

# **Autonomous Delivery Robot (ADR)**

## **System Requirements Document**

CLIN: HW9

Version Number: 1.0

Version Date: 11/01/2022

Team Name: Team 3

Lead Author: Mukundhan Rajendiran

Contributing Author(s): Sidney Leigh Molnar, Manu Madhu Pillai, Xinyi Yang

# Table of Contents

## System Requirements Document

<b>Table of Contents</b>	<b>2</b>
<b>1. Introduction</b>	<b>3</b>
1.1. Document Purpose	3
1.2. Brief System Description & Operational Concept	3
1.3. Document Overview	5
<b>2. List of References</b>	<b>5</b>
<b>3. Requirements</b>	<b>5</b>
3.1. Required States and Modes	5
3.2. System Capability Requirements	9
3.3. System External Interface Requirements	10
3.4. System Internal Interface Requirements	11
3.5. Design Constraints	13
3.6. Other Requirements	13
<b>4. Data Dictionary</b>	<b>13</b>
<b>5. Requirements Verification Matrix</b>	<b>15</b>
<b>6. Requirements Traceability Matrix</b>	<b>31</b>
<b>7. Requirements Allocation Matrix</b>	<b>42</b>
<b>Appendices</b>	<b>48</b>
A. Assumptions	48
B. Acronyms	48
C. Definitions	48

## 1. Introduction

### 1.1. Document Purpose

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

### 1.2. Brief System Description & Operational Concept

The ADR system consists of the following subsystems and their respective functionalities described below:

1. Sensor System: This sub-system is responsible for capturing raw sensor data acquired from the environment.
2. Locomotion System: This sub-system is responsible for the motion control of the ADR.
3. Computing System: This sub-system is responsible for the processing of the sensor data and navigational decision making of the ADR.
4. Communication System: This sub-system is responsible for maintaining the connectivity between the ADR and the central server.
5. Power System: This sub-system is responsible for providing the electrical energy needs of the ADR.

The principal system users are the Central server, sender, receiver and the maintainer. The environment consists of operational area, maintenance bay and charging station. The operational area consists of static obstacles, dynamic obstacles, and other ADRs.

The most important capabilities of the system in order of priority are listed in Table 1 below:

Table 1: Prioritized Capability List

Capability I.D.	Capability	Priority
C1.1	Detect sidewalks, roads, pedestrian crossings, and road signs.	1
C1.2	Detect Motor vehicles, pedestrians, cyclists, animals, and similar dynamic obstacles.	2
C1.3	Detect plants, trees, buildings, railings, and similar static obstacles.	3
C1.4	Detect and identify other ADRs.	4
C2	Avoid Collisions with dynamic and static obstacles in the surroundings.	5

C3	Navigate on the given path following road safety laws.	6
C4	Carry payloads from source to destination as assigned.	7
C5	Monitor the remaining battery and return to the charging station at the failsafe level.	8
C6.1	Provide tracking status and maintain communication with the central server.	9
C6.2	Report theft, vandalism, or tampering with the ADR and its payload.	10
C7	Open respective payload bay among the segmented payload bays when authorized.	11

The system measures of effectiveness (MOE) with their associated threshold and objective values are shown in Table 2.

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

### **1.3. 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 System & Operational Concept description, and the organizational structure of the document.
  - 1.1. Subsection 1.1 defines the purpose of this document
  - 1.2. Subsection 1.2 describes a brief system concept description of the system being developed, the users and the environment with which the system interacts, and identifies the principle MOEs.
  - 1.3. Subsection 1.3 defines the document's organizational overview.
2. Section 2 provides a list of references used in the generation of this document.
3. Section 3 provides the System Requirements of the ADR.
  - 3.1. Section 3.1 provides the required states and modes of the ADR system.
  - 3.2. Section 3.2 provides the System Capability Requirements.
  - 3.3. Section 3.3 provides the System External Interface Requirements.
  - 3.4. Section 3.4 provides the System Internal Interface Requirements.
  - 3.5. Section 3.5 provides the Design Constraints.
  - 3.6. Section 3.6 provides the Other Requirements.
4. Section 4 provides the Data Dictionary for the defines the data structures referenced in Sections 3.3 and 3.4.
5. Section 5 provides the Requirement Verification Matrix.
6. Section 6 provides the Requirements Traceability Matrix.
7. Section 7 provides the Requirement Allocation Matrix.

## **2. List of References**

The references used in this document are as follows:

1. HW 9 System Requirements - Template - V1, by Dr. Tony Barber, 2022.
2. HW6 Team 3 Project System Concept Description – Part 2, by Manu Madhu Pillai, Sidney Leigh Molnar, Mukundhan Rajendiran, Xinyi Yang, 2022.
3. HW7 Team 3 Stakeholder Requirements, by Mukundhan Rajendiran, Sidney Leigh Molnar, Manu Madhu Pillai, Xinyi Yang, 2022.
4. HW8 Team 3 System-Level Architecture, by Sidney Leigh Molnar, Mukundhan Rajendiran, Manu Madhu Pillai, Xinyi Yang, 2022.

## **3. Requirements**

### **3.1. Required States and Modes**

This section identifies transitions between the states/modes of the ADR system and its associated elements.

3.1.1. ADR States.

- 3.1.1.1. The ADR shall have the following states: Maintenance Bay, Navigation, Order Loaded, Order Emptied, Emergency Alert, Field Inspection, Scheduled Maintenance, and Charging.
- 3.1.1.2. The ADR shall transition from the Maintenance Bay state to its Navigation state if an order request is received.
- 3.1.1.3. The ADR shall transition from the Navigation state to the Maintenance Bay state when order requests are complete, and no maintenance is required.
- 3.1.1.4. The ADR shall transition from the Navigation state to the Order Loaded state if the navigation goal achieved is at the order location.
- 3.1.1.5. The ADR shall transition from the Order Loaded state to the Navigation state if the payload lid is closed after the order is placed within the payload.
- 3.1.1.6. The ADR shall transition from the Order Loaded state to the Emergency Alert state if the payload lid is left open and unattended after the order is placed within the payload.
- 3.1.1.7. The ADR shall transition from the Navigation state to the Emergency Alert state if a threat is detected in transit.
- 3.1.1.8. The ADR shall transition from the Emergency Alert state to the Navigation state if the threat is deemed to be avoided, or the payload lid is shut.
- 3.1.1.9. The ADR shall transition from the Emergency Alert state to the Field Inspection state if damage to the ADR is deemed critical, such that it inhibits further navigation.
- 3.1.1.10. The ADR shall transition from the Navigation state to the Order Emptied state if the navigation goal achieved is the customer location.
- 3.1.1.11. The ADR shall transition from the Order Emptied state to the Navigation state if the payload lid is closed after the order has been taken by the customer.
- 3.1.1.12. The ADR shall transition from the Order Emptied state to the Emergency Alert state if the lid is left open and unattended after the order has been taken by the customer.
- 3.1.1.13. The ADR shall transition from the Field Inspection state to the Scheduled Maintenance state if field maintenance is deemed necessary after the damage to the ADR has been inspected.

