ADR accepts the customer location from the central server.
6. The ADR navigates to the customer location.
7. The customer accesses the package being carried by the ADR and closes the lid.
8. The ADR notifies the central server that the order is complete.
9. The central server notifies the ADR of the next order location or if all orders are satisfied.
10. The ADR navigates to the next location request.

Extensions:

Extension 1: E1.1 ADR failure during navigation

Extension trigger: ADR experiences a critical failure

E1.1.1 ADR reports critical failure to the central server

E1.1.2 Central Server Requests a Field Inspection and Service.

Extension 2: E1.2 ADR experiences failure while available

Extension trigger: ADR experiences a critical failure

E1.2.1 ADR reports critical failure to the central server

E1.2.2 Central Server Requests a Functionality Inspection and Service

Note: More extensions are possible.

5.2. Use Case Narrative: UCN2- Maintain system battery levels

Introductory Information:

Use Case ID: 2

Use Case Name: Maintain System Battery Levels

Configuration Control Information:

Version:1.0
Date:10/14/2022
Team Name: Team 3
Author: Manu Madhu Pillai
Level: System and Element Level
Primary Actor(s):

1. Central Server

Supporting Actor(s):

1. Charging Station

Precondition(s): Central Server is fully operational and connected to all the ADRs in the operating area.
Post-condition(s):
Minimum Condition(s):

1. ADR is able to charge its battery.

Success Condition(s):

1. ADR replies to the central server when it is fully charged.
2. Central Server assigns new status to the fully-charged ADR.

Trigger: The central server asks the ADR for the system information

Main success scenario:

1. The central server requests the ADR to send its system information.
2. The ADR responds with the current battery levels.
3. The central server locates the closest charger to the ADR.
4. The central server sends route and task information to the ADR.
5. ADR follows route and task information to go to the charger.
6. ADR keeps sensing the environment to avoid collision.
7. ADR plugs itself into the charger.
8. ADR unplugs itself from the charger once it is fully charged.
9. ADR send current battery information to the central server.
10. The central server assigns a new status to ADR.

Extensions:

Extension 1: E2.1 ADR battery is sufficiently charged.

Extension trigger: The current battery levels sent to the central server by ADR is above the required threshold levels of operation.

E2.1.1 The central server requests the ADR to send its system information.

E2.1.2 The ADR responds with battery levels above threshold levels.

E2.1.3 The central server assigns new status to ADR.

Extension 2: E2.2 ADR battery is below operating levels during executing a task.

Extension trigger: The current battery levels sent to the central server by ADR is below the required threshold levels of operation.

E2.2.1 The central server requests the ADR to send its system information.

E2.2.2 The ADR responds with battery levels below threshold levels.

E2.2.3 The central server assigns new status to ADR that overrides current status.

E2.2.4 The central server updates the route destination to the nearest charging station to the ADR to commence charging.

Extension 3: E2.3 ADR experiences battery failure during transit.

Extension trigger: The current battery levels are not being sent to the central server by ADR.

E2.3.1 ADR reports critical failure to the central server.

E2.3.2 The central server assigns new status to ADR that overrides current status.

E2.3.3 Maintainer takes the ADR to the maintenance bay.

Note: More extensions are possible.

5.3. Use Case Narrative: UCN3- Operability inspection & service

Introductory Information:

Use Case ID: 3

Use Case Name: Operability inspection & service

Configuration Control Information:

Version:1.0
Date:10/14/2022
Team Name: Team 3
Author: Manu Madhu Pillai
Level: System and Element Level
Primary Actor(s):

1. Maintainer

Supporting Actor(s):

1. Central Server

Precondition(s): Central Server is fully operational and connected to the ADR. Maintainer is available for inspection and service.
Post-condition(s):
Minimum Condition(s):

1. ADR is able to turn off when requested by the central server.

Success Condition(s):

1. ADR replies to the central server when turned on.
2. Central Server assigns new status to the serviced ADR.

Trigger: Scheduled daily at the end of operational hours of the ADR.

Main success scenario:

1. The ADR system is physically cleaned by the maintainer.
2. The ADR system payload bay is cleared out and cleaned by the maintainer.
3. The ADR system is inspected for physical damage.

Extensions:

Extension 1: E3.1 Issue found in ADR is beyond repair skills of the maintainer.

Extension trigger: The maintainer troubleshoots the issue found upon inspection of the ADR.

E3.1.1 The maintainer requests the central server for functionality inspection and service.

E3.1.2 The central server issues a functionality inspection and service request for the ADR.

E3.1.3 The central server assigns new status to ADR.

Note: More extensions are possible.

5.4. Use Case Narrative: UCN4- Field inspection & service

Introductory Information:

Use Case ID: 4

Use Case Name: Field inspection & service

Configuration Control Information:

Version:1.0
Date:10/14/2022
Team Name: Team 3
Author: Manu Madhu Pillai
Level: System and Element Level
Primary Actor(s):

1. Central Server

Supporting Actor(s):

1. Maintainer

Precondition(s): Central Server is fully operational and connected to the ADR. Maintainer is available for inspection and service. Maintainer is able to travel within the operational area of the ADR.
Post-condition(s):
Minimum Condition(s):

1. ADR is able to turn off when requested by the central server.
2. ADR is able to send its current location to the central server.

Success Condition(s):

1. ADR replies to the central server when turned on.
2. Central Server assigns new status to the serviced ADR.

Trigger: ADR requests the central server for a field inspection.

Main success scenario:

1. The central server requests the maintainer to inspect the ADR at it’s current location.

2. The maintainer goes to the ADR's current location.
3. The maintainer inspects the ADR for issues.
4. The maintainer fixes the issues of the ADR.

Extensions:

Extension 1: E4.1 Issue found in ADR is beyond repair skills of the maintainer.

Extension trigger: The maintainer troubleshoots the issue found upon inspection of the ADR.

E4.1.1 The maintainer requests the central server for functionality inspection and service.

E4.1.2 The maintainer brings the ADR to the maintenance bay.

E4.1.3 The central server issues a functionality inspection and service request for the ADR.

E4.1.4 The central server assigns new status to ADR.

Note: More extensions are possible.

5.5. Use Case Narrative: UCN5- Functionality inspection & service

Introductory Information:

Use Case ID: 5

Use Case Name: Functionality inspection & service

Configuration Control Information:

Version:1.0
Date:10/14/2022
Team Name: Team 3
Author: Manu Madhu Pillai
Level: System and Element Level
Primary Actor(s):
1. Central Server

Supporting Actor(s):
1. Maintainer

Precondition(s): Central Server is fully operational and connected to the ADR. Maintainer is available for inspection and service.
Post-condition(s):
Minimum Condition(s):
1. ADR is able to turn off when requested by the central server.

Success Condition(s):
1. ADR replies to the central server when turned on.

2. Central Server assigns new status to the serviced ADR.

Trigger: Scheduled based on the expected lifespan of the critical parts in ADR, or requested by the central server due to escalation of lower inspection and services.

Main success scenario:

1. The maintainer dissasembles the ADR and separates the critical parts.
2. The maintainer performs a functionality inspection of critical components.
3. The maintainer checks mechanical components like wheels for wear and tear.
4. The maintainer checks electrical components like motors for wear and tear.
5. The maintainer decides whether to replace the components.
6. The maintainer replaces the required components.
7. The maintainer reassembles the ADR.
8. The maintainer performs a functionality inspection of the assembled ADR.

Extensions:

Extension 1: E5.1 Issue found in ADR is beyond repair skills of the maintainer.

Extension trigger: The maintainer replaces the faulty component of the ADR.

E5.1.1 The maintainer requests assistance from the manufacturer..

E5.1.2 The ADR is sent to the manufacturer for troubleshooting and service.

