Autonomous Delivery Robot (ADR)

Stakeholder Requirements

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1. Introduction

1.1. Document Purpose

This document enlists the Stakeholders Requirements for the Autonomous Delivery Robot (ADR) and it will lead towards the development of system-level architecture and the system requirements.

1.2. System Description

The ADR system is developed essentially for educational institutions seeking to automate the delivery system on campus. One part of the ADR system is a complete autonomous delivery robot capable of navigating its path across the campus using advanced planning algorithms. The robot is equipped with vision sensors, which would make the robot aware of its surroundings for dynamic obstacle avoidance and decision-making. The proposed system is equipped with individual compartments for material storage with sensors onboard for detecting the presence of the item. In addition, it also features an electronic lock system controlled via the app (QR code) to mainly avert theft and unintentional swapping of delivery items.

To make this system a bit more customer and client-friendly, an app is designed for the customer and the client team. The customer app lets them know various details about the robot such as location, estimated time of arrival, pickup time, and also a unique QR code for accessing the specific compartment of their item. The client app helps them control and manage multiple robots around the campus by providing data such as location, battery status, distress signal alerts in case the robot is stuck or has faced unforeseen circumstances, and timings of pickup and dropoff of the package. The management system provides maintenance and logistical support for the ADRs including charging, cleaning, and regular maintenance. This system requires minimal human effort and reduces human error. It increases efficiency and also assures the delivery of the package safely.

The primary stakeholders for our system would be companies like **Uber Eats, DoorDash, FedEx,** and **UPS**. The secondary stakeholders for our system would be private and state-owned Universities.

1.3. Document Overview

This section provides an overview of the structure of the document and other references that are being followed, Subsection 1 it is organized as follows:

1. Section 1 describes the purpose of this document, the System Description, and the document overview.
    - 1.1. Subsection 1.1 defines the purpose of this document.
    - 1.2. Subsection 1.2 describes the system that is being developed.
    - 1.3. Subsection 1.3 defines the document's organizational structure.
2. Section 2 lists all the references used to create the document.
3. Section 3 lists all the programmatic requirements of the system.
    - 3.1. Subsection 3.1 lists all the Deployment Schedule related Requirements.
    - 3.2. Subsection 3.2 lists all the Cost Constraints associated with the ADR.
    - 3.3. Subsection 3.3 lists all the Regulatory/Statutory/Certification Requirements of the ADR.
    - 3.4. Subsection 3.4 lists all the Unit Operational Life Requirements of the ADR.

3.5. Subsection 3.5 lists all the Other Programmatic Requirements of the ADR.

4. Section 4 deals with operational requirements for ADR.
5. Section 5 deals with the data dictionary.
6. Section 6 lists all the key assumptions made.

2. References

The references used in this document are:

1. HW 7 Stakeholder Requirements - 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.
4. Autonomous Delivery Vehicles, by Derick Omondi, 2021. [CrossRef]
5. 621 Wk 5.8 Lecture, Specialty Engineering(SEHB 10), John MacCarthy, 2022.
6. ANSI/ITSDF B56.5 - 2012. [CrossRef]
7. ISO 13482:2014. [CrossRef]
8. ANSI/RIA R15.08-1-2020. [CrossRef]

3. Programmatic Requirements

The programmatic requirements are tabulated in Table 1 with their descriptions. The SysML Programmatic Requirements Diagram is shown in Figure 1.

Table 1: Programmatic Requirements

ID	Requirement	Description
SHR1.1	Schedule Requirement	The ADR system shall be operational by May 2023.
SHR1.2	System Life Cycle Cost	The ADR shall have a unit cost less than $7000.
SHR1.3	Operational Life	The ADR shall have an operational life greater than 5 years.
SHR1.4	Regulations	The ADR shall get the necessary certifications and follow safety regulations: 1. Road Safety rules and regulations. 2. ANSI/ITSDF B56.5 - 2012, Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles (Effective from 03/01/13). 3. ISO 13482:2014. 4. ANSI/RIA R15.08-1-2020 Safety standard .
SHR1.5	Other Programmatic Requirements	None.