- 3.1.1.14. The ADR shall transition from the Scheduled Maintenance state to the Maintenance Bay state once maintenance on the ADR is complete.
- 3.1.1.15. The ADR shall transition from the Maintenance Bay state to the Scheduled Maintenance state if maintenance is requested for an ADR in storage.
- 3.1.1.16. The ADR shall transition from the Navigation state to the Charging state if the detected battery power is deemed to be “low” (< 20% battery capacity).
- 3.1.1.17. The ADR shall transition from the Charging state to the Maintenance Bay state once the ADR regains a full charge (100% battery capacity).
- 3.1.2. States for the User Interaction System (UIS) Element.
  - 3.1.2.1. The UIS shall have the following states: Order Placement, Order Transit, Customer Transit, Customer Reception, Error, and Idle.
  - 3.1.2.2. The UIS shall transition from the Order Placement state to the Order Transit state if the order placed has been accepted by an ADR.
  - 3.1.2.3. The UIS shall transition from the Order Placement state to the Error state if the order placed has been rejected by the central server.
  - 3.1.2.4. The UIS shall transition from the Error state to the Order Placement state if the order is resubmitted by the customer after it has been rejected by the central server.
  - 3.1.2.5. The UIS shall transition from the Order Transit state to the Customer Transit state if the order has been successfully picked up by the ADR.
  - 3.1.2.6. The UIS shall transition from the Order Transit state to the Error state if the ADR endures a navigation failure while in transit.
  - 3.1.2.7. The UIS shall transition from the Error state to the Order Transit state once the navigation failure has been amended.
  - 3.1.2.8. The UIS shall transition from the Customer Transit state to the Customer Reception state if the order has been delivered to (received by) the customer.
  - 3.1.2.9. The UIS shall transition from the Customer Transit state to the Error state if the ADR endures a navigation failure while in transit.
  - 3.1.2.10. The UIS shall transition from the Error state to the Customer Transit state once the navigation failure has been amended.

- 3.1.2.11. The UIS shall transition from the Customer Reception state to the Idle state once the order status is deemed complete (i.e. the order is delivered and the ADR moves to its next task).
- 3.1.2.12. The UIS shall transition from the Error state to the Idle state when an order has been canceled or a navigation failure is not able to be amended.
- 3.1.2.13. The UIS shall transition from the Idle state to the Order Placement state if the user application is deemed active.
- 3.1.3. States for the Maintenance Element (ME).
  - 3.1.3.1. The ME shall have the following states: OFF, Scheduled Maintenance, Daily Inspection, Field Maintenance/Inspection, and ON.
  - 3.1.3.2. The ME shall transition from the OFF state to the Scheduled Maintenance state if the ADR is shutdown by the maintainer's request.
  - 3.1.3.3. The ME shall transition from the Scheduled Maintenance state to the OFF state when a part replacement is necessary.
  - 3.1.3.4. The ME shall transition from the Scheduled Maintenance state to the ON state when scheduled maintenance tasks are complete.
  - 3.1.3.5. The ME shall transition from the OFF state to the Daily Inspection state if the ADR is shutdown by an active charge station.
  - 3.1.3.6. The ME shall transition from the Daily Inspection state to the OFF state when further maintenance is required.
  - 3.1.3.7. The ME shall transition from the Daily Inspection state to the ON state if daily inspection tasks are complete.
  - 3.1.3.8. The ME shall transition from the OFF state to the Field Maintenance/Inspection state if the ADR is shutdown due to an emergency alert while in transit.
  - 3.1.3.9. The ME shall transition from the Field Maintenance/Inspection state to the OFF state if damage levels are severe (i.e. the ADR is no longer fit for navigation purposes).
  - 3.1.3.10. The ME shall transition from the Field Maintenance/Inspection state to the ON state once all field maintenance and inspection tasks are complete.
  - 3.1.3.11. The ME shall transition from the ON state to the OFF state if maintenance services have been requested by the ADR or maintainer.



## **3.2. System Capability Requirements**

This section identifies functional and performance requirements for the system.

### **3.2.1. Sensor System Requirements.**

#### **3.2.1.1. Optical Sensing Requirements.**

- 3.2.1.1.1. The ADR shall detect sidewalks, roads, pedestrian crossings, and road signs.
- 3.2.1.1.2. The ADR shall detect Motor vehicles, pedestrians, cyclists, animals, and similar dynamic obstacles.
- 3.2.1.1.3. The ADR shall detect plants, trees, buildings, railings, and similar static obstacles.
- 3.2.1.1.4. The ADR shall detect and identify other ADRs.
- 3.2.1.1.5. The ADR shall detect every static and dynamic obstacle in its line of sight within a distance of 165 ft.

#### **3.2.1.2. Global Positioning System Sensing Requirements.**

- 3.2.1.2.1. The ADR shall detect its Global Positioning System (GPS) coordinates with 4 ft accuracy.

#### **3.2.1.3. Proximity Sensing Requirements.**

- 3.2.1.3.1. The ADR shall detect and identify every entity in near proximity of 4ft.

### **3.2.2. Locomotion System Requirements.**

- 3.2.2.1. The ADR shall have a maximum speed of 15 mph.
- 3.2.2.2. The ADR shall lift a maximum payload of 100 lbs.
- 3.2.2.3. The ADR shall have a turning radius of 2.5 ft.
- 3.2.2.4. The ADR shall have a turning speed of 0.785 rad/sec.

### **3.2.3. Computing System Requirements.**

- 3.2.3.1. The ADR shall process information from the optical sensors, GPS sensors, and proximity sensors to make navigational decisions.

### **3.2.4. Communication System Requirements.**

- 3.2.4.1. The ADR shall use 915 MHz for its communication with the central server.
- 3.2.4.2. The ADR shall have a 4G LTE (Long-Term Evolution) cellular connectivity for redundant communication with the central server.
- 3.2.4.3. The ADR shall have two long range omnidirectional 915 Mhz antennas.
- 3.2.4.4. The ADR shall have an omnidirectional 4G LTE antenna.
- 3.2.4.5. THE ADR shall have a communication range of 2 miles.

### **3.2.5. Power System Requirements.**

- 3.2.5.1. The ADR shall have an operational time of 8 hours on a single charge.
- 3.2.5.2. The ADR shall have a sensor to measure battery voltage and calculate battery percentage.
- 3.2.5.3. The ADR shall have temperature sensors for its battery packs.
- 3.2.5.4. The ADR shall enter into an overheat failure mode when the operating temperature rises over 115 F.

### **3.2.6. Availability Requirements.**

- 3.2.6.1. The ADR shall have a steady state operational availability greater than 0.8.

- 3.2.6.2. The sensor subsystem shall have a mean time between critical failures (MTBCF) greater than 2000 hours.
- 3.2.6.3. The locomotion subsystem shall have a mean time between critical failures (MTBCF) greater than 1000 hours.
- 3.2.6.4. The computing subsystem shall have a mean time between critical failures (MTBCF) greater than 2000 hours.
- 3.2.6.5. The communication subsystem shall have a mean time between critical failures (MTBCF) greater than 2000 hours.
- 3.2.6.6. The power subsystem shall have a mean time between critical failures (MTBCF) greater than 1500 hours.
- 3.2.6.7. The ADR shall have a mean maintenance time less than 2 hours.
- 3.2.7. Accessibility Requirements.
  - 3.2.7.1. The ADR shall store a log containing time stamped history of each task performed.
  - 3.2.7.2. The ADR shall store maintenance history for each ADR element.
  - 3.2.7.3. The ADR shall provide access to all stored data to authorized users such as central server and maintainer.