Note: More extensions are possible.

6. System-Level Activity Diagrams

This section provides SysML Activity Diagrams (with swim lanes) for each Use Case Narrative (UCN). These activity diagrams show the principal actions taken by the users, the system, and external systems in accomplishing the Use Cases' goals. The Activity diagram represents the sequence of actions that describe the behavior of a Block or other structural element and the sequence is defined using Control Flows. The Actions can contain Input and Output Pins that act as buffers for items that flow from one Action to another as the task carried out by the Action either consumes or produces them. The items, in our system's case, can range from physical materials, power, raw sensor data, information.

Figure 7 provides a schematic representation of UCN1 - Order Request and Execution using an Activity Diagram. Figure 8 provides a schematic representation of UCN2- Maintain system battery levels using an Activity Diagram. Figure 9 provides a schematic representation of UCN3- Operability inspection & service using an Activity Diagram. Figure 10 provides a schematic representation of UCN4- Field

inspection & service using an Activity Diagram. Figure 11 provides a schematic representation of UCN5-Functionality inspection & service using an Activity Diagram.

6.1. Activity Diagram UCN1 - Order Request and Execution

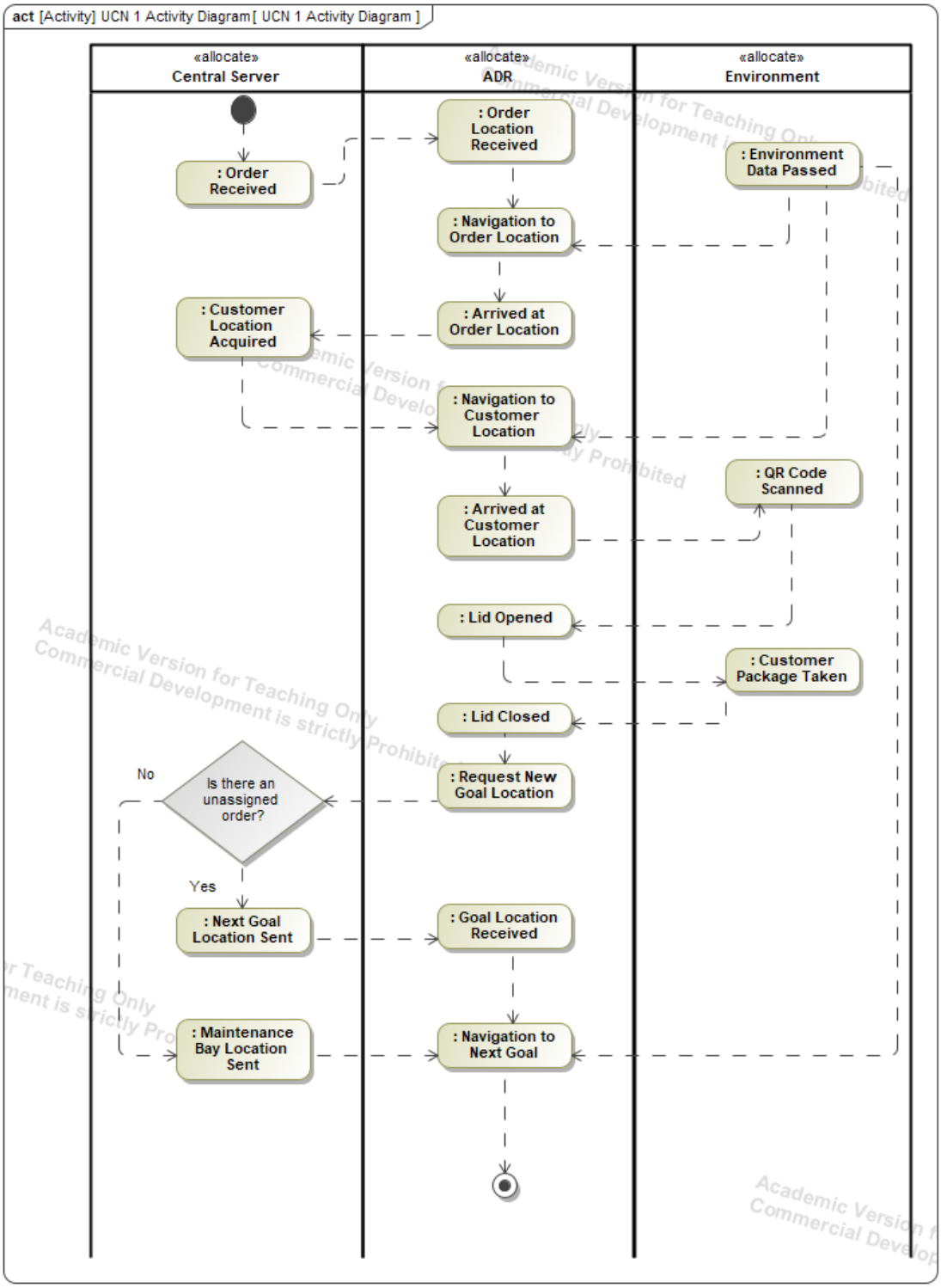

Figure 7: SysML Context-Level Activity Diagram for UCN1 - Order Request and Execution