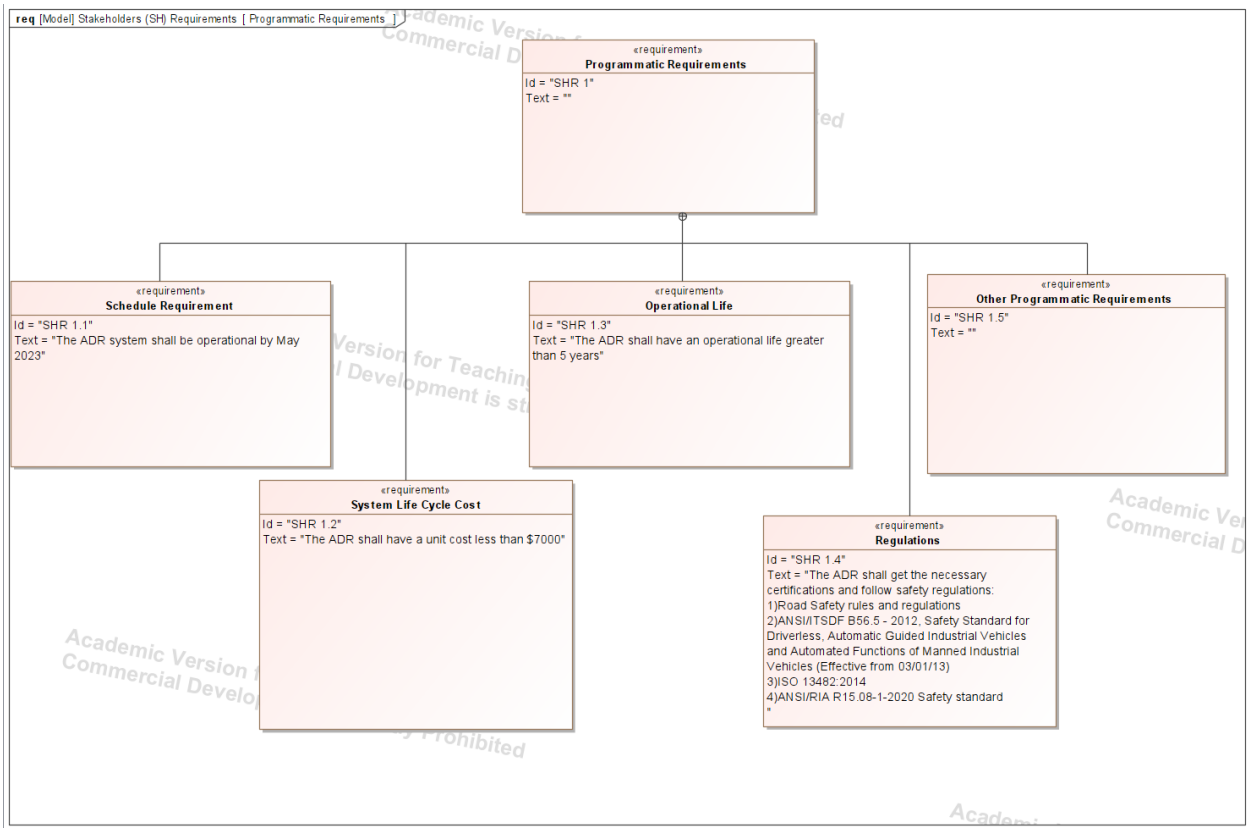

Figure 1: Programmatic Requirements SysML Diagram

3.1. Deployment Schedule Requirements

The tentative deployment schedule for the ADR system is that it shall be operational by May 2023.

3.2. Cost Constraints

Considering the total life cycle cost constraints and other cost constraints like development, unit production cost, Operation and Supports costs, etc.. the total cost of an ADR shall be approximately $7000/unit.

3.3. Regulatory/Statutory/Certification Requirements

The following Regulatory/statutory/certification requirements are considered for the ADR system:

1. The maximum speed of the ADR is limited by the maximum speed permissible according to road safety rules of the particular road it's navigating.
2. ANSI/ITSDF B56.5 - 2012, Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles Effective 03/01/13. This Standard defines the safety requirements relating to the elements of design, operation, and maintenance of powered, not mechanically restrained, unmanned automatic guided industrial vehicles and the system of which the vehicles are a part. It also applies to vehicles modified to operate in an unmanned, automatic mode, or semiautomatic, manual, or maintenance mode.
3. ISO 13482:2014 describes hazards associated with the use of these robots and provides requirements to eliminate, or reduce, the risks associated with these hazards to an acceptable level.