### **3.3. System External Interface Requirements**

This section identifies the external systems with which the system of interest (SOI) must interface, as well as requirements for the outputs from the SOI to external systems, the inputs to the SOI from the external systems, and the nature of the interface.

- 3.3.1. Central Server Interface Requirements.
  - 3.3.1.1. Central Server Interface Input Requirements.
    - 3.3.1.1.1. The ADR system shall accept task information from the Central Server.
    - 3.3.1.1.2. The ADR system shall accept route information from the Central Server.
  - 3.3.1.2. Central Server Interface Output Requirements.
    - 3.3.1.2.1. The ADR system shall provide its battery level.
    - 3.3.1.2.2. The ADR system shall provide system information.
    - 3.3.1.2.3. The ADR system shall provide the payload bay Information.
    - 3.3.1.2.4. The ADR system shall provide user information.
    - 3.3.1.2.5. The ADR system shall provide locomotion information.
- 3.3.2. Maintainer Interface Requirements.
  - 3.3.2.1. Maintainer Interface Input Requirements.
    - 3.3.2.1.1. The ADR system shall provide maintainers with the tools required to perform maintenance.
    - 3.3.2.1.2. The ADR system shall provide access for firmware updates.
    - 3.3.2.1.3. The ADR system shall provide access for sensor calibration.

- 3.3.2.1.4. The ADR system shall provide self malfunctioning detections to determine errors or failures.
- 3.3.2.1.5. The ADR system shall provide the access to maintainers for parts replacement.
- 3.3.2.1.6. The ADR system shall provide access for inspections.
- 3.3.2.2. Maintainer Interface Output Requirements.
  - 3.3.2.2.1. The ADR system shall provide battery health information.
  - 3.3.2.2.2. The ADR system shall provide connection status information.
  - 3.3.2.2.3. The ADR system shall provide diagnostic information about subsystems.
  - 3.3.2.2.4. The ADR system shall provide diagnostic information about sensors.
- 3.3.3. Environment Interface Requirements.
  - 3.3.3.1. Environment Interface Input Requirements.
    - 3.3.3.1.1. The ADR system shall gather raw video and proximity data from the environment.
    - 3.3.3.1.2. The ADR system shall accept power from a charging station.
  - 3.3.3.2. Environment Interface Output Requirements.
    - 3.3.3.2.1. The ADR system shall interface with operating base utilities - internet access and charging stations etc.
    - 3.3.3.2.2. The ADR system shall provide audio signals.
    - 3.3.3.2.3. The ADR system shall provide visual signals.

### **3.4. System Internal Interface Requirements**

This section identifies the required internal (element-element) interfaces, as well as requirements for the outputs from each element, the inputs to each element, and the nature of each element-element interface.

- 3.4.1. ADR - User Interaction System Interface Requirements.
  - 3.4.1.1. ADR - User Interaction System Interface Input Requirements.
    - 3.4.1.1.1. The ADR shall provide payload bay information.
    - 3.4.1.1.2. The ADR shall provide its system information.
    - 3.4.1.1.3. The ADR shall provide its locomotion information such as speed and acceleration etc.
    - 3.4.1.1.4. The ADR shall provide its task information obtained from the Central Server.
    - 3.4.1.1.5. The ADR shall provide Payload Bay ID Number to ADR.
  - 3.4.1.2. ADR - User Interaction System Interface Output Requirements.
    - 3.4.1.2.1. The User Interaction System shall provide Order ID Number to ADR.

- 3.4.1.2.2. The User Interaction System shall provide confirmation commands in accordance with the payload bay information.
- 3.4.1.2.3. The User Interaction System shall provide payload bay commands in accordance with task information.

#### 3.4.2. ADR - Maintenance System Interface Requirements.

##### 3.4.2.1. ADR - Maintenance System Interface Input Requirements.

- 3.4.2.1.1. The ADR shall provide the system information.
- 3.4.2.1.2. The ADR shall provide its battery levels.
- 3.4.2.1.3. The ADR shall provide malfunctioning detections.

##### 3.4.2.2. ADR - Maintenance System Interface Output Requirements.

- 3.4.2.2.1. The Maintenance System shall provide the ADR field service.
- 3.4.2.2.2. The Maintenance System shall provide the ADR daily maintenance check.
- 3.4.2.2.3. The Maintenance System shall provide the updates to ADRs.
- 3.4.2.2.4. The Maintenance System shall provide the component replacement repair to ADRs.

#### 3.4.3. User Interaction System - Maintenance System Interface Requirements.

##### 3.4.3.1. User Interaction System - Maintenance System Interface Input Requirements.

- 3.4.3.1.1. The User Interaction System shall provide user software feedback.
- 3.4.3.1.2. The User Interaction System shall provide package takeout and minimal cleaning.
- 3.4.3.1.3. The User Interaction System shall provide user information.

##### 3.4.3.2. User Interaction System - Maintenance System Interface Output Requirements.

- 3.4.3.2.1. The Maintenance System shall provide constant software updates based on the user feedback.
- 3.4.3.2.2. The Maintenance System shall provide complete cleaning of the payload bay.
- 3.4.3.2.3. The Maintenance System shall provide regular cyber security checks on user information.

### **3.5. Design Constraints**

This section identifies any constraints on the design of the system.

- 3.5.1. The ADR shall have the dimensions : 4ft x 2ft x 3ft (Length x Width x Height).
- 3.5.2. The ADR shall have a mass of 150 pounds excluding the payload.
- 3.5.3. The ADR shall have a ground clearance of 5 inches above the ground level.
- 3.5.4. The ADR shall have the ten individual payload bays.
- 3.5.5. The ADR shall be disassembled for replacement, inspection, packaging and transportation purposes effortlessly and efficiently.

### **3.6. Other Requirements**

This section identifies other requirements for the system (e.g., specialty engineering-related requirements).

- 3.6.1. The ADR shall be configured to be compatible with off the shelf components such as batteries.
- 3.6.2. The ADR shall make sure the electronics inside are not affected or tampered by external disturbances or environment such as heavy rain, snowfall, electromagnetic disturbances.
- 3.6.3. The central server and the algorithm shall make sure that all the idle ADRs are given a task when there are multiple orders.
- 3.6.4. Systems Safety Requirements.
  - 3.6.4.1. The ADR shall operate in an environment with temperature levels from 0 to 50 degrees.
  - 3.6.4.2. The ADR shall be operated manually when necessary.
  - 3.6.4.3. The ADR shall always be active and aware of its surroundings even if it is in idle mode, to make sure it shall react and avoid any damages to the system.
  - 3.6.4.4. The ADR shall have an emergency stop button that can be triggered by the central server and the maintainer.
- 3.6.5. System Security Requirements.
  - 3.6.5.1. The ADR shall have security protocols and algorithms that help it prevent cyber attacks.
  - 3.6.5.2. The ADR shall have mechanical security systems that would alert the central server it was being tampered with without approval.