6.2. Activity Diagram UCN2- Maintain system battery levels

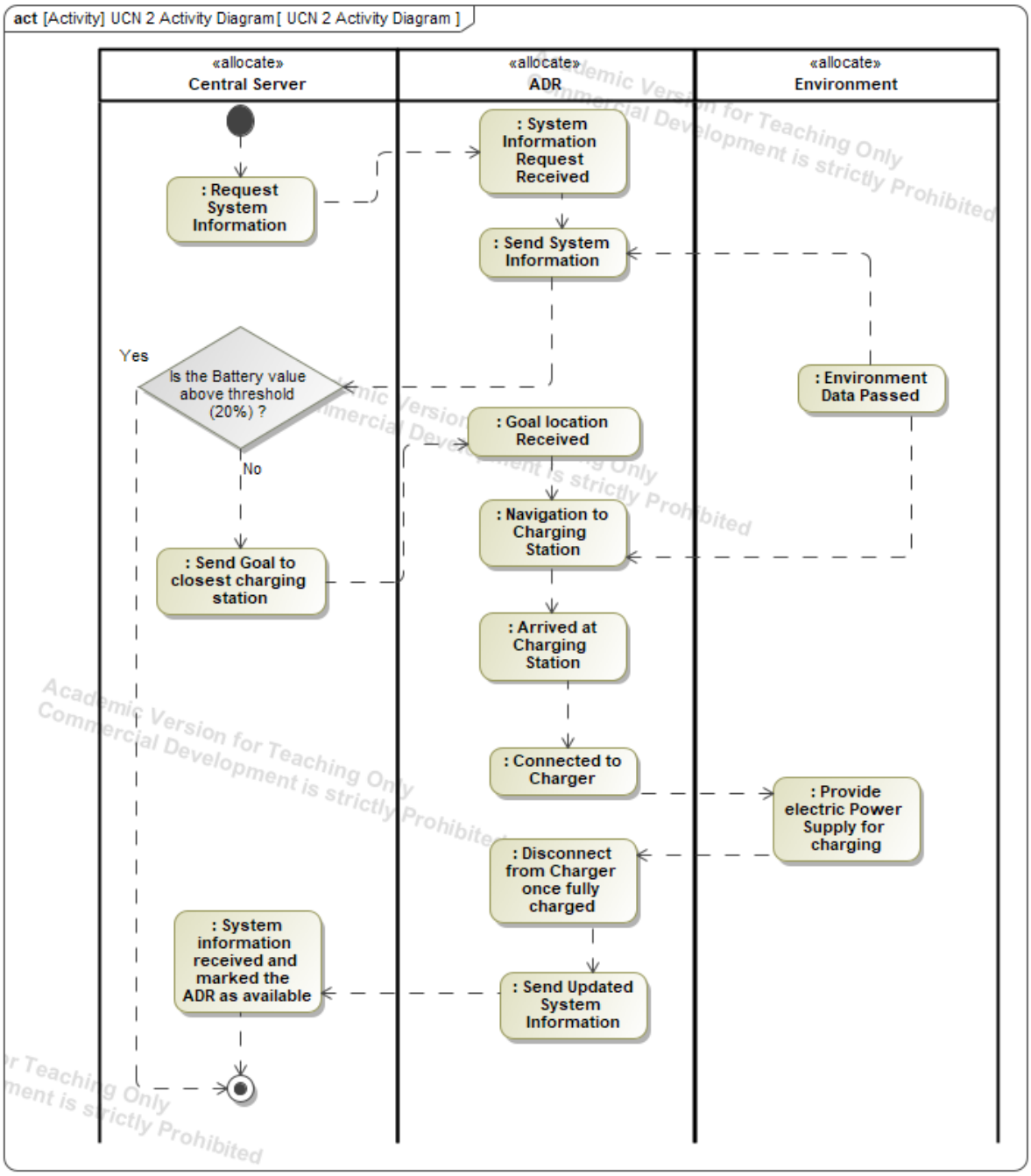

Figure 8: SysML Context-Level Activity Diagram for UCN2- Maintain system battery levels

6.3. Activity Diagram UCN3- Operability inspection & service

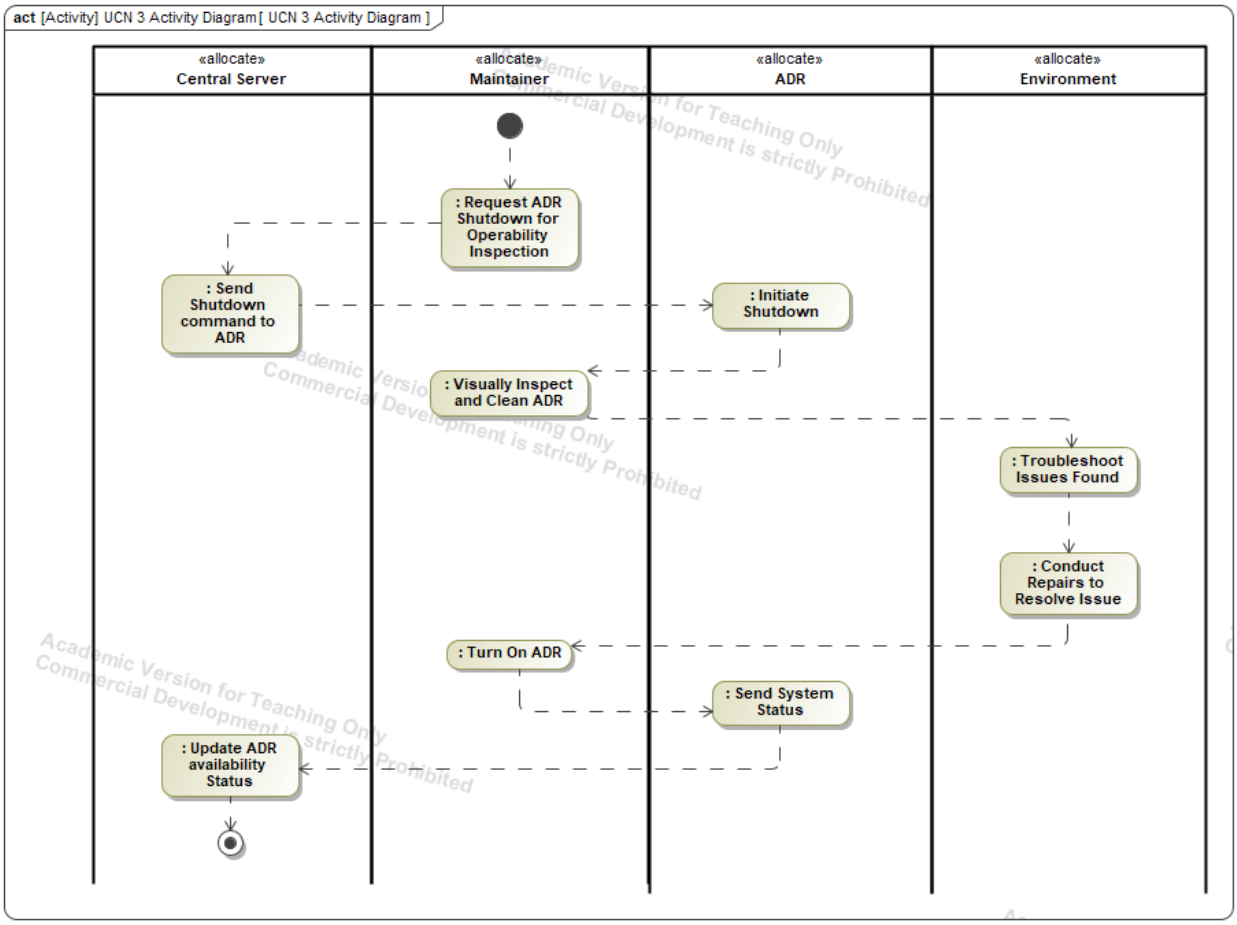

Figure 9: SysML Context-Level Activity Diagram for UCN3- Operability inspection & service

