Automated Driving System Demonstration (ADS)
Grant Application| NOFO693JJ319NF00001

Safe Integration of Automated Vehicles into Work Zones

|PKG 00247169

Operations and Maintenance Plan

for the

Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ) Project

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16. Abstract

This Automated Driving System Demonstration will evaluate the impact of improved connectivity, visibility, and mapping between automated vehicles and work zone objects to allow for the integration of automated vehicles into work zones.

This document presents the Operations and Management (O&M) Plan that describes the roles and responsibilities of the organizations tasked with the operating and maintaining the Automated Vehicle (AV), Mapping Vehicle, Simulation System, Roadside Infrastructure, Data Management System (DMS), other equipment, and supporting capabilities for deploying the ADS Demonstration system. The O&M plan presents a high-level overview of the operating and maintenance procedures and configuration and inventory management.

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VERSION HISTORY

Version	Date	Author(s)	Reviewer(s)	Summary of Changes
1	02/11/22	MBI		Initial Version

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1 INTRODUCTION

The United States Department of Transportation (USDOT) Automated Driving System (ADS) Demonstration Grants Program appropriated funding for a "highly automated vehicle research and development program" to fund planning, direct research, and demonstration grants for ADS and other driving automation systems and technologies. The demonstration grant included funds for testing the safe integration of ADS into our nation's on-road transportation system.

Pennsylvania Department of Transportation (PennDOT) was awarded one of these grants to develop an approach to allow automated vehicles (AVs) to operate safely in work zones ("the Project"). Work zones are challenging for AVs to navigate through because of their dynamic nature and the various construction activities specific to different site conditions that cannot always be predefined.

The intent of PennDOT's ADS Demonstration is to develop a consistent approach to enable AVs to safely operate in work zones. Knowing that there is unlikely to be a single technology solution, the project focuses on using a combination of strategies including connectivity, computer perception, and High-Definition (HD) mapping. To demonstrate the viability of these solutions, the project will perform simulations and demonstrations in a variety of work zone configurations with varying scale, complexity, and duration. PennDOT plans to take a systematic approach of working with testers to verify the proposed AV solutions. The simulations and demonstrations will be conducted in a controlled, closed-course environment. Eventually, upon successful testing, PennDOT will work with the project team to safely integrate the solutions into limited, small-scale, on-road, live demonstrations.

1.1 Document Purpose and Scope

The Operations and Maintenance (O&M) Plan describes the roles and responsibilities of the organizations tasked with the operating and maintaining the AV, Mapping Vehicle, Simulation System, Roadside Infrastructure, Data Management System (DMS), other equipment, and supporting capabilities for deploying the ADS Demonstration system. The O&M plan presents a high-level overview of the operating and maintenance procedures and configuration and inventory management. At the time of this draft O&M plan submission, details such as simulation software and sensor capabilities testing are in progress. These items will be updated as they become finalized or available. The final deliverable will be completed when device and software testing and validation have been verified by the stakeholders prior to the start of the ADS Demonstration.

The document is organized to meet the requirements of the USDOT System Engineering Process and ISO/IEC/IEEE 42010-2011 standard.

1.2 Document Organization

The ADS O&M Plan is organized into the following sections:

- **Section 1: Introduction** provides a high-level overview of the project, the ADS and its system components, users, and stakeholders.
- **Section 2: Materials & Resources** identifies the required personnel, resources, software, and equipment needed for O&M.
- **Section 3: Operations** provides details of the types of activities necessary to run the ADS operations.
- **Section 4: Maintenance** identifies the maintenance steps and activities that are necessary to keep the ADS project operational.
- **Section 5: Configuration & Inventory Management** describes the configuration management tools and procedures that will be followed.

1.3 Project Overview

PennDOT and the project team aim to solve the challenge of safe integration of AVs into most work zones by examining the benefit of improved connectivity, computer perception, and HD mapping. PennDOT has assembled a comprehensive team of project partners and subject matter experts to successfully conduct the planned research. The project team will demonstrate how the operation of AVs in work zones can be tested, improved, and standardized in three phases, as shown in **Figure 1.**

Figure 1. Project Work Breakdown Structure

Phase I Planning		Phase II Deployment	Phase III Post-Deployment
I-1. Project Management	I-7. Deployment Plan	II-1. Data Management System	III-1. Final Evaluation
I-2. Risk Management	I-8. O&M Plan	II-2. Simulation	
I-3. Systems Engineering Management Plan	I-9. Data Privacy and Data Management Plan	II-3. Closed Track Testing	
I-4. Concept of Operations	I-10. Data Evaluation Plan	II-4. Live-On Road Testing	
I-5. Systems Requirements / Test Plan	I-11. Human Use Approval		
I-6. System Architecture and Standards Plan	I-12. Coordination, Communication, and Outreach		
	I-13. Data Management System Sandbox		

SOURCE: ADS DEMONSTRATION CONCEPT OF OPERATIONS

In the current phase (Phase I) the team will develop the appropriate project management and systems engineering planning documentation for the deployment of the testing and analysis phase. Also during this phase, the team will develop the project management and systems engineering documentation to meet project requirements and support the deployment, including this Operations and Maintenance (O&M) Plan.