## **4. Data Dictionary**

This Section defines the data structures referenced in Sections 3.3 and 3.4.

1. Task Information: This data is sent from the central server to ADRs. This information consists of details about the task type, the task location and the task status (preparing, picking up, in delivery etc.).
2. Route information: This data is sent from the central server to ADRs. This information consists of details about the current location speed limit of the ADR and static and dynamic obstacle location around the ADR.

3. Battery level: It refers to the battery pack's state of charge.
4. System Information: This data is sent from the ADRs to the central server. This information consists of details about the battery level, the location of the ADR, the velocity and acceleration of the ADR, telemetry signal strength of the ADR, and the status of the ADR (active in delivery/ inactive in delivery/ in maintenance).
5. Payload Bay ID: Each Payload Bay has its unique QR code for the users to scan. Payload Bay ID is the unique QR code assigned to each payload Bay.
6. Order ID: It is the unique number generated and assigned to the users when they placed a delivery order.
7. Payload Bay Information: This data is sent from the ADRs to the central server. This information consists of details about Payload Bay IDs, the payload weight and the lid of the Payload Bay status (open/closed), the number of occupied payload bay and the order ID for each Payload.
8. User Information: This data is sent from the User Interaction system to the central server. This information consists of details about Order ID, name of the user, and the address of the user.
9. Locomotion Information: This data is sent from the ADR to the central server. This information consists of details about the velocity and acceleration of the ADR as well as the distance between the nearest obstacle and the ADR.
10. Battery Health Information: This data is sent from the ADR to the central server. This information consists of details about the health of the battery pack on ADRs. This data is for maintenance purposes to see if the battery packs need to be replaced.
11. Malfunctioning Detection: The operating status defines the ADRs current operating state. This state could be available/inspection/busy.
12. Connection Status: The connection status refers to the ADRs connection to the network. It can be verified by pinging the central server.
13. Audio Signal: The audio feedback refers to the buzzer of the ADR that is used to dissipate information regarding collision avoidance.
14. Visual Signal: The visual feedback refers to the LED lights on the ADR that are used to dissipate information regarding operating status and states such as Idle, Available, Sensing and Failure.
15. Confirmation Commands: The confirmations commands refer to the actions the user interaction system needs to take which the users need to verify the package in the payload bay.
16. Payload Bay Commands: The payload bay commands refer to the actions of the specific payload bay to open and close.
17. Daily Maintenance Check: The daily maintenance check refers to daily cleaning and charging of the ADR.
18. Field Service: Field Service refers to the maintenance done on site without disturbing the tasks of the ADR. This usually consists of visual inspection and checks.
19. User Software Feedback: The user software feedback refers to the data collected from the user reviews on the ADR software system using the user interaction system.
20. Cyber Security Checks: Cyber Security Checks refer to the testing performed to check if there are any vulnerabilities on the ADR system to avoid vicious attacks on the user information.

## 5. Requirements Verification Matrix

This section provides the Requirements Verification Matrix for the system in the Table 3 below.

Table 3: Requirements Verification Matrix for ADR

System Req ID	System Req Title	Verification Method	Method Description	System Validation Test	Syst Validation on TRR Date	System Verification Test	Sys Verification TRR Date	Syst em Integration Test	Syst em Integration TRR Date	System Element Verification Test	System Element Verification TRR Dates
S3.0	Provide ADR Capability	Test		x	TBD	x	TBD	x	TBD	N/A	N/A
S3.1	Provide ADR States & Modes	Test		x	TBD	x	TBD	x	TBD	N/A	N/A
S3.2	Provide ADR Capabilities	Test		x	TBD	x	TBD	x	TBD	N/A	N/A
S3.2.1	Sensor System	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.1	Optical Sensing	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.1.1	Roadway Detection	Test & Analysis	The ADR shall detect sidewalks, roads, pedestrian crossings, and road signs.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.1.2	Traffic Detection	Test & Analysis	The ADR shall detect Motor vehicles, pedestrians,	x	TBD	x	TBD	x	TBD	x	TBD

			cyclists, animals, and similar dynamic obstacles								
S3.2.1.1.3	Static Obstacle Detection	Test & Analysis	The ADR shall detect plants, trees, buildings, railings, and similar static obstacles.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.1.4	ADR Detection	Test & Analysis	The ADR shall detect and identify other ADRs	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.1.5	Minimum Detection Distance	Test & Analysis	The ADR shall detect every static and dynamic obstacle in its line of sight within a distance of 165 ft	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.2	GPS Sensing	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.2.1	GPS Accuracy	Test & Analysis	The ADR shall detect its Global Positioning System (GPS) coordinates with 4 ft accuracy.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.3	Proximity Sensing	Test & Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.1.3.1	Proximity Accuracy	Test & Analysis	The ADR shall detect and identify every entity in near proximity of 4ft.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.2	Locomotion System	Test		x	TBD	x	TBD	x	TBD	x	TBD



S3.2.2.1	Maximum Speed	Test, Analysis & Demonstration	The ADR shall have a maximum speed of 15 mph.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.2.2	Maximum Payload	Test & Analysis	The ADR shall lift a maximum payload of 100 lbs.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.2.3	Minimum Turn Radius	Test, Analysis & Demonstration	The ADR shall have a turning radius of 2.5 ft.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.2.4	Minimum Turn Speed	Test, Analysis & Demonstration	The ADR shall have a turning speed of 0.785 rad/sec.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.3	Computing System	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.3.1	Information Processing	Test	The ADR shall process information from the optical sensors, GPS sensors, and proximity sensors to make navigational decisions.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.4	Communication System	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.4.1	Communication Frequency	Test	The ADR shall use 915 MHz for its communication with the central server.	x	TBD	x	TBD	x	TBD	x	TBD

S3.2.4.2	Cellular Connectivity	Test	The ADR shall have a 4G LTE (Long-Term Evolution) cellular connectivity for redundant communication with the central server.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.4.3	Antenna Frequency	Test	The ADR shall have two long range omnidirectional 915 Mhz antennas.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.4.4	Antenna Connectivity	Test	The ADR shall have an omnidirectional 4G LTE antenna.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.4.5	Communication Range	Test , Analysis	THE ADR shall have a communication range of 2 miles.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.5	Power System	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.5.1	Operational Time	Test, Analysis & Demonstration	The ADR shall have an operational time of 8 hours on a single charge	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.5.2	Measurement Sensors	Test	The ADR shall have a sensor to measure battery voltage and calculate battery percentage.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.5.3	Temperature Sensors	Test	The ADR shall have temperature sensors for its battery packs	x	TBD	x	TBD	x	TBD	x	TBD