6.4. Activity Diagram UCN4- Field inspection & service

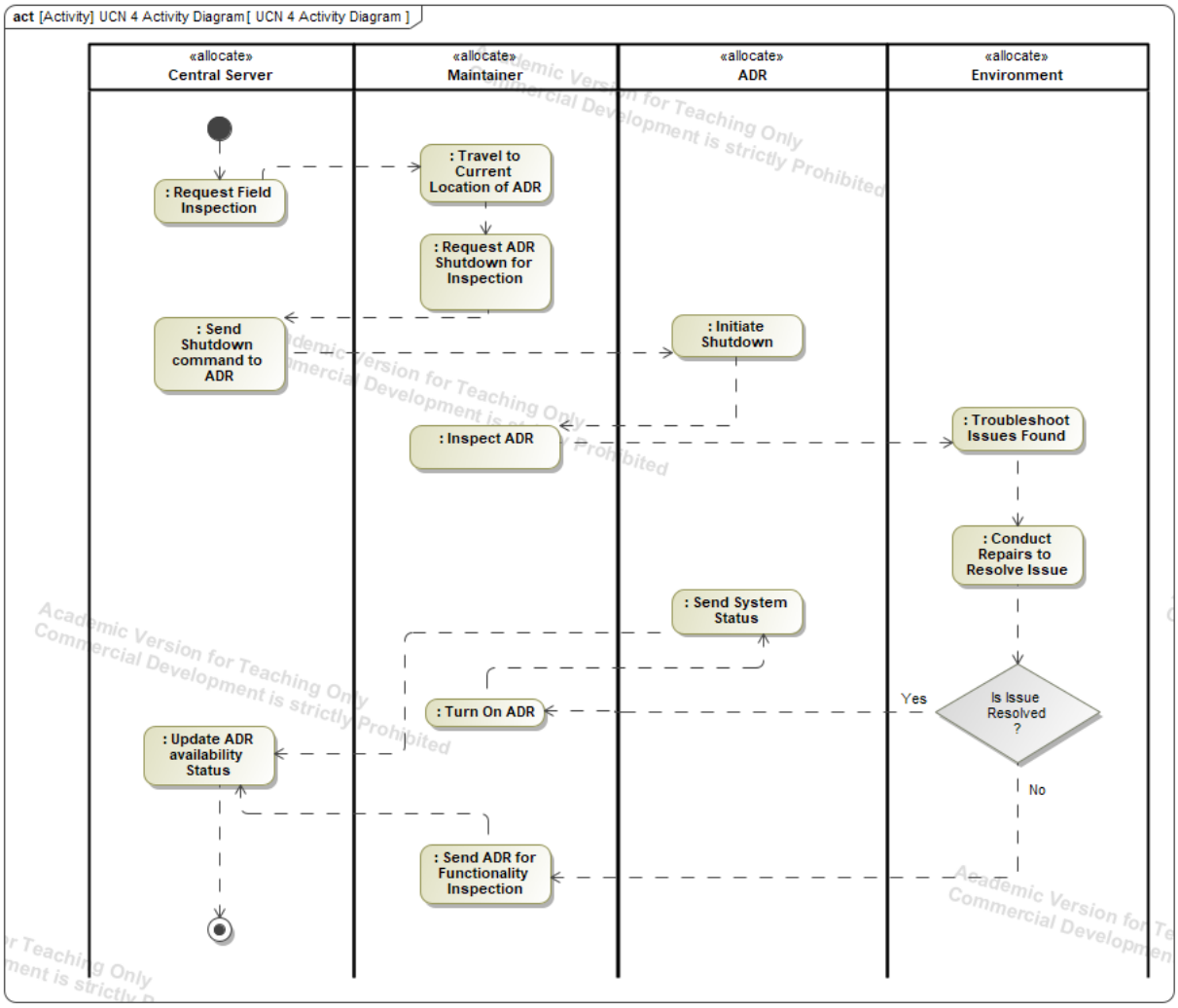

Figure 10: SysML Context-Level Activity Diagram for UCN4- Field inspection & service

6.5. Activity Diagram UCN5- Functionality inspection & service

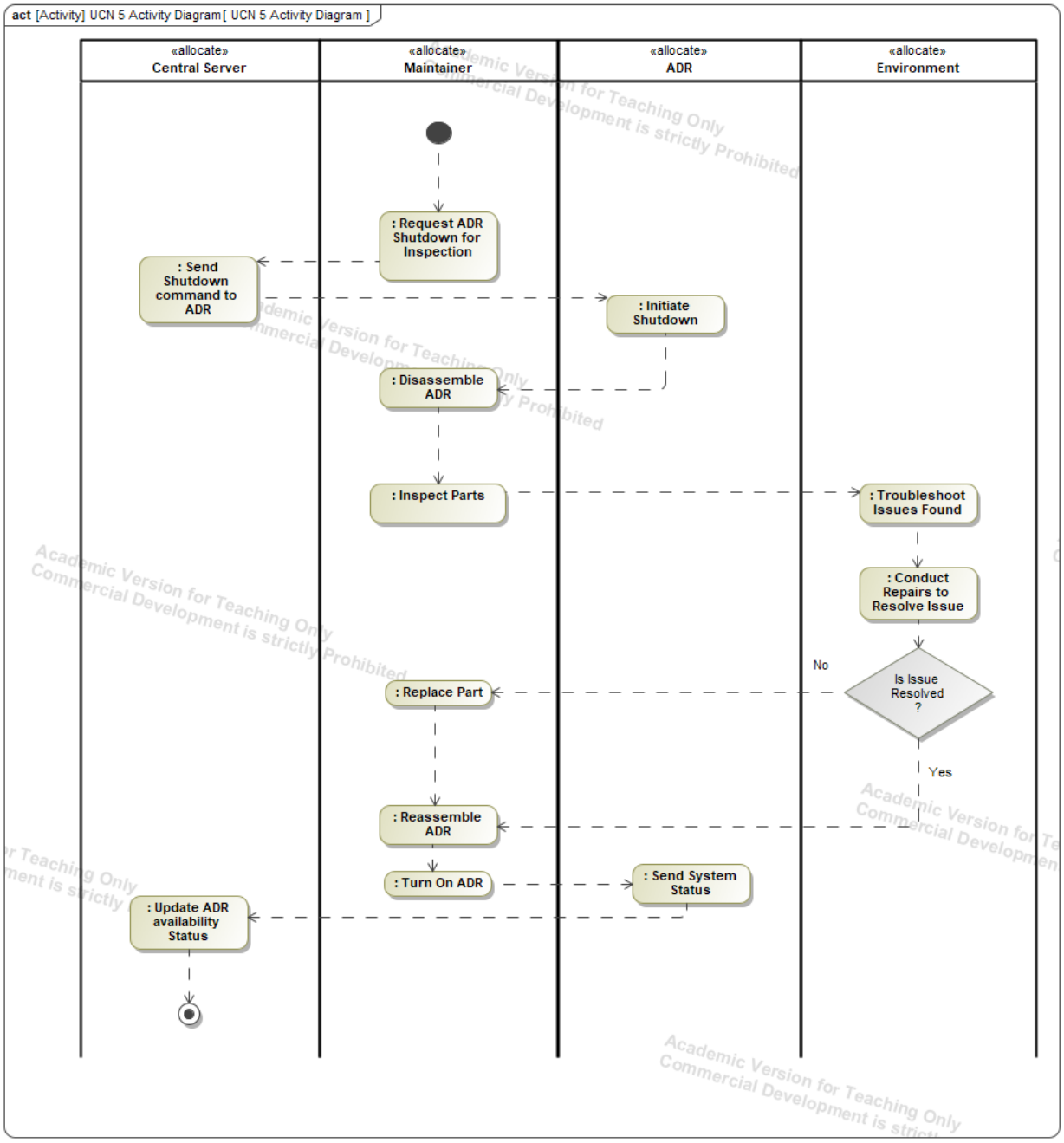

Figure 11: SysML Context-Level Activity Diagram for UCN5- Functionality inspection & service

7. System-Level Sequence Diagrams

Sequence Diagram specifies dynamic system behaviors as message-passing collaborations among Blocks (Parts) of the system. It is a form of Interaction diagram, which shows how the users will interact with the system and what happens internally to accomplish the use case. They provide a visual representation

of the objects communicating with the system of interest, and what messages trigger those communications.

Figure 12 provides a sequence diagram for UCN1 - Order Request and Execution. Figure 13 provides a sequence diagram for UCN2 - Maintain system battery levels. Figure 14 provides a sequence diagram for UCN3 - Operability inspection & service. Figure 15 provides a sequence diagram for UCN4 - Field inspection & service. Figure 16 provides a sequence diagram for UCN 5- Functionality inspection & service.