Based on PennDOT's experience, the team has identified 17 common work zone scenarios in different urban, rural, and suburban settings. In addition, limited access facilities and urban arterials, typical in not only Pennsylvania but also in other states, have been identified. The work zone scenarios are outlined in the Concept of Operations (ConOps).

In Phase II, the team will implement and deploy the plan developed as part of Phase I. During Phase III, the team will evaluate the performance of the demonstration project by following the procedures identified in the Project Evaluation Plan, developed in Phase I.

The vision, mission, goals, and objectives of the project are as follows:

- **Vision:** Enable AVs to safely operate in work zones without human intervention.
- **Mission:** Reduce traffic fatalities and increase mobility for all Americans in work zones through AVs.
- **Goals:** Achieve safe navigation of AVs on par with non-distracted, human-operated vehicles within work zones.
- **Objectives:**
  1. Evaluate the impact of improved connectivity between an AV and the work zone objects using V2X

2. Evaluate the impact of increased visibility (machine vision) of pavement markings and work zone objects on AVs through innovative coatings.
3. Evaluate the impact of providing HD mapping of work zone objects (including cones, barrels, workers, vehicles).
4. Improve the map information dissemination process from the mapping providers and/or infrastructure owners/operators to the AV through standardization of digital mapping information for work zones.

Note: At the time of this writing the objectives are not finalized, once completed this section will be updated as part of the final O&M plan.

1.4 System Components

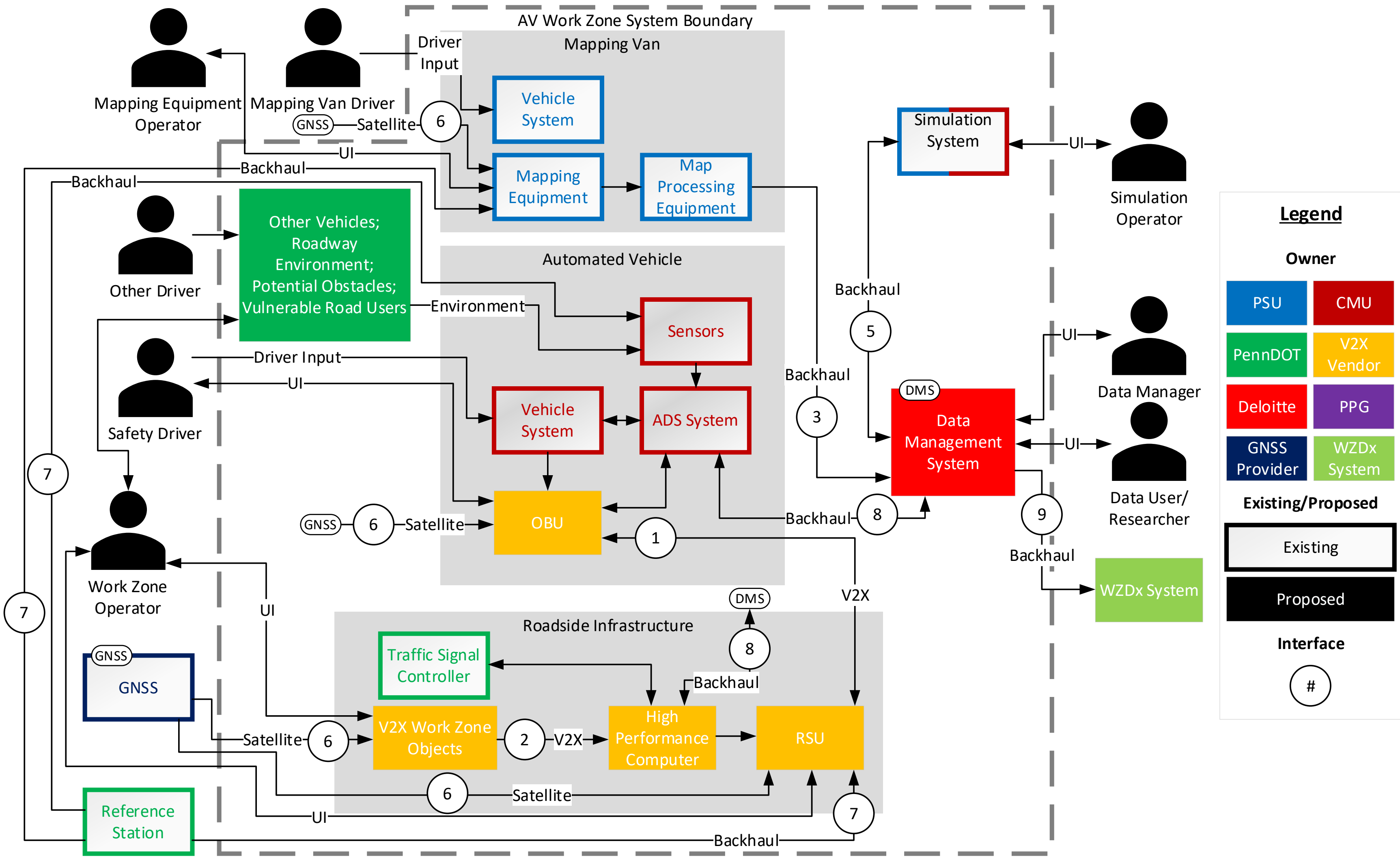
The ADS Demonstration System is composed of five main subsystem components:

- **Automated Vehicle:** the vehicle to be used for the ADS demonstration. Includes embedded sensors, Vehicle-to-Everything (V2X) onboard unit (OBU), communication interfaces, and onboard ADS computer hardware.
- **Mapping Van:** the vehicle that will create the HD maps. Includes embedded sensors and onboard map processing equipment.
- **Roadside Infrastructure:** includes Roadside Units (RSU), traffic signal controllers, and V2X work zone objects.
- **Simulation System:** a digital representation of the operational environment of AVs in work zones to determine the interaction among the variables within the system.
- **Data Management System:** a cloud-based system that ingests and stores volumes of data received across the various systems; the system will be responsible for data archiving, data versioning, managing application programming interfaces (API), and securing data exchanges to, from, and at rest within storage container(s).

Figure 2 illustrates the data flow for the DMS as shown in ConOps document. The following are external interfaces that support the ADS system components.

- **Reference Station –** facilitates a real-time Global Navigation Satellite System (GNSS) based on a set of reference stations.
- **GNSS –** generates vehicle location, speed, and orientation in safe assisted driving and broadcasts the data to the OBU and the RSU.

Figure 2: ADS Demonstration System Context Diagram



SOURCE: ADS DEMONSTRATION CONCEPT OF OPERATIONS

1.5 Stakeholders

This section describes the stakeholders as identified in the ADS ConOps. These include all existing stakeholders who have an influence on the operation of the proposed ADS Demonstration System. This will include all staff and agencies whose operation and duties may be affected by the envisioned system.

1.5.1 Carnegie Mellon University (CMU)

Founded in 1900, CMU is a private research university based in Pittsburgh, Pennsylvania. CMU's College of Engineering is the academic unit that manages engineering research and education at CMU. The College of Engineering employs 207 faculty members and has over 700 doctoral students performing research activities. CMU is the birthplace of AVs and has been a pioneering leader in AV technologies since the 1980s. Within the College of Engineering, CMU has various labs working on technology specifically for the advancement of AV technology, like the Argo AI Center for AV Research. These centers focus on fundamental research that will produce advanced perception and next-generation decision-making algorithms that enable vehicles to perceive and navigate autonomously in diverse real-world urban conditions. CMU's Department of Electrical and Computer Engineering, within the College of Engineering, will be the stakeholder participating in this project and will be responsible for the operation of the AV, the simulation of AV operations, and research and analysis activities of the project.

1.5.2 Contractor

For the live on-road testing, it is anticipated that a real work zone with limited traffic will be used. The testing location may be either a work zone set up by PennDOT maintenance crews or a contractor. In the event that the work zone is operated by a contractor, the contractor will be responsible for acting as the role of the Work Zone Operator and will coordinate with PennDOT Central Office, PennDOT District and PennDOT County (maintenance crew). The contractor will be responsible for setting up the work zone in accordance with the traffic control plan for the project. Prior to choosing the work zone location, PennDOT Central Office will verify that the traffic control plan for the project accurately reflects the PATA figures.

1.5.3 Deloitte

Deloitte Consulting LLP, known as Deloitte, is the US division of a multinational professional services network with offices around the world. Deloitte's Cloud Engineering department is one of the global leaders of cloud infrastructure and engineering and managing cloud services. The Cloud Engineering department will be participating in this project as the developer of the DMS and DMS documentation, including the DMP, Data Privacy Plan, and DMS Incident Response Plan.

1.5.4 PennDOT Maintenance

There are 11 district maintenance offices that encompass 67 county maintenance offices in the Commonwealth. Each district and county have their own maintenance team that is responsible for coordinating the maintenance of the state-owned roadway network in their respective jurisdictions.

1.5.5 PennDOT Central Office

PennDOT Central Office is located in Harrisburg, PA. PennDOT Central Office is responsible for the central planning activities of PennDOT and coordinating with the PennDOT districts. For this project, the Central Office will refer to the Bureau of Operations and the Office of Transformational Technology. PennDOT Central Office is responsible for the overall project, grant management, and on-road testing coordination.

1.5.6 PennDOT Districts

There are 11 PennDOT districts in the Commonwealth. Each district has their own district office and staff. The districts are responsible for managing their state-owned roadway network and coordination with local governments, residents, and contractors.

1.5.7 PPG Industries

PPG, headquartered in Pittsburgh, PA, is an American Fortune 500 company and global supplier of paints, coatings, and specialty materials. They are the largest coatings company in the world. In recent years, PPG has developed advanced coatings that can improve detection for cameras and LIDAR sensors. As part of this project, these coatings will be tested to see if they aid ADS operations.