4. ANSI/RIA R15.08-1-2020 is meant for the manufacturer of the industrial mobile robot, and what safety requirements the industrial mobile robot must meet. It indicates how to design and manufacture a safe industrial mobile robot.
5. According to international standards, the emergency stop function must be initiated by a single human action using a manually actuated control device designed to stop the machine without creating additional hazards.

3.4. Unit Operational Life Requirements

The operational life of the ADR system shall be greater than 5 years when all maintenance procedures are followed timely.

3.5. Other Programmatic Requirements

There are no other programming requirements.

4. System Operational Requirements

4.1. Performance Requirements and Constraints

Table 2 identifies the Measures of Effectiveness (MOEs) for the ADR system and their associated threshold and objective values.

Table 2: ADR System MOEs

Cap ID	Attributes	Metric	MOE ID	Definition	Threshold Value (units)	Objective Value (units)
C5	Endurance	Continuous operating time	MOE1	Maximum Operational Time on a single charge.	> 4 hours	> 8 hours
C3 & C5	Operational Range	Operational radius	MOE2	Maximum operational range (radius) on a single charge.	> 1 mile	> 2 miles
C4	Payload	Payload Capacity	MOE3	Maximum payload capacity.	> 50 lbs	> 100 lbs
C5	Charging Time	Time to charge	MOE4	Empty to full charging time.	< 4 hours	< 2 hours
C6	Communication Range	Radius for optimal communication	MOE5	Maximum communication (telemetry) range from central server.	> 1 mile	> 2 miles
C1 & C2	Collision avoidance	Farthest object detected	MOE6	Perception Range for Collision avoidance.	> 66 ft	> 165 ft

C3	Operational Speed	Maximum safe navigational speed	MOE7	Maximum Operational speed.	> 5 mph	> 15 mph

The performance requirements are tabulated in Table 3 with their descriptions. The SysML Programmatic Requirements Diagram is shown in Figure 2.

Table 3: Performance Requirements

ID	Requirement	Description
SHR2.1	Operation Time	The ADR shall be able operate for at least 8 hours on a single charge.
SHR2.2	Operational Range	The ADR shall be fully functional within a 2 mile radius from the central server.
SHR2.3	Payload Capacity	The ADR shall be able to carry packages upto 100 lbs.
SHR2.4	Automated Charging	The ADR shall be able to monitor battery levels and charge when needed.
SHR2.5	Collision Avoidance	The ADR shall be able to detect its surroundings and avoid collision.