7.1. Sequence Diagram UCN1 Order Placement and Execution

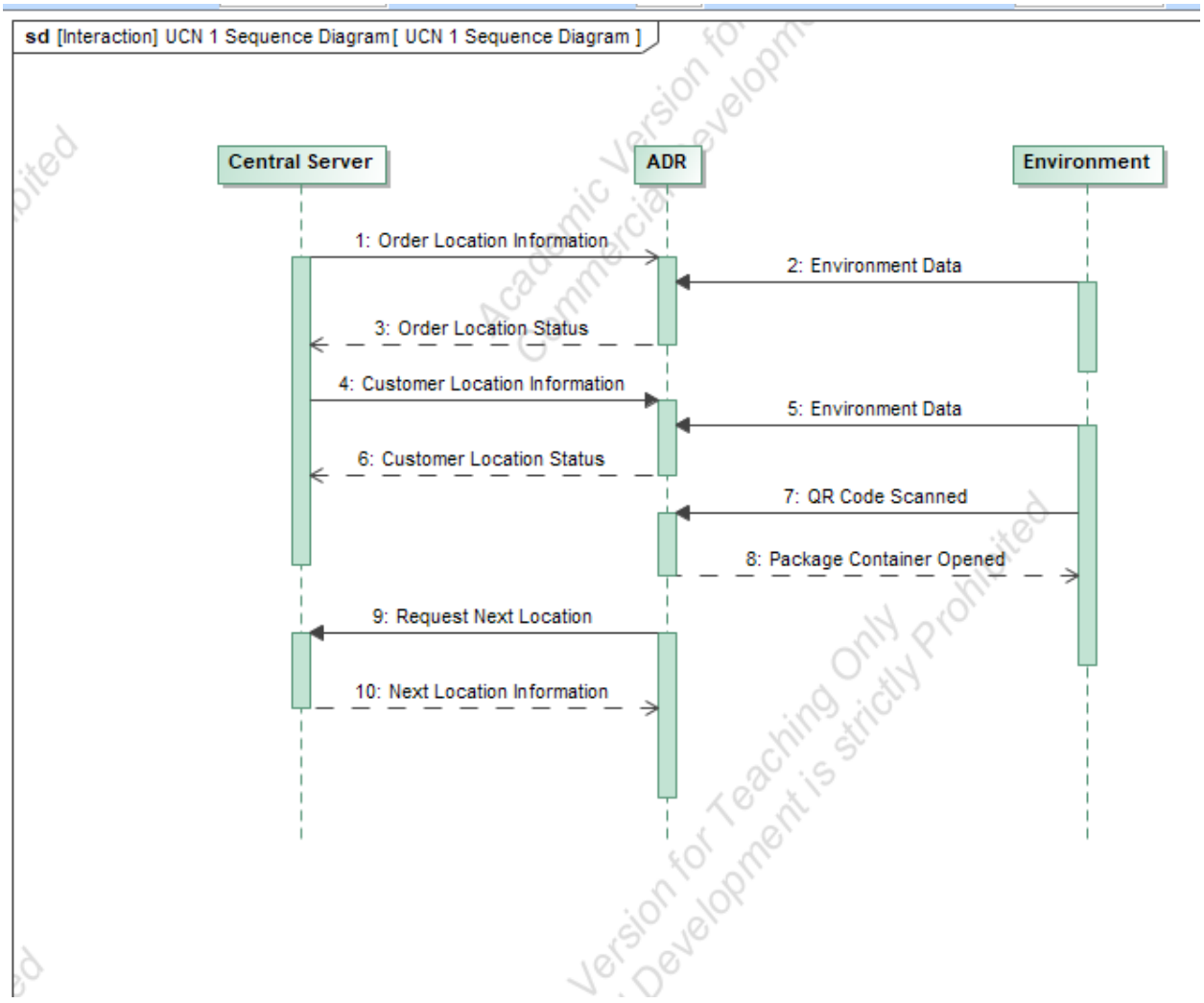

Figure 12: SysML Sequence Diagram for UCN1 - Order Request and Execution

7.2. Sequence Diagram UCN2 Maintain system battery levels

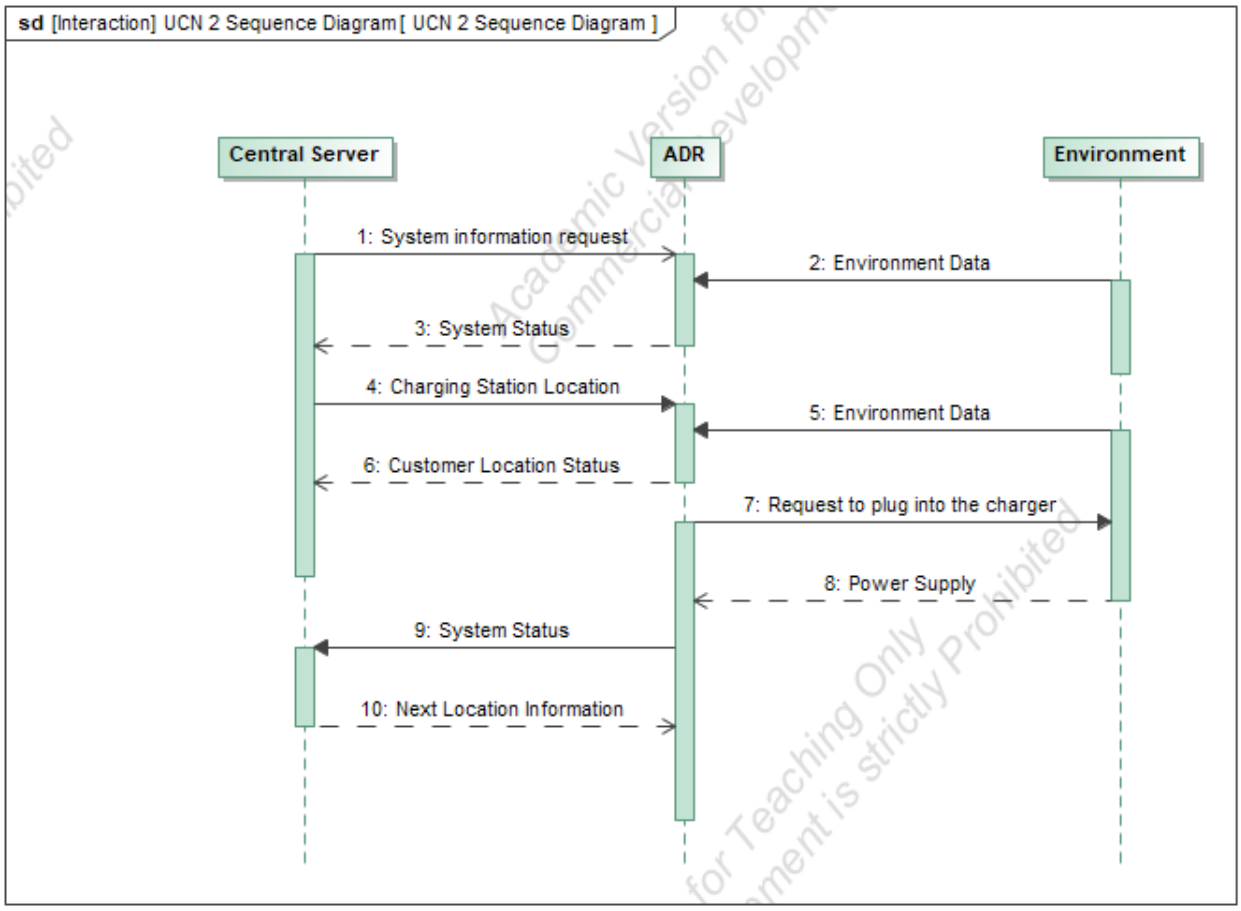

Figure 13: SysML Sequence Diagram for UCN2 - Maintain system battery levels

7.3. Sequence Diagram UCN3 Operability inspection & service

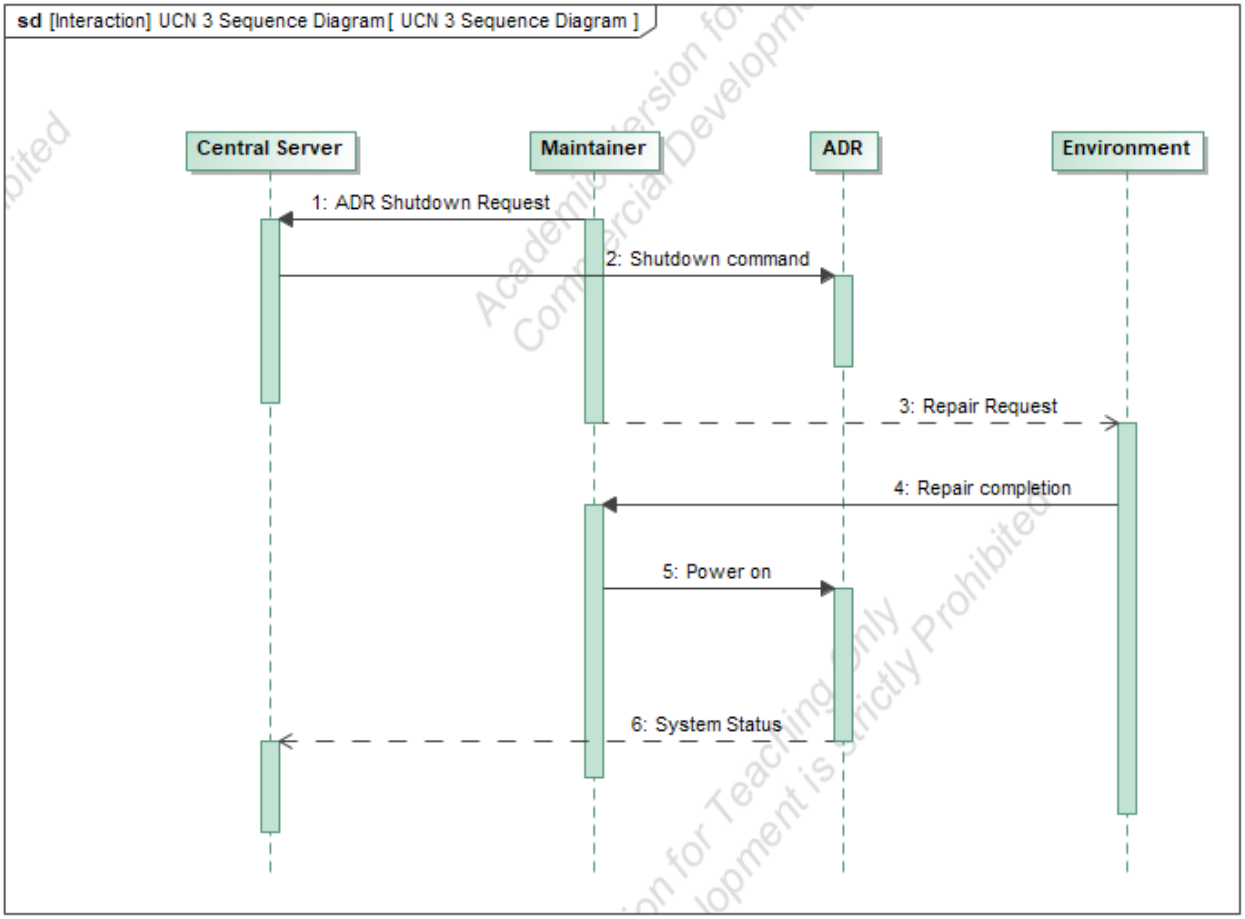

Figure 14: SysML Sequence Diagram for UCN3 - Operability inspection & service

7.4. Sequence Diagram UCN4 Field inspection & service

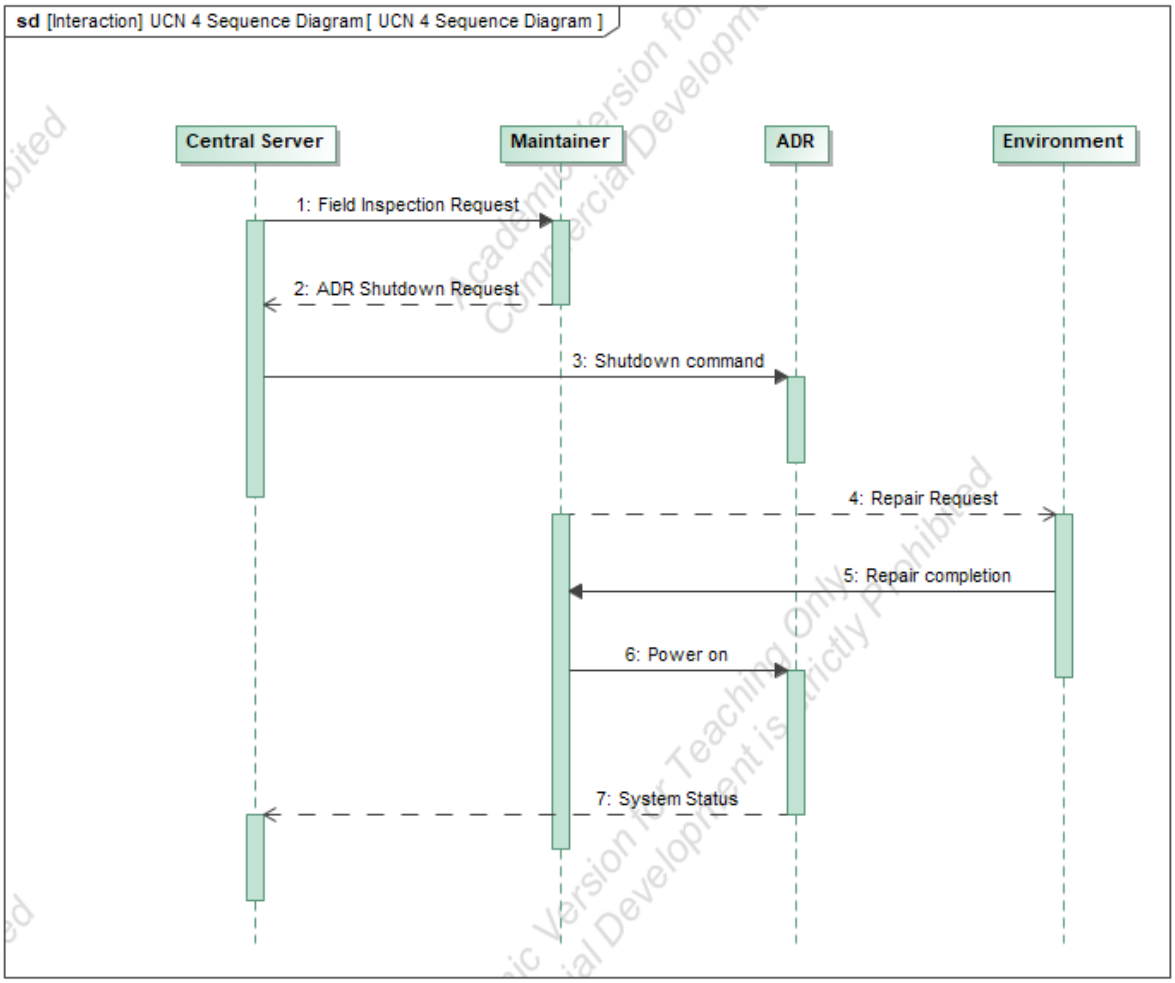

Figure 15: SysML Sequence Diagram for UCN4 - Field inspection & service