S3.2.5.4	Overheating Threshold	Test & Analysis	The ADR shall enter into an overheat failure mode when the operating temperature rises over 115 F	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6	Availability	Test , Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.1	Operational Availability	Test, Analysis & Demonstration	The ADR shall have a steady state operational availability greater than 0.8.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.2	Sensor Subsystem	Test	The sensor subsystem shall have a mean time between critical failures (MTBCF) greater than 2000 hours	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.3	Locomotion Subsystem	Test	The locomotion subsystem shall have a mean time between critical failures (MTBCF) greater than 1000 hours.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.4	Computing Subsystem	Test	The computing subsystem shall have a mean time between critical failure (MTBCF) greater than 2000 hours.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.5	Communication Subsystem	Test	The communication subsystem shall have a mean time between	x	TBD	x	TBD	x	TBD	x	TBD

			critical failures (MTBCF) greater than 2000 hours.								
S3.2.6.6	Power Subsystem	Demonstration	The power subsystem shall have a mean time between critical failures (MTBCF) greater than 1500 hours.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.6.7	Maintenance Time	Inspection	The ADR shall have a mean maintenance time less than 2 hours.	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.7	Accessibility	Test & Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.2.7.1	Task Log	Test & Analysis	The ADR shall store a log containing time stamped history of each task performed	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.7.2	Maintenance History	Test, Analysis & Demonstration	The ADR shall store maintenance history for each ADR element	x	TBD	x	TBD	x	TBD	x	TBD
S3.2.7.3	Data Access	Test	The ADR shall provide access to all stored data to authorized users such as central server and maintainer	x	TBD	x	TBD	x	TBD	x	TBD
S3.3	Provide External Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD

S3.3.1	Central Server Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.1	Central Server Interface Inputs	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.1.1	Task Information	Test, Analysis & Demonstration	The ADR system shall accept task information from the Central Server.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.1.2	Route Information	Test, Analysis & Demonstration	The ADR system shall accept route information from the Central Server.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.2	Central Server Interface Outputs	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.2.1	Battery Level	Test, Analysis & Demonstration	The ADR system shall provide its battery level.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.2.2	System Information	Test	The ADR system shall provide system information.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.2.3	Payload Bay Information	Test	The ADR system shall provide the payload bay information.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.1.2.4	User Information	Test & Analysis	The ADR system shall provide user information.	x	TBD	x	TBD	x	TBD	x	TBD

S3.3.1.2.5	Locomotion Information	Test	The ADR system shall provide locomotion information.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2	Maintainer Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1	Maintainer Interface Inputs	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.1	Maintenance Tools	Test	The ADR system shall provide maintainers with the tools required to perform maintenance	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.2	Firmware Updates Access	Test	The ADR system shall provide access for firmware updates	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.3	Sensor Calibration Access	Test	The ADR system shall provide access for sensor calibration.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.4	Malfunction Detection	Test & Analysis	The ADR system shall provide self malfunctioning detections to determine errors or failures	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.5	Parts Replacement Access	Test	The ADR system shall provide the access to maintainers for parts replacement.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.1.6	Inspection Access	Test	The ADR system shall provide	x	TBD	x	TBD	x	TBD	x	TBD

			access for inspections								
S3.3.2.2	Maintainer Interface Outputs	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.2.1	Battery Health Information	Test & Analysis	The ADR system shall provide battery health information	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.2.2	Connection Status	Test & Analysis	The ADR system shall provide connection status information	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.2.3	Diagnostic Information for Subsystems	Test & Analysis	The ADR system shall provide diagnostic information about subsystems	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.2.2.4	Diagnostic Information for Sensors	Test & Analysis	The ADR system shall provide diagnostic information about sensors.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.3	Environment Interface	Test & Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.3.1	Environment Input Interface	Test & Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.3.3.1.1	Video and Proximity Data	Test & Analysis	The ADR system shall gather raw video and proximity data from the environment.	x	TBD	x	TBD	x	TBD	x	TBD
S3.3.3.1.2	Charging Station	Test & Demo	The ADR system shall accept	x	TBD	x	TBD	x	TBD	x	TBD

		nstrati on	power from a charging station.								
S3.3.3.2	Environm ent Output Interface s	Test & Analysi s		x	TBD	x	TB D	x	TBD	x	TBD
S3.3.3.2 .1	Base Utilities	Test	The ADR system shall interface with operating base utilities - internet access and charging stations etc.	x	TBD	x	TB D	x	TBD	x	TBD
S3.3.3.2 .2	Audio Signals	Test	The ADR system shall provide audio signals.	x	TBD	x	TB D	x	TBD	x	TBD
S3.3.3.2 .3	Visual Signals	Test	The ADR system shall provide visual signals.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4	Provide Internal Interface s	Test		x	TBD	x	TB D	x	TBD	x	TBD
S3.4.1	ADR-UIS Interface s	Test		x	TBD	x	TB D	x	TBD	x	TBD
S3.4.1.1	ADR-UIS Input Interface s	Test		x	TBD	x	TB D	x	TBD	x	TBD
S3.4.1.1 .1	Payload Bay Informati on	Test	The ADR shall provide payload bay information.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.1.1 .2	System Informati on	Test	The ADR shall provide its system information.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.1.1 .3	Locomoti on	Test	The ADR shall provide its	x	TBD	x	TB D	x	TBD	x	TBD



	System Information		locomotion information such as speed and acceleration etc.								
S3.4.1.1.4	Task Information	Test	The ADR shall provide its task information obtained from the Central Server.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.1.1.5	Payload ID Number	Test	The ADR shall provide Payload Bay ID Number to ADR.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.1.2	ADR-UIS Output Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.4.1.2.1	Order ID Number	Test	The User Interaction System shall provide Order ID Number to ADR.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.1.2.2	Payload Bay Information	Test	The User Interaction System shall provide confirmation commands in accordance with the payload bay information	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.1.2.3	Task Information	Test	The User Interaction System shall provide payload bay commands in accordance with task information.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.2	ADR-Mainten	Test		x	TBD	x	TBD	x	TBD	x	TBD

	ance System Interface s										
S3.4.2.1	ADR - Mainten ance System Input Interface s	Test		x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.1 .1	System Informati on	Test	The ADR shall provide the system information.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.1 .2	Battery Informati on	Test	The ADR shall provide its battery levels.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.1 .3	Malfunct ioning Detectio n Informati on	Test	The ADR shall provide malfunctioning detections.	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.2	ADR - Mainten ance System Output Interface s	Test		x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.2 .1	ADR Field Service	Test, Analysi s & Demo nstrati on	The Maintenance System shall provide the ADR field service	x	TBD	x	TB D	x	TBD	x	TBD
S3.4.2.2 .2	ADR Daily Mainten ance Check	Test, Analysi s & Demo nstrati on	The Maintenance System shall provide the ADR daily maintenance check	x	TBD	x	TB D	x	TBD	x	TBD

S3.4.2.2.3	ADR System Updates	Test, Analysis & Demonstration	The Maintenance System shall provide the updates to ADRs	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.2.2.4	ADR Component Replacement	Test, Analysis & Demonstration	The Maintenance System shall provide the component replacement repair to ADRs.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3	UIS - Maintenance System Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.1	UIS - Maintenance System Input Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.1.1	Software Feedback Information	Test	The User Interaction System shall provide user software feedback	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.1.2	Package Removal from ADR	Test, Analysis & Demonstration	The User Interaction System shall provide package takeout and minimal cleaning	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.1.3	User Information	Test	The User Interaction System shall provide user information.	x	TBD	x	TBD	x	TBD	x	TBD