1.5.8 Pennsylvania State University (PSU)

PSU, founded in 1855, is a public state-related land-grant research university with campuses and facilities throughout Pennsylvania. The PSU College of Engineering employs over 400 research and teaching faculty. The Department of Civil and Environmental Engineering and Department of Mechanical Engineering will be the stakeholders from PSU involved in the project. The activities in this project are coordinated through the Thomas D. Larson Transportation Research Institute, often called the Larson Transportation Institute (LTI). This is a center housed within the College of Engineering whose purpose is to coordinate transportation projects and research. PSU is responsible for coordinating transportation research, providing the test track facilities, managing and operating the Mapping Van, and managing and operating the V2X RSUs.

1.5.9 Pennsylvania Turnpike Commission (PTC)

The Pennsylvania Turnpike is a 550-mile controlled access toll highway system operated by the PTC in Pennsylvania. The 360-mile mainline runs east-west across the state, connecting the Pittsburgh, Harrisburg, and Philadelphia areas. In addition to the mainline, the PTC operates the Beaver Valley Expressway, the Greensburg Bypass, the PA Turnpike 576, the Mon/Fayette Expressway (PA Turnpike 43) and the Northeastern Expressway. The PTC has its own maintenance crews, which set up work zones on the Turnpike roadway for maintenance activities. Construction contractors set up work zones for all short- and long-term construction work zones. For this project, the Traffic Engineering and Operations department will be the stakeholder group that participates in the project. Maintenance and Construction may also be a stakeholder if a live scenario is tested on the PTC.

1.5.10 United States Department of Transportation

USDOT is a federal Cabinet department of the U.S. government concerned with transportation. USDOT employs almost 55,000 people across the country, in its operating administrations and bureaus, each with its own management and organizational structure. The Federal Highway Administration (FHWA) provides stewardship over the construction, maintenance and preservation of the Nation's highways, bridges, and tunnels. FHWA also conducts research and provides technical assistance to state and local agencies to improve safety, mobility, and to encourage innovation. For this project, USDOT is responsible for the ADS grant demonstration program.

1.5.11 FHWA Pennsylvania Division

FHWA Pennsylvania office will be working directly with PennDOT as part of the federal aid program.

1.5.12 V2X Work Zone Object Vendors

For this project, V2X Work Zone Objects collectively refer to all the appropriate traffic control devices, vehicles (OBUs) and other equipment which are equipped with V2X technology within the work zone. Multiple V2X Work Zone Object Vendors will be procured as part of deployment. The V2X Vendors will be responsible for providing guidance on setting up and configuring the V2X Work Zone Objects. It will be expected that the V2X Vendors will have a history of successful V2X deployments and have the ability to provide guidance and expertise on V2X device integration.