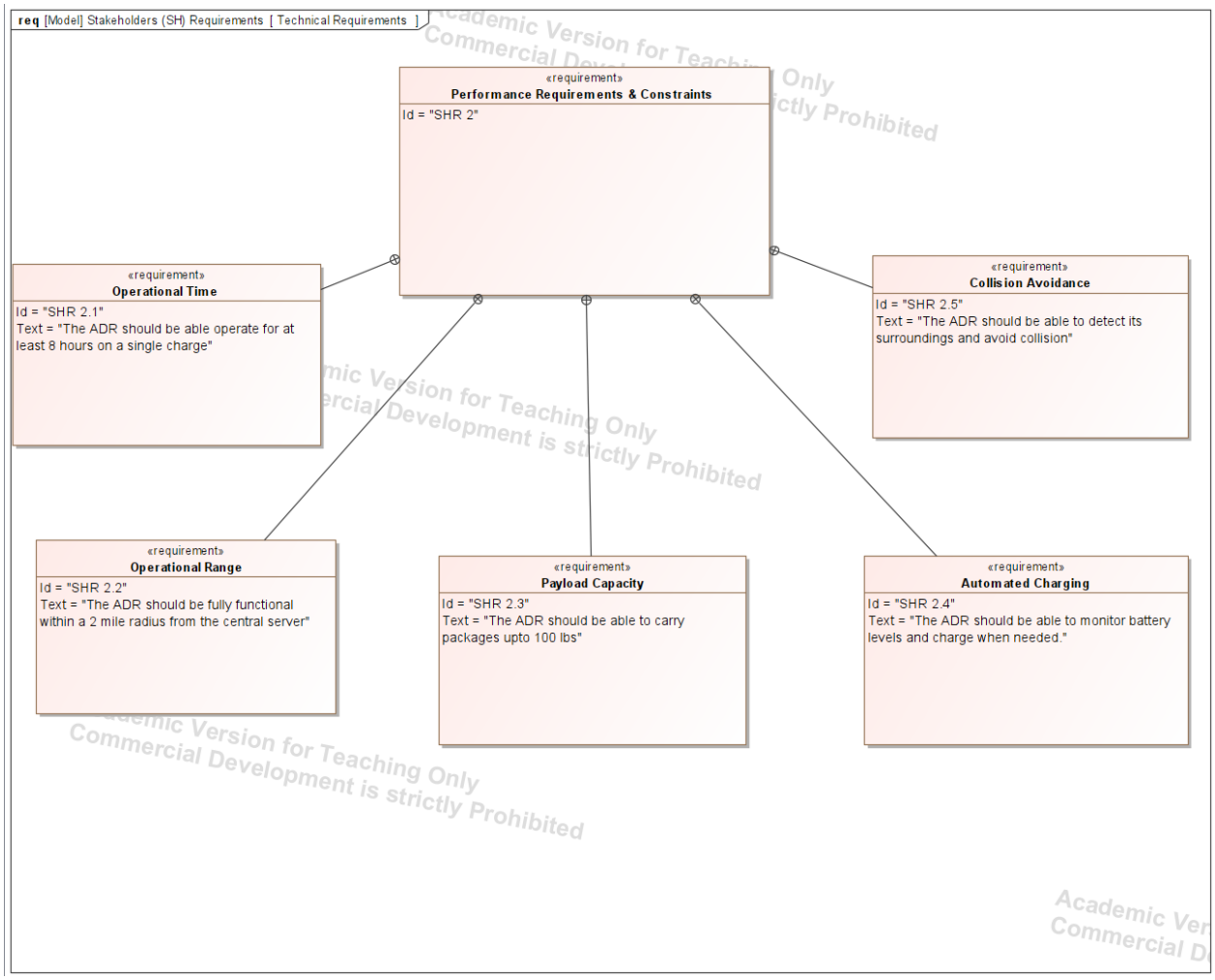

Figure 2: Performance Requirements SysML Diagram

4.2. Functional Requirements

This section identifies functional requirements that have not been addressed in the prior sections. The functional requirements are tabulated in Table 4 with their descriptions. The SysML Functional Requirements Diagram is shown in Figure 3.

Table 4: Functional Requirements

ID	Requirement	Description
SHR5.1	Speed	The ADR shall be able to maintain speeds up to 20 mph at full payload capacity.
SHR5.2	Battery Capacity	The ADR shall have a minimum battery capacity of 1kWh.
SHR5.3	Dimensions	The dimensions of ADR would be limited such that it can navigate on sidewalks. The dimensions of the ADR are: Length: 4 ft

		Width: 2 ft Height: 3 ft
SHR5.4	Minimum Ground Clearance	The ADR shall be able to climb over small obstacles like rocks and debris. The minimum ground clearance of the ADR should be 5 inches.
SHR5.5	Climbing inclination	The ADR shall be able to climb up or down an inclination of 22 degrees at full payload.