S3.4.3.2	UIS - Maintenance System Output Interfaces	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.2.1	Software update Information	Test	The Maintenance System shall provide constant software updates based on the user feedback	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.2.2	Cleaning Services of Payload Bay	Test & Demonstration	The Maintenance System shall provide complete cleaning of the payload bay.	x	TBD	x	TBD	x	TBD	x	TBD
S3.4.3.2.3	Cyber Security Check	Test & Demonstration	The Maintenance System shall provide regular cyber security checks on user information.	x	TBD	x	TBD	x	TBD	x	TBD
S3.5	Design Constraints	Test & Analysis		x	TBD	x	TBD	x	TBD	x	TBD
S3.5.1	ADR Dimension Information	Test	The ADR shall have the dimensions : 4ft x 2ft x 3ft (Length x Width x Height)	x	TBD	x	TBD	x	TBD	x	TBD
S3.5.2	ADR Mass Information	Test	The ADR shall have a mass of 150 pounds excluding the payload.	x	TBD	x	TBD	x	TBD	x	TBD
S3.5.3	ADR Ground Clearance	Test	The ADR shall have a ground clearance of 5 inches	x	TBD	x	TBD	x	TBD	x	TBD

	Information		above the ground level.								
S3.5.4	ADR Number of Payload Bays Information	Test	The ADR shall have the ten individual payload bays.	x	TBD	x	TBD	x	TBD	x	TBD
S3.5.5	ADR Disassembly Capability	Test , Analysis & Demonstration	The ADR shall be disassembled for replacement, inspection, packaging and transportation purposes effortlessly and efficiently.	x	TBD	x	TBD	x	TBD	x	TBD
S3.6	Other Requirements	Test		x	TBD	x	TBD	x	TBD	x	TBD
S3.6.1	ADR Compatibility Information	Test	The ADR shall be configured to be compatible with off the shelf components such as batteries	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.2	ADR Electronics Safety System	Test , Analysis & Demonstration	The ADR shall make sure the electronics inside are not affected or tampered by external disturbances or environment such as heavy rain, snowfall, electromagnetic disturbances.	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.3	ADR Efficiency System	Test , Analysis &	The central server and the algorithm shall make	x	TBD	x	TBD	x	TBD	x	TBD

		Demonstration	sure that all the idle ADRs are given a task when there are multiple orders.								
S3.6.4	Systems Safety Requirements	Test , Analysis & Demonstration		x	TBD	x	TBD	x	TBD	x	TBD
S3.6.4.1	Environment Temperature Information	Test , Analysis & Demonstration	The ADR shall operate in an environment with temperature levels from 0 to 50 degrees.	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.4.2	ADR Manual Operation Mode	Test , Analysis & Demonstration	The ADR shall be operated manually when necessary	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.4.3	ADR Awareness Functionality	Test , Analysis & Demonstration	The ADR shall always be active and aware of its surroundings even if it is in idle mode, to make sure it shall react and avoid any damages to the system	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.4.4	ADR Emergency Stop Button	Test , Analysis & Demonstration	The ADR shall have an emergency stop button that can be triggered by the central server and the maintainer.	x	TBD	x	TBD	x	TBD	x	TBD
S3.6.5	Systems Security	Test		x	TBD	x	TBD	x	TBD	x	TBD

	Require ments										
S3.6.5.1	Security Protocol Informati on	Test	The ADR shall have security protocols and algorithms that help it prevent cyber attacks.	x	TBD	x	TB D	x	TBD	x	TBD
S3.6.5.2	Mechani cal Security System	Test,A nalysis & Demo nstrati on	The ADR shall have mechanical security systems that would alert the central server it was being tampered with without approval.	x	TBD	x	TB D	x	TBD	x	TBD

## 6. Requirements Traceability Matrix

This section provides the upward trace to stakeholder requirements and the downward trace from the stakeholder requirements. The Requirements Traceability Matrix is provided in Table 4 below:

Table 4: Requirements Traceability Matrix for ADR

		Source Requirement																
System Req ID	System Req Title	SH 2 Performance Requirements	SH 2.1 Operational Range	SH 2.2 Operational Capacity	SH 2.3 Payload Capacity	SH 2.4 Automated Charging	SH 2.5 Collision Avoidance	SH 3 External Interface Requirements	SH 3.1 User Interface Requirements	SH 3.2 External System Interface Requirements	SH 4 Specialty Engineering Requirements	SH 5 Functional Requirements	SH 5.1 Battery Capacity	SH 5.2 Battery Dimensions	SH 5.3 Minimum Ground Clearance	SH 5.4 Minimum Ground Clearance	SH 5.5 Climbing Inclination	Sum Chk

										me nts	me nts							
S3.0	Provide ADR Capability	1																1
S3.1	Provide ADR States & Modes	1																1
S3.2	Provide ADR Capabiliti es	1			1													2
S3.2.1	Sensor System	1					1					1						3
S3.2.1. 1	Optical Sensing	1					1					1						3
S3.2.1. 1.1	Roadway Detection s	1					1					1					1	4
S3.2.1. 1.2	Traffic Detection s	1					1					1						3
S3.2.1. 1.3	Static Obstacle Detection	1					1					1						3
S3.2.1. 1.4	ADR Detection	1					1					1						3
S3.2.1. 1.5	Minimum Detection Distance	1			1		1					1						4
S3.2.1. 2	GPS Sensing	1					1					1						3
S3.2.1. 2.1	GPS Accuracy	1					1					1						3
S3.2.1. 3	Proximity Sensing	1					1					1						3
S3.2.1. 3.1	Proximity Accuracy	1										1	1			1		4



S3.2.2	Locomotion System	1		1													1	3
S3.2.2.1	Maximum Speed	1		1									1					3
S3.2.2.2	Maximum Payload	1			1								1					3
S3.2.2.3	Minimum Turn Radius	1											1				1	3
S3.2.2.4	Minimum Turn Speed	1											1				1	3
S3.2.3	Computing System	1													1			2
S3.2.3.1	Information Processing	1																1
S3.2.4	Communication System	1													1			2
S3.2.4.1	Communication Frequency	1																1
S3.2.4.2	Cellular Connectivity	1																1
S3.2.4.3	Antenna Frequency	1																1
S3.2.4.4	Antenna Connectivity	1																1
S3.2.4.5	Communication Range	1	1															2

S3.2.5	Power System	1													1			2
S3.2.5.1	Operational Time	1	1															2
S3.2.5.2	Measurement Sensors					1												1
S3.2.5.3	Temperature Sensors									1								1
S3.2.5.4	Overheating Threshold									1								1
S3.2.6	Availability																	0
S3.2.6.1	Operational Availability																	0
S3.2.6.2	Sensor Subsystem														1			1
S3.2.6.3	Locomotion Subsystem												1		1			2
S3.2.6.4	Computing Subsystem														1			1
S3.2.6.5	Communication Subsystem														1			1
S3.2.6.6	Power Subsystem														1			1
S3.2.6.7	Maintenance Time																	0