7.5. Sequence Diagram UCN5 Functionality inspection & service

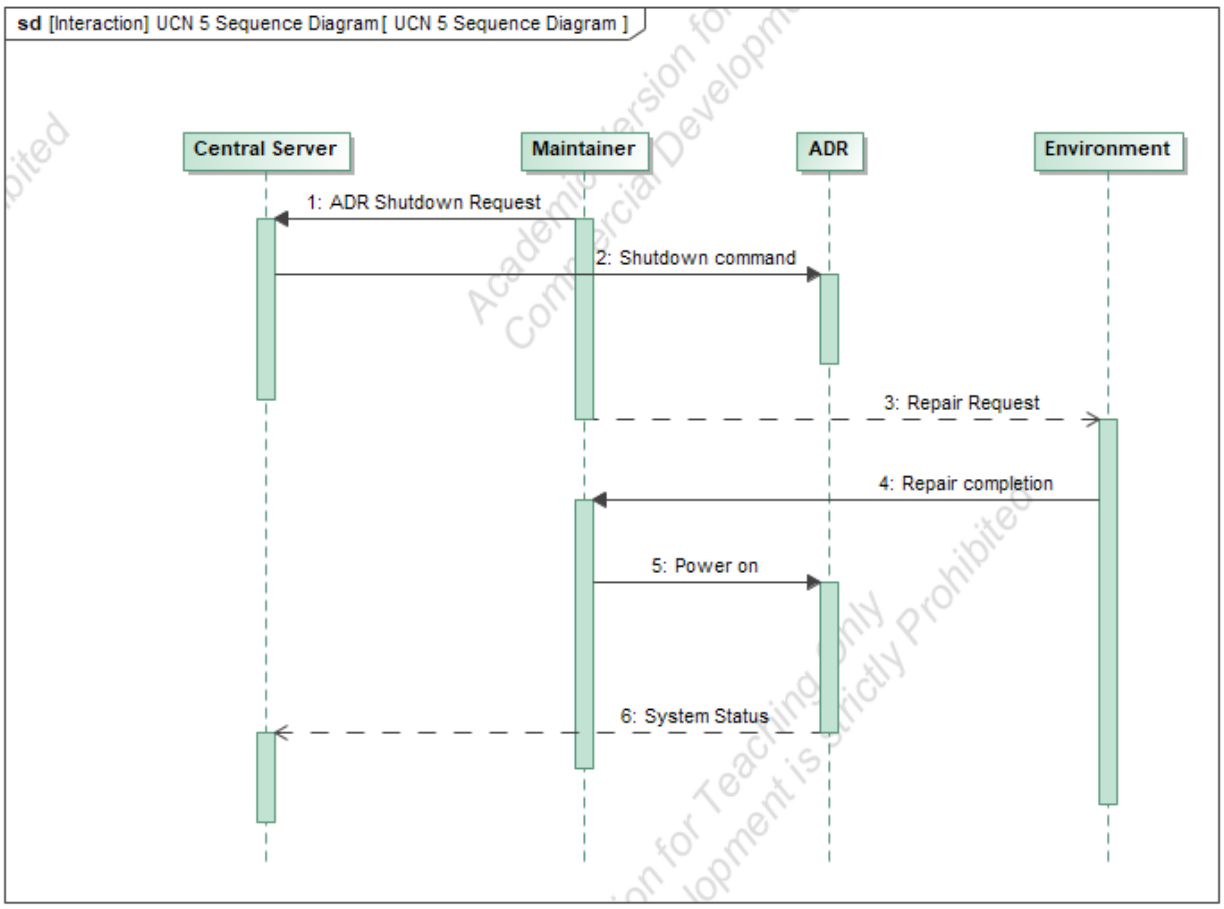

Figure 16: SysML Sequence Diagram for UCN5 - Functionality inspection & service

8. System-Level State Machine Diagrams (SMD)

This section provides a system-level State Machine Diagram (SMD) for each element of the ADR system. As shown in Figure 1 (provided in Section 2), the ADR system is composed of three primary elements: the ADR, the User Interaction System, and the Maintenance Element. Section 8.1 shows and describes the SMD for the ADR Robot. Section 8.2 shows and describes the SMD for the User Interaction System. Section 8.3 shows and describes the SMD for the Maintenance Element.