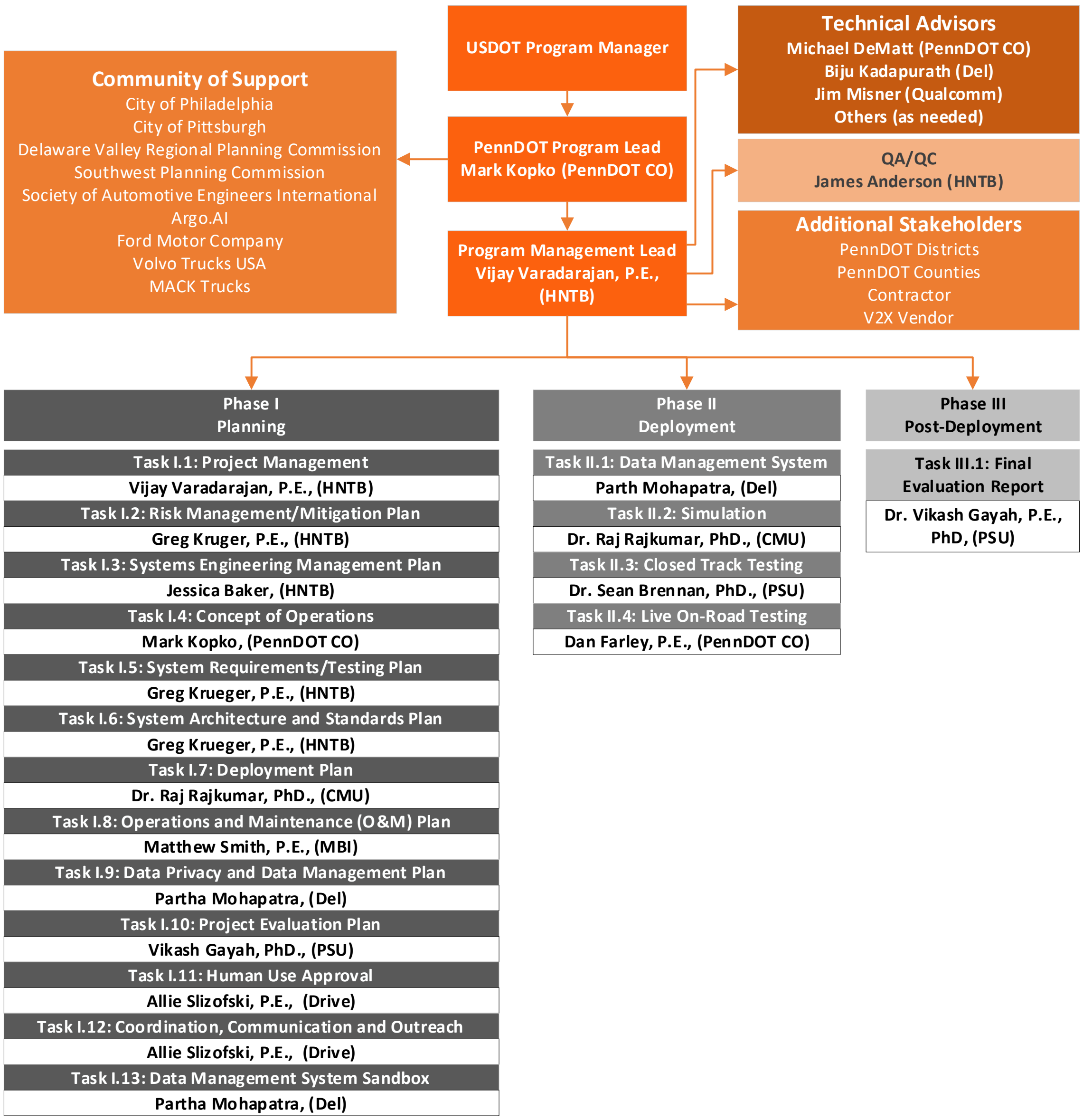
1.5.13 Commsignia

Commsignia was chosen as one of the V2X Work Zone Objects Vendors to provide the V2X RSU and OBU. They will be responsible for setting up and configuring the devices and it is expected that they will provide guidance and expertise on integrating the devices into the vehicles and infrastructure.

1.5.14 Organizational Structure

The organization chart for the ADS Demonstration Project can be found in **Figure 3**. It is not anticipated that there will be any changes to individuals' roles within their own organizations for this project. A detailed description of each role's responsibility for deliverable development can be found in the *Project Management Plan* and *Systems Engineering Management Plan*.

Figure 3: ADS Demonstration Organizational Chart



SOURCE: ADS DEMONSTRATION CONCEPT OF OPERATIONS

1.5.14.1 Core Team

The core team will consist of key management staff from PennDOT, PSU, PTC, and CMU. HNTB Corporation (HNTB), a consulting firm, is also a part of the Core Team.

The core team is responsible for the essential business issues associated with the project which are critical to the delivery of the project outputs and the attainment of project outcomes. The core team members will meet weekly to monitor and control the scope, schedule, budget, quality, deliverables, and risks of the project.

1.6 Referenced Documents

Table 1 lists documents and literature referenced during the development and update of this document.

Table 1. References

Title	Date
Project Management Plan (PMP) for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ)	May 2021
Systems Engineering Management Plan (SEMP) for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ)	October 2021
Concept of Operations (ConOps) for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ) (Draft)	March 2022
Data Management Plan (DMP) for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ) (Draft)	Under Development
System Requirements Document (SRD) for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ) (Draft)	Under Development
Deployment Plan for the for the Safe Integration of Automated Vehicles into Work Zones (SI-AV-WZ) (Draft)	Under Development

2 MATERIALS AND RESOURCES

This section identifies the personnel responsible for operating and maintaining the components and subsystems of the ADS Demonstration and the resources use for the ADS project O&M. Table 2 provides a list of system components and the organization that is responsible for operation and maintenance during the project.

Table 2. ADS Demonstration System Stakeholder Responsibility

System/ Component	Name	Organization	Role/Responsibility
Automated Vehicle	Raj Rajkumar	Carnegie Mellon University	In-vehicle systems and sensors Hardware manager CMU Vehicle
Mapping Vehicle	Sean Brennan	Pennsylvania State University	In-vehicle system Hardware Manager Data processing system PSU Vehicle
Roadside Infrastructure	Sean Brennan	Pennsylvania State University	V2X RSU (Comsignia)
	Sean Brennan	Pennsylvania State University	V2X RSU – Off road (Track)
	Gunnar Rhone	PennDOT	V2X RSU – On road (Live)
	Brian Crossley	PennDOT (point of contact) Vest Vendor (Virginia Tech University (VT)) VT Point of Contact (Jean Paul Talledo Vilela)	V2X Work Zone Object - Vests
	TBD	PennDOT Contractor / Maintenance / PTC Contractor (TBD)	V2X Work Zone Object - Other
	Mark Kopko	Pennsylvania DOT	Non-V2X Work Zone Objects
	TBD	Pennsylvania State University Vest Vendor (Vtech)	High Performance Computer (HPC)
Data Management System	David Breslin	Deloitte	Data Management System Configuration control Access control
Simulation System	Raj Rajkumar	Carnegie Mellon University	CADRE TROCS CARLA
	Sean Brennan	Pennsylvania State University	SUMO Simulation System CARLA

2.1 Personnel

Table 3 lists the personnel, their role, name, organization, and key functions. This table will be reviewed for any needed revisions during the project.