S3.2.7	Accessibil ity								1									1
S3.2.7. 1	Task Log								1									1
S3.2.7. 2	Maintena nce History								1									1
S3.2.7. 3	Data Access								1									1
S3.3	Provide External Interfaces									1								1
S3.3.1	Central Server Interfaces									1								1
S3.3.1. 1	Central Server Interface Inputs									1								1
S3.3.1. 1.1	Task Informati on									1								1
S3.3.1. 1.2	Route Informati on									1							1	2
S3.3.1. 2	Central Server Interface Outputs									1								1
S3.3.1. 2.1	Battery Level		1			1				1								3
S3.3.1. 2.2	System Informati on									1					1			2
S3.3.1. 2.3	Payload Bay Informati on								1	1								2

S3.3.1.2.4	User Information									1								1
S3.3.1.2.5	Locomotion Information												1					1
S3.3.2	Maintainer Interfaces								1									1
S3.3.2.1	Maintainer Interface Inputs								1									1
S3.3.2.1.1	Maintenance Tools								1									1
S3.3.2.1.2	Firmware Updates Access								1									1
S3.3.2.1.3	Sensor Calibration Access								1									1
S3.3.2.1.4	Malfunction Detection								1									1
S3.3.2.1.5	Parts Replacement Access								1									1
S3.3.2.1.6	Inspection Access								1									1
S3.3.2.2	Maintainer Interface Outputs																	0
S3.3.2.2.1	Battery Health Information													1				1
S3.3.2.2.2	Connection Status																	0

S3.3.2.2.3	Diagnostic Information for Subsystems																	0
S3.3.2.2.4	Diagnostic Information for Sensors																	0
S3.3.3	Environment Interfaces								1									1
S3.3.3.1	Environment Input Interfaces								1									1
S3.3.3.1.1	Video and Proximity Data								1									1
S3.3.3.1.2	Charging Station					1			1									2
S3.3.3.2	Environment Output Interfaces								1									1
S3.3.3.2.1	Base Utilities								1									1
S3.3.3.2.2	Audio Signals								1									1
S3.3.3.2.3	Visual Signals								1									1
S3.4	Provide Internal Interfaces							1			1							2
S3.4.1	ADR-UIS Interfaces							1			1							2
S3.4.1.1	ADR-UIS Input Interfaces							1			1							2

S3.4.1.1.1	Payload Bay Information								1			1						2
S3.4.1.1.2	System Information											1						1
S3.4.1.1.3	Locomotion System Information											1	1					2
S3.4.1.1.4	Task Information											1						1
S3.4.1.1.5	Payload ID Number											1						1
S3.4.1.2	ADR-UIS Output Interfaces											1						1
S3.4.1.2.1	Order ID Number											1						1
S3.4.1.2.2	Payload Bay Information											1						1
S3.4.1.2.3	Task Information											1						1
S3.4.2	ADR-Maintenance System Interfaces											1						1
S3.4.2.1	ADR - Maintenance System Input Interfaces											1						1

S3.4.2.1.1	System Information											1						1
S3.4.2.1.2	Battery Information					1						1		1				3
S3.4.2.1.3	Malfunctioning Detection Information											1						1
S3.4.2.2	ADR - Maintenance System Output Interfaces											1						1
S3.4.2.2.1	ADR Field Service											1						1
S3.4.2.2.2	ADR Daily Maintenance Check											1						1
S3.4.2.2.3	ADR System Updates											1						1
S3.4.2.2.4	ADR Component Replacement											1						1
S3.4.3	UIS - Maintenance System Interfaces											1						1
S3.4.3.1	UIS - Maintenance System Input Interfaces											1						1

S3.4.3.1.1	Software Feedback Information											1						1
S3.4.3.1.2	Package Removal from ADR											1						1
S3.4.3.1.3	User Information											1						1
S3.4.3.2	UIS - Maintenance System Output Interfaces											1						1
S3.4.3.2.1	Software update Information											1						1
S3.4.3.2.2	Cleaning Services of Payload Bay											1						1
S3.4.3.2.3	Cyber Security Check										1							1
S3.5	Design Constraints														1			1
S3.5.1	ADR Dimension Information														1			1
S3.5.2	ADR Mass Information															1		1



S3.5.3	ADR Ground Clearance Information																	0
S3.5.4	ADR Number of Payload Bays Information				1													1
S3.5.5	ADR Disassembly Capability				1													1
S3.6	Other Requirements									1								1
S3.6.1	ADR Compatibility Information									1								1
S3.6.2	ADR Electronics Safety System									1								1
S3.6.3	ADR Efficiency System									1								1
S3.6.4	Systems Safety Requirements								1	1								2
S3.6.4.1	Environment Temperature Information									1								1

S3.6.4.2	ADR Manual Operation Mode										1							1
S3.6.4.3	ADR Awareness Functionality								1		1							2
S3.6.4.4	ADR Emergency Stop Button										1							1
S3.6.5	Systems Security Requirements										1							1
S3.6.5.1	Security protocol Information										1							1
S3.6.5.2	Mechanical Security system Information										1							1
	Sum Check	29	3	3	4	4	10		19	18	15	41	8	2	12	1	5	

## 7. Requirements Allocation Matrix

This section provides a Requirements Allocation Matrix in Table 5. The matrix indicates the leaf-level system requirements that are allocated to each sub-element.

Table 5: Requirements Allocation Matrix for ADR

System Req ID	System Req Title	ADR Element	UIS Element	Maintenance Element	Chk Sum
S3.0	Provide ADR Capability	N/A	N/A	N/A	

S3.1	Provide ADR States & Modes	N/A	N/A	N/A	
S3.2	Provide ADR Capabilities	N/A	N/A	N/A	
S3.2.1	Sensor System	1			1
S3.2.1.1	Optical Sensing	1			1
S3.2.1.1.1	Roadway Detections	1			1
S3.2.1.1.2	Traffic Detections	1			1
S3.2.1.1.3	Static Obstacle Detection	1			1
S3.2.1.1.4	ADR Detection	1			1
S3.2.1.1.5	Minimum Detection Distance	1			1
S3.2.1.2	GPS Sensing	1	1		2
S3.2.1.2.1	GPS Accuracy	1	1		2
S3.2.1.3	Proximity Sensing	1			1
S3.2.1.3.1	Proximity Accuracy	1			1
S3.2.2	Locomotion System	1			1
S3.2.2.1	Maximum Speed	1			1
S3.2.2.2	Maximum Payload	1			1
S3.2.2.3	Minimum Turn Radius	1			1
S3.2.2.4	Minimum Turn Speed	1			1
S3.2.3	Computing System	1			1
S3.2.3.1	Information Processing	1	1		2
S3.2.4	Communication System	1	1		2
S3.2.4.1	Communication Frequency	1	1		2
S3.2.4.2	Cellular Connectivity	1	1		2
S3.2.4.3	Antenna Frequency	1			1
S3.2.4.4	Antenna Connectivity	1			1
S3.2.4.5	Communication Range	1			1
S3.2.5	Power System	1		1	2
S3.2.5.1	Operational Time	1			1
S3.2.5.2	Measurement Sensors	1			1
S3.2.5.3	Temperature Sensors	1			1
S3.2.5.4	Overheating Threshold	1		1	2