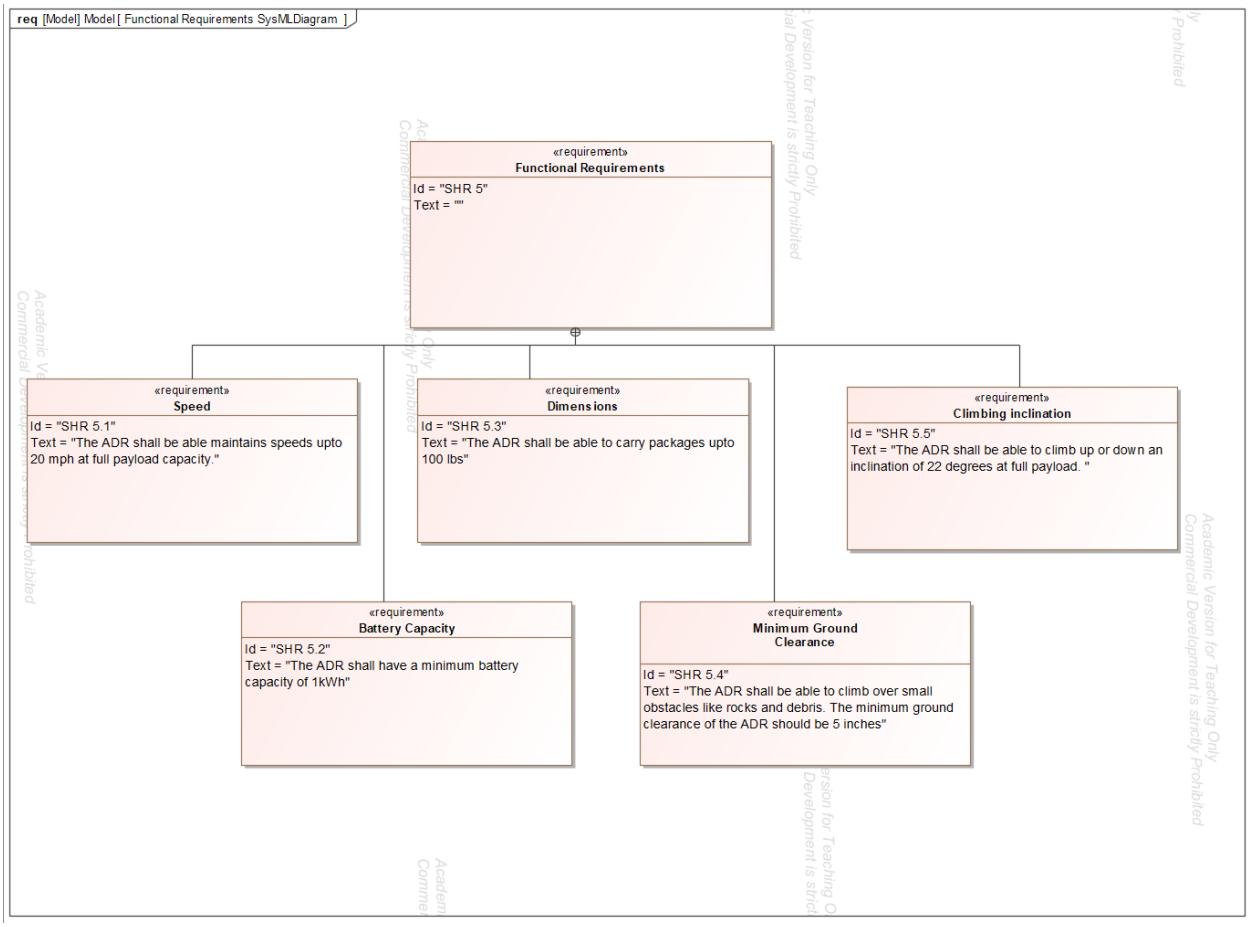

Figure 3: Functional Requirements SysML Diagram

4.3. External Interface Requirements

This section identifies the external interface requirements for the ADR system including user interface requirements and external system interface requirements.

4.3.1. User Interface Requirements

The user interface requirements are shown and described below in Table 5.

Table 5: User Interface Requirements

ID	Name	Requirement
SHR3.1.1	Authenticated Payload Bay	The sender and receiver using the ADR shall be able to open the payload bay by scanning a QR code.
SHR3.1.2	Emergency Stop	The ADR shall have an emergency stop button that can be triggered by the central server and the maintainer.
SHR3.1.3	Power Button	The maintainer shall be able to power off the ADR.
SHR3.1.4	Data Logging	The maintainer shall be able to access the sensor feed, telemetry log and event log of the ADR.
SHR3.1.5	Firmware Update	The maintainer shall be able to load and update firmware on the ADR.

4.3.2. External System Interface Requirements

The external system interface requirements are shown and described below in Table 6.