Table 3. ADS Demonstration System Personnel

Role	Names	Organization	Function
Safety Driver	Raj Rajkumar	CMU	The safety driver operates the AV when the AV is not in autonomous mode and intervenes when the AV malfunctions in autonomous mode. The safety driver is trained by CMU on how to safely operate the vehicle and how to determine when the vehicle is malfunctioning in order to intervene. The safety driver will be responsible for driving the AV to the testing location, starting/stopping AV mode, and disengaging the AV when necessary. The safety driver will be inside the vehicle and attentive during all vehicle operations
Safety Associate	Shounak Sural	CMU	The safety associate operates equipment on board the AV and acts as a backup safety operator who can disengage autonomous mode to stop the AV. The safety associate is trained by CMU on how to safely operate the vehicle and how to determine when the vehicle is malfunctioning in order to intervene. The safety associate will be responsible for disengaging the AV when necessary, monitoring the AV performance, communicating with testing staff, and retrieving data from the AV. The safety associate will be inside the vehicle and attentive during all vehicle operations.
Software Programming	Gregory Su	CMU	The software programmer designs and develops software, writes and updates source-code and related documentation, and manages operating systems. CMU staff will oversee the AV and simulation. PSU staff will oversee the Mapping Van and simulation software. Deloitte staff will oversee the DMS software.
	Alex He	CMU	
	TBD	PSU	
	TBD	PSU	
	TBD	Deloitte	
	TBD	Deloitte	
Vehicle Maintenance	Raj Rajkumar	CMU	The vehicle maintenance staff performs and coordinates vehicle maintenance tasks.
Simulation Operators	Shounak Sural	CMU	The simulation operator manages, operates, and maintains the simulation system. The simulation operator is responsible for setting up a work zone configuration in the simulation and conducting the simulation (including both the AV simulation and the traffic simulation within the Simulation System).
	TBD	CMU	
	Sean Brennan	PSU	
	Wushuang Bai	PSU	
	Craig Beal	PSU	
Mapping Van Driver	TBD (Various)	PSU	The Mapping Van driver drives the Mapping Van in the work zone. The Mapping Van driver is trained by PSU on how to operate the vehicle. The Mapping Van driver is responsible for driving the Mapping Van and communicating with the mapping equipment operator.
Mapping Equipment Operator	Wushuang Bai	PSU	The mapping equipment operator operates the mapping equipment on the Mapping Van. The mapping equipment operator is trained in the installation, calibration, and/or operation of the

Role	Names	Organization	Function
			mapping equipment. The Mapping Van equipment operator will be responsible for starting/stopping the mapping equipment, monitoring the Mapping Van system performance, communicating with testing staff, retrieving data from the Mapping Van, and preprocessing data prior to insertion into the DMS.
Data Users/ Researchers	Sean Brennan Wushuang Bai Craig Beal Students (Various)	PSU	The data user/researcher queries data from the DMS to prepare reports and to conduct research. A data user/researcher may be a third-party user accessing the public datasets. The data user/researchers that are a part of the project team will be responsible for preparing reports and conducting research on behalf of the project team.
Administrative Staff	Raj Rajkumar	CMU	The administrative staff schedules maintenance appointments, coordinates staff hours, and serves as a point of contact to the support team.
Safety Manager	Dennis (Denny) Kovalick	PSU	The safety manager manages site safety at each of the work zone setup locations
Site Manager	Dennis (Denny) Kovalick	PSU	The site manager is in charge of testing track facility and has the authority to end testing if security violations are found.
Safety Manager (Live Testing)	TBD	PennDOT	The safety manager manages site safety at each of the work zone setup locations during live testing.
Site Manager (Live Testing)	TBD	PennDOT	The site manager is in charge of the live testing sites and has the authority to end testing if security violations are found.
Test Lead	TBD	PennDOT	The test lead will be responsible for scheduling all staff and resources required for the testing; overseeing the conducting of the testing, development, and setup of the work zones; monitoring staff performance; and making sure that the required data is stored in the DMS.
Project Manager	Vijay Varadarajan	HNTB	The project manager is responsible for planning and estimating the resources required to complete the task.
Data Manager	David Breslin	Deloitte	The data manager manages, operates, and maintains the DMS. The data manager is responsible for creating user accounts and managing user roles, as well as checking the integrity of data being used by the system and monitoring the DMS status.

2.2 Facilities

This section discusses the facilities used for operations of the ADS Demonstration.

2.2.1.1 Laboratory

PSU's lab facilities will be used for simulation and research during the project. The labs will be equipped with computers and servers equipped with software required for performing simulation and research activities.

CMU's lab facility will be used for simulation during the project. If the simulation software can be integrated so that CMU may use a remote location, CMU will likely host their computers and servers at their own lab. If the simulation software requires a lower latency to function properly and in a timely manner, CMU's computers will be hosted in the PSU lab facilities. The hosted location will be determined in the beginning Phase 2.

2.2.1.2 Storage

The Mapping Van, AV, and traffic control devices will need to be stored at night and during times where testing is not occurring. The storage facilities should have space for the vehicle, traffic control devices, maintenance equipment, and site equipment. The storage facilities must be secured with locks for protection. Storage facilities will be available at LTI, PSU's campus garage, and near construction sites.