8.1. System-Level SMD for ADR

Figure 17 provides the system-level SMD for the ADR. The purpose of this diagram is to show the various states the ADR takes and what events or actions trigger each state.

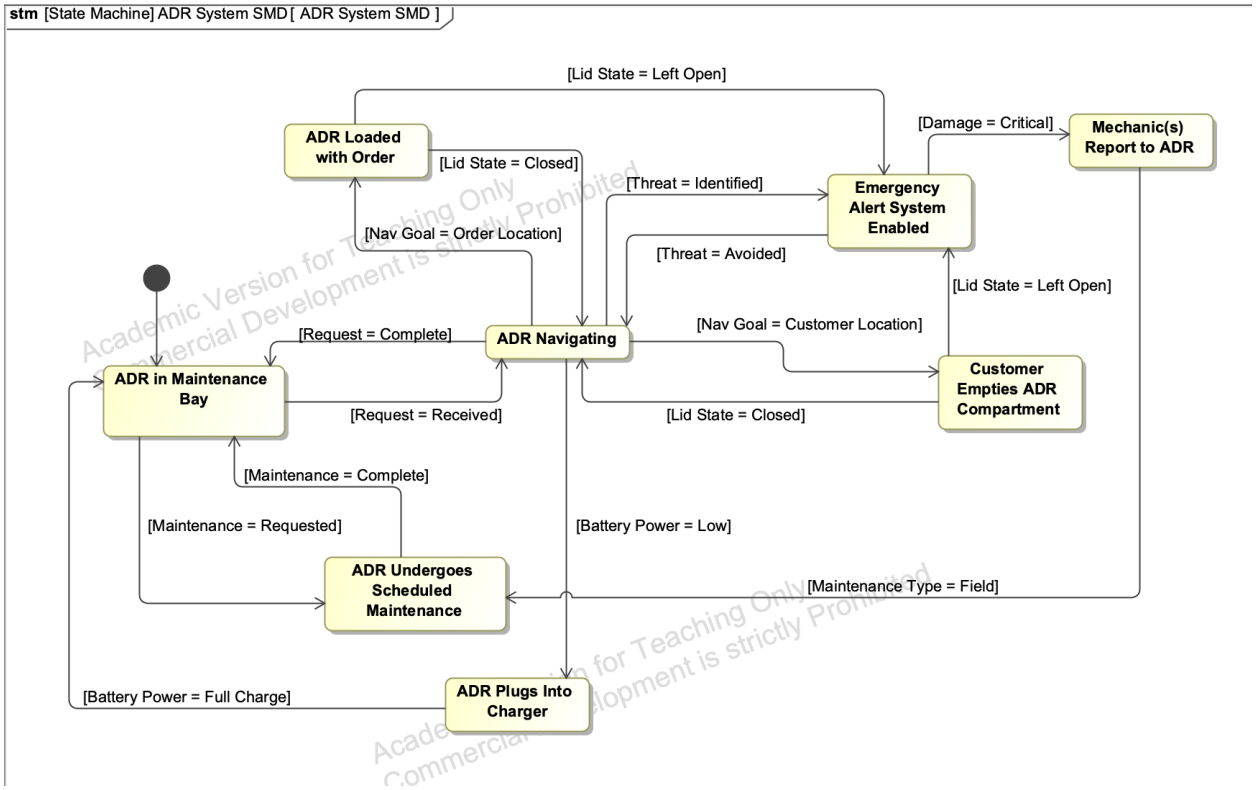

Figure 17: System-Level SMD for the ADR.

8.2. System-Level SMD for User Interaction System

Figure 18 provides the system-level SMD for the User Interaction System. The purpose of this diagram is to show the states of information portrayed to the user on the customer application via the central server and the events or actions that trigger each application state throughout the delivery process.