Table 6: External System Interface Requirements

ID	Name	Requirement
SHR3.2.1	Communication with central server	ADRs are able to communicate with the central server to send its own status and location and receive tasks.
SHR3.2.2	Communication with other ADRs	ADRs are able to communicate with each other to avoid collisions and better manage tasks.

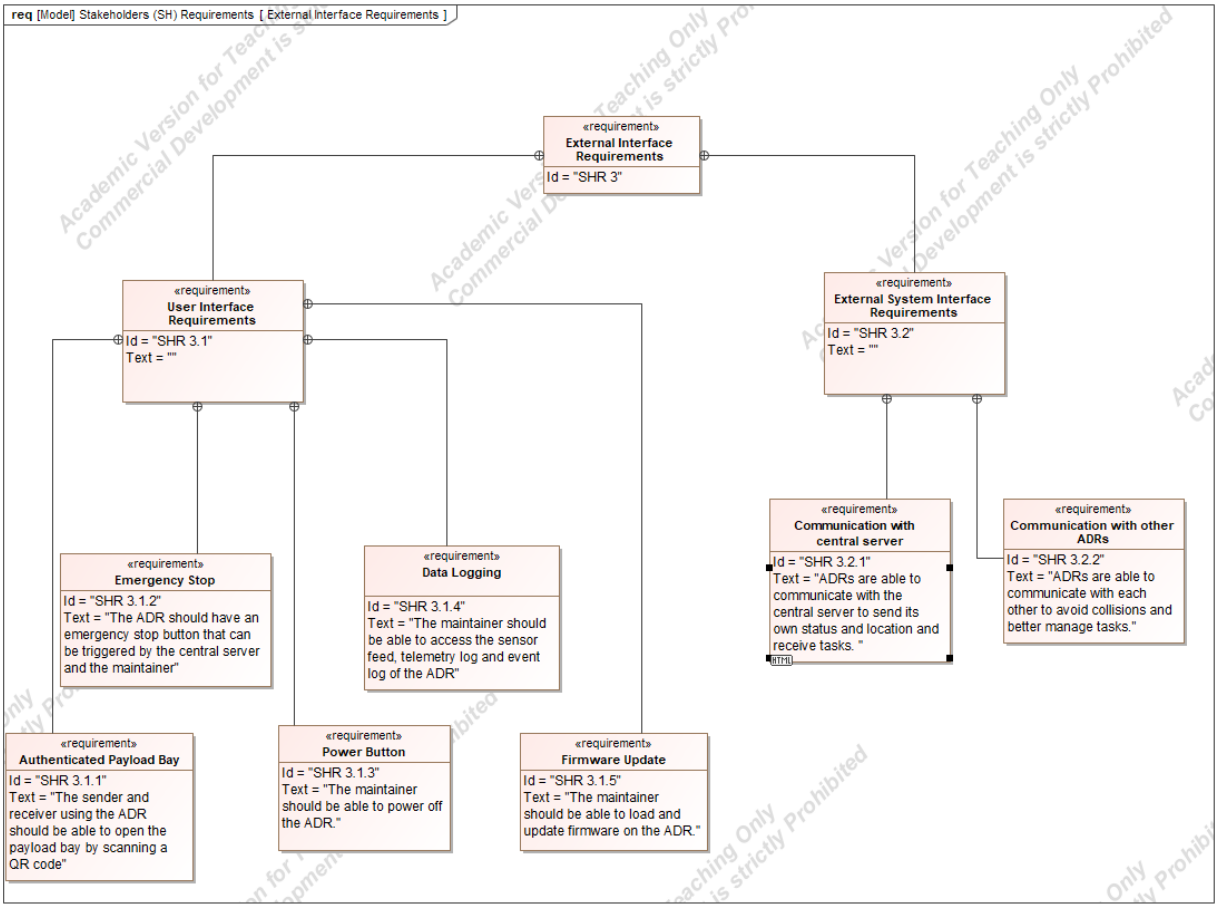

Figure 4: External Interface Requirements SysML Diagram

4.4. Specialty Engineering Requirements

All specialty engineering-related requirements of the ADR system are shown and described below in Table 7.