2.2.1.3 Larson Transportation Institute (LTI) Test Track

PSU's LTI test track is located in Benner Township, Centre County, PA, just outside State College, will be used for setting up work zones to be used in both simulation and closed track testing. LTI features a one-mile oval loop with an in-field area that may be used for staging, fueling stations, and offices which may be utilized by the testers.

LTI does not have the required equipment to set up the work zone and perform line striping setup/removal. PennDOT will be responsible for providing all equipment and services required to set up the work zones.

2.2.1.4 Construction Site

The construction sites used for testing live on-road environments will have facilities for testing staff. The required items needed for testing are construction trailers, portable toilets (if not in the construction trailers), computers, office furniture, a printer, climate control, utility connections, and secure storage. Additionally, the sites must have a 120V AC pluggable charging station for the Mapping Van. The construction sites need to have an outdoor viewing area near the testing staff to view the testing from a safe distance, which will be identified when live on-road testing sites are selected.

PennDOT and the Contractor will be responsible for providing the facilities at the construction sites. The items that will be the responsibility of the Contractor to provide will be identified during the development of the *Deployment Plan*. In order for the contractor to perform their role, the project items will need to be included in the construction project's plans, specifications, and estimate prior to bidding. Prior to live on-road testing, prospective construction projects will be identified by PennDOT Central Office and Districts. PennDOT Central Office will coordinate with the PennDOT District offices to generate the required construction project documents. Long-term work zone scenarios will first be identified during the development of the *Deployment Plan* because they have a longer contracting process.

2.2.1.5 Short-Term/Maintenance Work Zones

The short-term or maintenances work zones used for testing live on-road environments will have limited facilities for testing staff. Short-term work zone scenarios will be identified three to six months before live on-road testing commences. The project core team will be responsible for identifying the necessary items needed for testing.

2.3 Equipment/Hardware

This section lists and provides details on the operating equipment used for operating the ADS Demonstration System components.

2.3.1 Mapping Van

The Mapping Van is a retrofitted Ford Transit van developed by PSU and equipped with inertial and perception-based sensors for measuring the position of the vehicle and the surrounding environment.

The Mapping Van houses three (3) HD FLIR Blackfly USB3 cameras mounted on a camera bar located above the windshield to measure the surrounding environment, and three (3) additional downward-facing cameras on a rear bar to image the road surface features.

The main sensor used to provide a global position estimate of the vehicle is a military-grade Novatel/Honeywell INS which integrates a Global Positioning System, Inertial Measurement Unit, and ring-laser gyroscope through an Extended Kalman Filter to provide a state estimate. A base station at the Larson Institute was calibrated to provide differential corrections. A lower-cost Inertial Measurement Unit produced by Analog Devices is attached to the same frame as the Honeywell INS.

Additionally, two US Digital HD25 optical wheel encoders are mounted on the rear tires to measure the orientation and angular velocity of each wheel.

A downward-facing SICK LMS511 LIDAR system, oriented in a “rake” style to measure the road perpendicular to the direction of travel, is mounted on the rear of the vehicle. This LIDAR generates a two-dimensional scan of the road, measuring both the range and bearing for a particular laser return. For point-cloud mapping, the vehicle is typically equipped with either a 16-scan line or 32-scan line LIDAR (Velodyne) similar to those used by AVs.

Unimeasure JX-PA string potentiometers are mounted to each front wheel to measure the road wheel angle.

Onboard sensors are managed by the vehicle’s robot operating system (ROS) and are triggered via embedded trigger processes which use GPS/PPS for synchronization.

2.3.2 Automated Vehicle

The AV used for this project will be provided by CMU. The vehicle make is Cadillac and model is SRX. The vehicle is equipped with embedded sensors that allow the onboard ADS to control the vehicle. The vehicle has an OBU that allows the AV to interact with Connected Vehicle (CV) infrastructure and other vehicles with CV technology. The OBU will be capable of operating on both Dedicated Short Range Communications (DSRC) and Cellular Vehicle-to-Everything (C-V2X) radios.

- **Sensors:** LiDAR, radar, cameras, an inertial measurement unit (IMU), GPS (Global Positioning System) pulse per second (PPS) receivers.
- **Compute:** 5 embedded PCs and a dSPACE microAutoBox II (“box”). The box serves as the interface between the ADS software stack & the vehicle’s by-wire (actuation) subsystem. It is capable of receiving digital inputs to produce digital outputs as well as accepting analog inputs to produce analog outputs.
- **Communications:** 100Mbps ethernet backbone, multiple Controller Area Network(CAN) buses, DSRC & C-V2X transceivers, and 4G/5G radio.
- **Actuation:** primary controls: steering, braking, throttling, and secondary controls: turn signals, flashers, horns, etc.

2.3.2.1 On-Board Unit

The OBU for this project will be procured from the vendor Commsignia. The vendor will work with CMU and PSU to integrate the OBU into the AV and Mapping Van for testing.