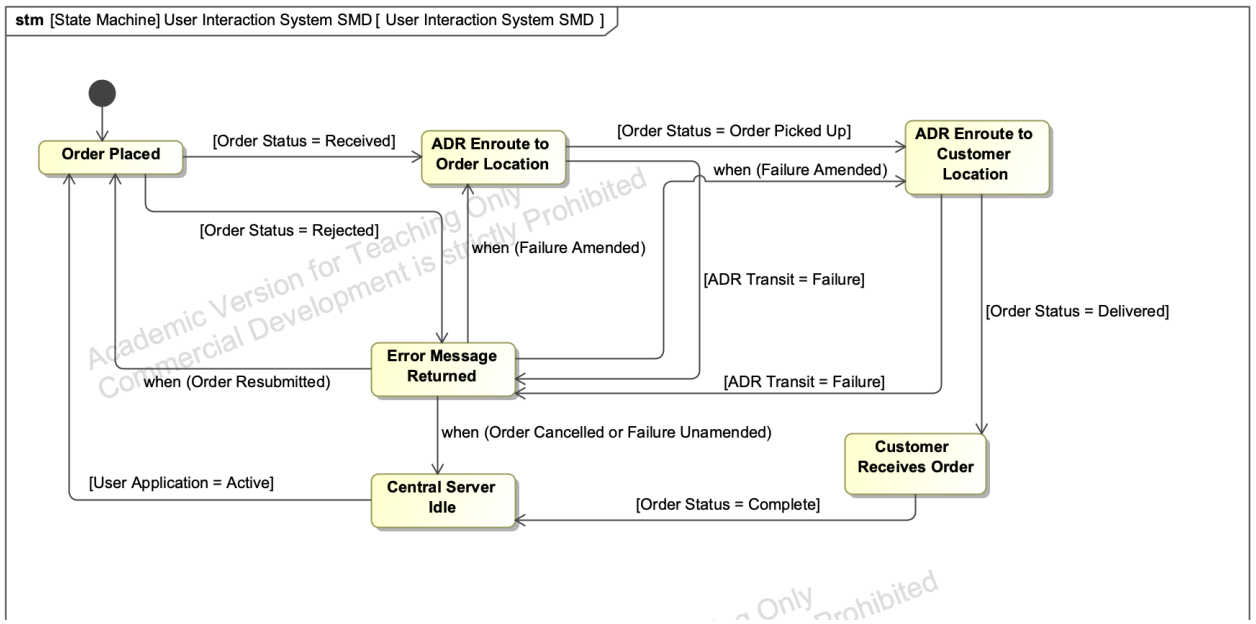

Figure 18: System-Level SMD for User Interaction System.

8.3. System-Level SMD for Maintenance Element

Figure 19 provides the system-level SMD for the Maintenance Element. The purpose of this diagram is to show the maintenance states required for proper functionality of the ADR and the triggers or actions taken to initiate each maintenance state.

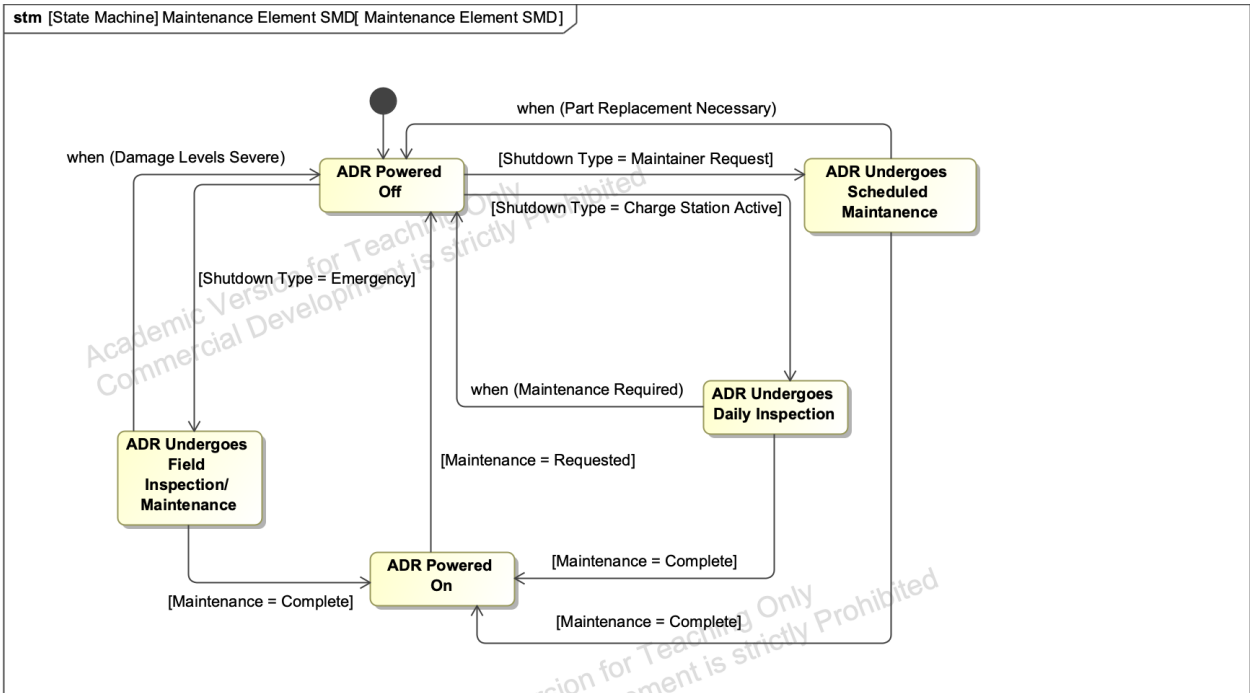

Figure 19: System-Level SMD for Maintenance Element.

9. Package Diagrams

The architecture of the ADR system is provided in a SysML Package Diagram as shown above in Figure 20. The System Element Package is used to create and organize the model into sub-packages which consists of several SysML diagrams. The purpose of it is to help model navigation and reuse, and access and change control. The whole system of interest can be organized into Behavior Diagrams, Structure Diagrams, and Requirements. And they can be divided into sub-packages for easy documentation of the several SysML diagram types.

The system-level architecture diagram is found in the “ADR system Architecture” package.

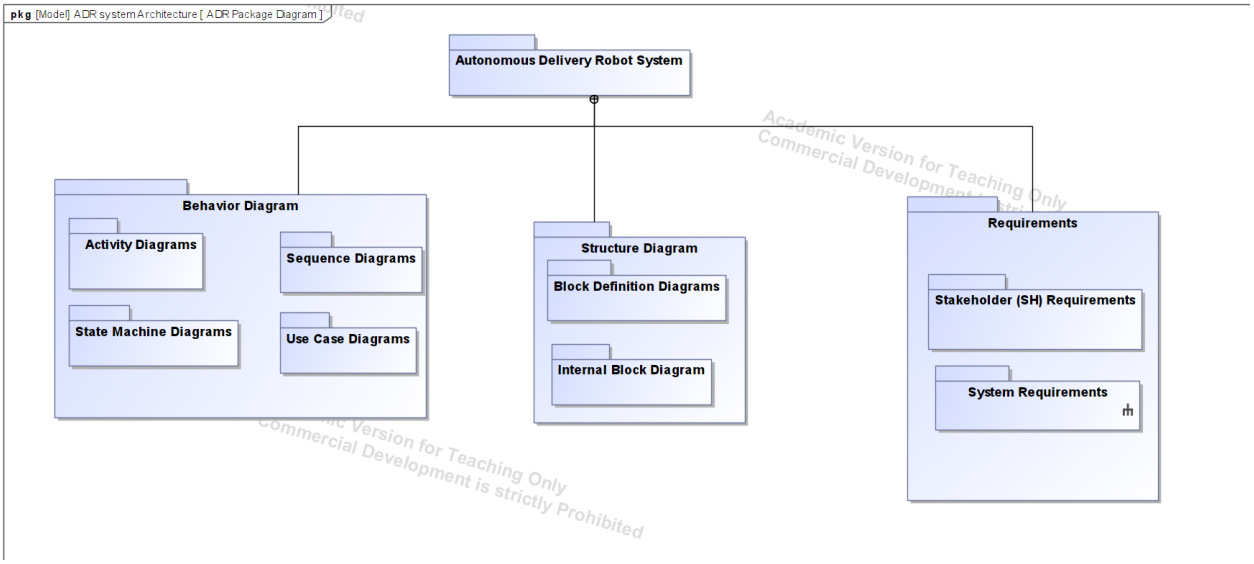

Figure 20: SysML Package Diagram for ADR