Table 7: Specialty Engineering Requirements [5]

ID	Name	Requirement
SHR4.1	Affordability	Find the balance of system performance, cost and schedule constraints over the whole life cycle to accomplish the ADR system.
SHR4.2	Interoperability	The elements of the ADR system need to be compatible with each other and they can communicate with each other as well.
SHR4.3	System Safety Engineering	The design of the ADR system needs to fulfill all the safety related requirements throughout the life cycle.
SHR4.4	System Security Engineering	The ADR system needs to ensure that the user information stored in the database of the central server

		is secured.
SHR4.5	Manufacturing and Producibility	It needs to simplify the design of the ADR system as well as stabilize the manufacture of ADRs to reduce risk and cost.
SHR4.6	Reliability, Availability, and Maintainability	It needs to ensure the reliability of the ADR system during its entire life cycle and determine the probability of a satisfying performance of the ADR system at any requested time and the maintenance cost and times.
SHR4.7	Training Needs	It needs to consider how much training is necessary for the maintenance staff for the ADR system.

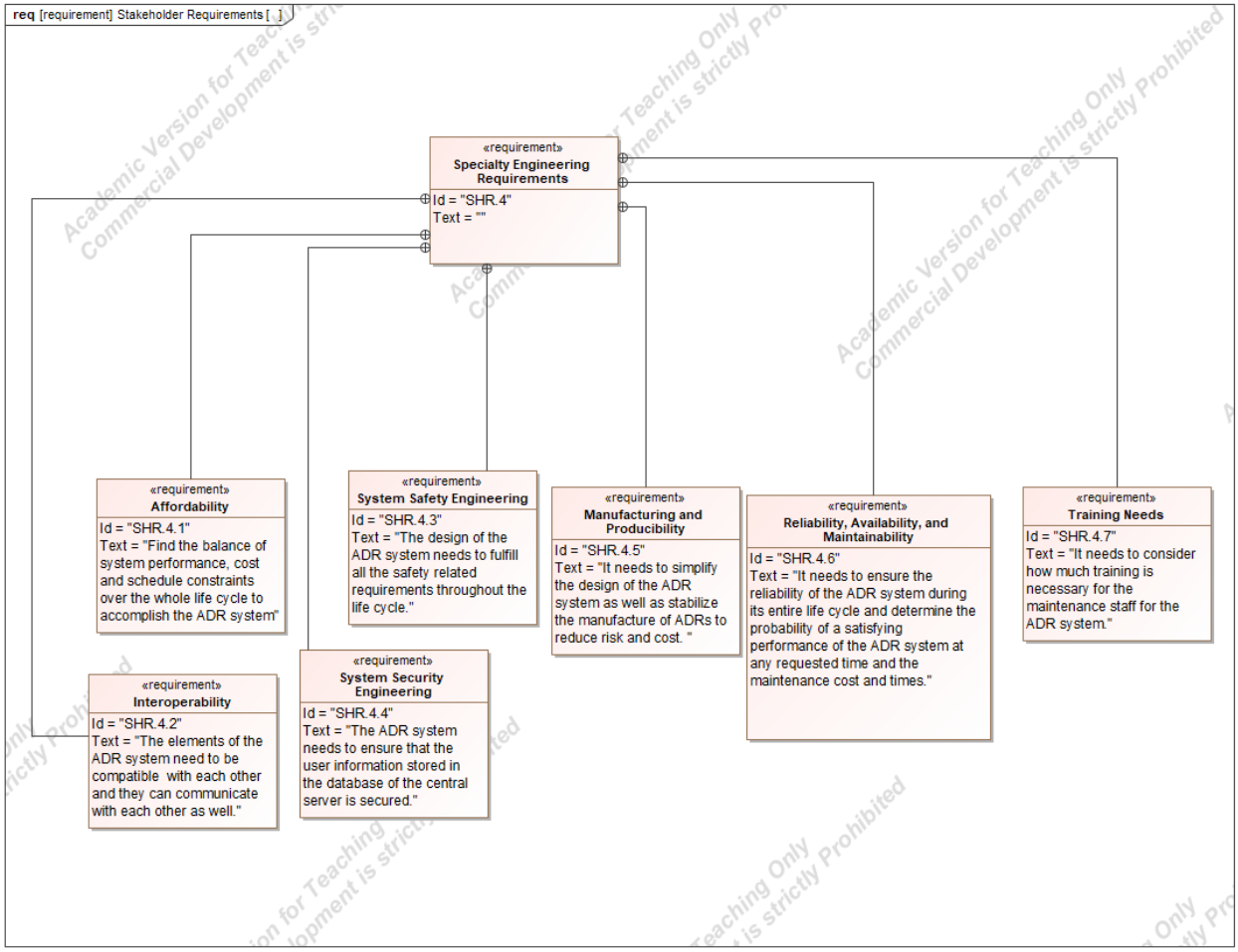

Figure 5: Specialty Engineering Requirements SysML Diagram

4.5. Other Operational Requirements

There are no other operational requirements at this time.

5. Data Dictionary

Major constraints on the ADR system include:

1. Dimensional constraints as to not overcrowd the sidewalk but hold the desired number of payload bins as specified by the stakeholder.
2. The minimum operational and communication range as specified by the stakeholder.
3. The minimum battery lifetime for a single charge as specified by the stakeholder.
4. The minimum payload capacity as specified by the stakeholder.
5. Maximum navigation speed as to not exceed sidewalk regulations, but meet the stakeholder's satisfaction.
6. Maximum perception distance as specified by the stakeholder.

6. Assumptions

Some assumptions made for the ADR system are:

1. Inclement weather patterns (such as rain, wind, or light snow) will not have severe effects on sensor/perception capabilities.
2. Selected materials for the ADRs will not wear in inclement weather conditions.
3. The system material is tested for the durability to carry a load of about 100 lbs but it assumes that there will be no extreme Impulse force of such degree on the system.

Appendices

Appendix A: Acronym List

This appendix defines all acronyms used in the document.