S3.2.6	Availability	1		1	2
S3.2.6.1	Operational Availability	1		1	2
S3.2.6.2	Sensor Subsystem	1		1	2
S3.2.6.3	Locomotion Subsystem	1		1	2
S3.2.6.4	Computing Subsystem	1		1	2
S3.2.6.5	Communication Subsystem	1	1	1	3
S3.2.6.6	Power Subsystem	1		1	2
S3.2.6.7	Maintenance Time			1	1
S3.2.7	Accessibility	1	1	1	3
S3.2.7.1	Task Log	1	1		2
S3.2.7.2	Maintenance History	1		1	2
S3.2.7.3	Data Access	1	1	1	3
S3.3	Provide External Interfaces	1	1	1	3
S3.3.1	Central Server Interfaces	1	1		2
S3.3.1.1	Central Server Interface Inputs	1	1		2
S3.3.1.1.1	Task Information	1	1		2
S3.3.1.1.2	Route Information	1	1		2
S3.3.1.2	Central Server Interface Outputs	1			1
S3.3.1.2.1	Battery Level	1			1
S3.3.1.2.2	System Information	1			1
S3.3.1.2.3	Payload Bay Information	1			1
S3.3.1.2.4	User Information	1			1
S3.3.1.2.5	Locomotion Information	1			1
S3.3.2	Maintainer Interfaces	1		1	2
S3.3.2.1	Maintainer Interface Inputs	1		1	2
S3.3.2.1.1	Maintenance Tools	1		1	2
S3.3.2.1.2	Firmware Updates Access	1		1	2
S3.3.2.1.3	Sensor Calibration Access	1		1	2
S3.3.2.1.4	Malfunction Detection	1		1	2
S3.3.2.1.5	Parts Replacement Access	1		1	2
S3.3.2.1.6	Inspection Access	1		1	2

S3.3.2.2	Maintainer Interface Outputs	1			1
S3.3.2.2.1	Battery Health Information	1			1
S3.3.2.2.2	Connection Status	1			1
S3.3.2.2.3	Diagnostic Information for Subsystems	1			1
S3.3.2.2.4	Diagnostic Information for Sensors	1			1
S3.3.3	Environment Interfaces	1			1
S3.3.3.1	Environment Input Interfaces	1			1
S3.3.3.1.1	Video and Proximity Data	1			1
S3.3.3.1.2	Charging Station	1			1
S3.3.3.2	Environment Output Interfaces	1			1
S3.3.3.2.1	Base Utilities	1			1
S3.3.3.2.2	Audio Signals	1			1
S3.3.3.2.3	Visual Signals	1			1
S3.4	Provide Internal Interfaces	1	1	1	3
S3.4.1	ADR-UIS Interfaces	1	1		2
S3.4.1.1	ADR-UIS Input Interfaces	1	1		2
S3.4.1.1.1	Payload Bay Information	1			1
S3.4.1.1.2	System Information	1			1
S3.4.1.1.3	Locomotion System Information	1			1
S3.4.1.1.4	Task Information	1	1		2
S3.4.1.1.5	Payload ID Number	1			1
S3.4.1.2	ADR-UIS Output Interfaces	1	1		2
S3.4.1.2.1	Order ID Number	1	1		2
S3.4.1.2.2	Payload Bay Information		1		1
S3.4.1.2.3	Task Information		1		1
S3.4.2	ADR- Maintenance System Interfaces	1		1	2
S3.4.2.1	ADR - Maintenance System Input Interfaces	1			1
S3.4.2.1.1	System Information	1			1
S3.4.2.1.2	Battery Information	1			1
S3.4.2.1.3	Malfunctioning Detection Information	1			1

S3.4.2.2	ADR - Maintenance System Output Interfaces			1	1
S3.4.2.2.1	ADR Field Service			1	1
S3.4.2.2.2	ADR Daily Maintenance Check			1	1
S3.4.2.2.3	ADR System Updates			1	1
S3.4.2.2.4	ADR Component Replacement			1	1
S3.4.3	UIS - Maintenance System Interfaces		1	1	2
S3.4.3.1	UIS - Maintenance System Input Interfaces		1		1
S3.4.3.1.1	Software Feedback Information		1		1
S3.4.3.1.2	Package Removal from ADR		1		1
S3.4.3.1.3	User Information		1		1
S3.4.3.2	UIS - Maintenance System Output Interfaces			1	1
S3.4.3.2.1	Software update Information			1	1
S3.4.3.2.2	Cleaning Services of Payload Bay			1	1
S3.4.3.2.3	Cyber Security Check			1	1
S3.5	Design Constraints	1			1
S3.5.1	ADR Dimension Information	1			1
S3.5.2	ADR Mass Information	1			1
S3.5.3	ADR Ground Clearance Information	1			1
S3.5.4	ADR Number of Payload Bays Information	1			1
S3.5.5	ADR Disassembly Capability	1			1
S3.6	Other Requirements	1	1	1	3
S3.6.1	ADR Compatibility Information	1			1
S3.6.2	ADR Electronics Safety System	1			1
S3.6.3	ADR Efficiency System		1		1
S3.6.4	Systems Safety Requirements	1	1	1	3
S3.6.4.1	Environment Temperature Information	1			1
S3.6.4.2	ADR Manual Operation Mode	1			1
S3.6.4.3	ADR Awareness Functionality	1			1

S3.6.4.4	ADR Emergency Stop Button	1	1	1	3
S3.6.5	Systems Security Requirements	1			1
S3.6.5.1	Security protocol Information	1			1
S3.6.5.2	Mechanical Security system Information	1			1

## **Appendices**

### **A. 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.

### **B. Acronyms**

This Appendix defines all acronyms used in the main body of the document.

1. ADR- Autonomous Delivery Robot.
2. UIS - User Interaction System.
3. ME - Maintenance Element.
4. MOE - Measures of Effectiveness.
5. GPS - Global Positioning System.
6. 4G LTE - cellular fourth generation long-term evolution.
7. MHz - Mega Hertz.
8. MTBCF - Mean time between critical failures.
9. SOI - System of interest.
10. QR Code - Quick Response Code .
11. LED - Light-emitting diode.

### **C. Definitions**

This Appendix defines key terms used in the main body of the document.

1. LTE (Long-Term Evolution): LTE is a fourth-generation wireless standard that provides increased network capacity and speed for cellphones and other cellular devices.
2. Telemetry: Telemetry is the in situ collection of measurements or other data at remote points and their automatic transmission to receiving equipment for monitoring.
3. Operational Area: Area where the ADR will navigate to perform delivery operations. Usually university campuses and their immediate surroundings.
4. Payload: Part of the vehicle's load from which revenue is generated. In ADR, payload are the packages carried from the sender to the receiver.
5. Global Positioning System (GPS): GPS is a satellite-based radionavigation system that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there



is an unobstructed line of sight to four or more GPS satellites. It is owned by the United States government and operated by the United States Space Force.

6. Turning Radius: It is the radius of the smallest circle within which a vehicle can be turned around completely.
7. Cybersecurity: Cybersecurity is the practice of protecting systems, networks, and programs from digital attacks. These cyberattacks are usually aimed at assessing, changing, or destroying sensitive information; extorting money from users via ransomware; or interrupting normal business processes.
8. QR Code: A QR code (quick response code) is a type of matrix barcode. A barcode is a machine-s optical label that can contain information about the item to which it is attached.