1. ADR stands for Autonomous Delivery Robot.
2. SHR stands for Stakeholder's Requirement. SHR# stands for Stakeholder Requirement ID.
3. C stands for Capability.
4. Cap stands for Capability.
5. MOE stands for Measure Of Effectiveness.
6. QR code stands for quick response code.

Appendix B: Definitions

This appendix provides definitions for parameters and specialized terms that were not defined in the main body itself.

1. ANSI: The American National Standards Institute is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States.
2. ANSI/ITSDF B56.5 - 2012, Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles (Effective from 03/01/13).
3. ISO 13482:2014.
4. ANSI/RIA R15.08-1-2020 Safety standard for ADR: The R15.08 defines is the safety standards for Industrial Mobile Robots (IMR, also known as ADR). The arrival of Autonomous Delivery Robots (ADR), with their advanced navigation able to bypass obstacles by autonomously redefining new paths, has raised new challenges related to the safety requirements of such robots.
5. ISO (International Organization for Standardization) is an independent, non-governmental, international organization that develops standards to ensure the quality, safety, and efficiency of products, services, and systems.

Appendix C: System Capabilities

The system capabilities and their priorities are documented in Table 8.

Table 8: ADR System capabilities and their priorities

Cap ID	Capability	Rationale	Priority
C1.1	Detect sidewalks, roads, pedestrian crossings, and road signs.	Defines "Path Detection".	1
C1.2	Detect Motor vehicles, pedestrians, cyclists, animals, and similar dynamic obstacles.	Defines "Dynamic Obstacle Detection".	2
C1.3	Detect plants, trees, buildings, railing, and similar static obstacles.	Defines "Static Obstacle Detection" .	3

C1.4	Detect and identify other ADRs.	Defines “Dynamic Obstacle Detection”.	4
C2	Avoid Collisions with dynamic and static obstacles in the surroundings.	Defines “Safety”.	5
C3	Navigate on the given path following road safety laws.	Defines “Navigation”.	6
C4	Carry payloads from source to destination as assigned.	Defines” Payload Delivery”.	7
C5	Monitor the remaining battery and return to the charging station at the failsafe level.	Defines “Status Monitoring”.	8
C6.1	Provide tracking status and maintain communication with the central server.	Defines “Communication”.	9
C6.2	Report theft, vandalism, or tampering with the ADR and its payload.	Defines “Security”.	10
C7	Open respective payload bay among the segmented payload bays when authorized.	Defines “Security”.	11