2.3.3 Simulation System

The project Simulation System is made up of other simulation systems owned by CMU and PSU. CMU will create a simulation of AV behaviors within a construction environment; their subsystem is known as CADRE TROCS and is used to simulate ADS in a virtual environment. CMU currently has two high performance desktops owned and operated by the AV team. PSU will create traffic simulations using the SUMO tool and will have two or three desktops for their portion of the simulation.

2.3.4 Data Management System

The DMS will be built on Microsoft's public cloud computing platform, Microsoft Azure, which provides a range of cloud services, including compute, analytics, storage, and networking. The DMS will be hosted on the Azure platform; therefore, additional hardware will not be needed for the project.

2.3.5 Roadside Infrastructure

Roadside infrastructure consists of the RSU, any present traffic signal controllers, the High-Performance Computer (HPC), and any present V2X Work Zone Objects. Together, these components generate, aggregate, and broadcast relevant work zone information to the AV. Other non-connected infrastructure may also be included as part of the roadside infrastructure, such as traditional cones, barrels, barriers, and other traffic control components.

2.3.5.1 Roadside Unit (RSU)

The RSU is responsible for two primary functions: broadcasting relevant data from various systems to the AV and (potentially) receiving V2X messages from the AV, forwarding them to other systems for processing. Various types of messages may be sent via the RSU, but the most important ones for ADS piloting are position-related messages. Positioning data generated by V2X Work Zone Objects will be received by the local HPC over Zigbee, an Internet of Things (IoT) broadcast protocol. The HPC then dissects, processes, and combines the data into SAE J2735 encoded messages that the AV can understand, containing that same positioning data; these V2X messages are then relayed to the RSU and broadcast over V2X to the AV.

The HPC (and/or auxiliary systems) may also send other messages to the AV via the RSU; SPaT messages may be sent from a local traffic signal controller, MAP messages may be sent by the HPC, messages may be configured directly on the RSU for store-and-repeat broadcasting, etc.

In most cases, messages will be sent to and/or generated by the HPC, with the HPC encoding those messages and broadcasting them via the RSU with the RSU acting as a passthrough radio. In some instances, however, it may be necessary for other systems to send messages directly to the RSU or for the RSU to contain statically configured messages itself. Additionally, it may be necessary in some use cases to have the RSU forward Basic Safety Messages (BSMs) received from the AV to the HPC for logging and additional processing.

2.3.5.2 V2X Work Zone Objects

For this project, V2X Work Zone Objects collectively refer to all the appropriate traffic control devices, construction workers, and vehicles which are equipped with V2X technology within the work zone. Work zone objects that are not equipped with V2X connectivity are not included in this object definition. Note that the term V2X here refers both to vehicles transmitting to infrastructure (V2I) and other vehicles (V2V), and also to infrastructure elements communicating to vehicle (I2V) and to the road-side infrastructure (I2I), namely the RSU. Each work zone object's V2X capability allows information flow directly from the object to either the vehicle or RSU. Example implementations would include smart construction worker vests, V2X equipped construction vehicles, or even smart traffic cones, barrels, barriers, and signs that transmit "here I am" data to approaching vehicles to avoid collisions. The communications equipment required to create the V2X Work Zone Objects is anticipated to include a communication radio (DSRC/C-V2X, Zigbee, LoRA, Wi-Fi, etc.), and a GNSS receiver mounted on each device alongside power management systems. The V2X Work Zone Objects will have their positions communicated to a central point (the HPC). The HPC in turn will process the messages, re-broadcast the object location information to the AV via the RSU, and perform time-synchronized logging of the information.

2.3.5.3 Digital Worker Vest

The Digital Worker Vest will be instrumented with GPS, cellular radio (4G or 5G) or Wi-Fi radio and Zigbee radio. The vest system uses a USB battery pack to operate. Currently the system can last up to 22 hours processing GPS data and 10 hours when the HMI alerting is fully active. The base station is powered using PoE.

2.3.6 Support Equipment

2.3.6.1 Traffic Control Devices

The traffic control devices required for the project include barrels, cones, barriers, traffic control signs, sign flashing lights, temporary traffic signals, flagger equipment, and arrow boards trailers. Any additional traffic control equipment that is needed will be procured by PennDOT Central Office. The barrels, cones, barriers, signs, and flagger equipment will be treated with the enhanced PPG coating in some variations of the work zone scenarios.

In lieu of a concrete barrier, a water-filled plastic barrier may be used at LTI in order to make the work zone scenarios easier to set up. If a water-filled plastic barrier is used, its color will be consistent with work zones.

When designing for the testing scenarios, traffic control devices of varying conditions will be used in the work zones, ranging from new equipment to equipment that is deteriorated past its usable condition. In existing work zones, traffic control devices may be in a wide range of conditions and due to budget constraints, many of the devices are of poor quality or past their end of life. Using devices that are of a wide range of quality will allow the team to create conditions that are similar to what an AV would experience in a real work zone.

2.3.6.2 Temporary Traffic Signal

At the time of this writing, PennDOT is evaluating the procurement of the Temporary Traffic Signal. Details will be added to this section once it is procured.

2.3.6.3 Lane Striping

Lane striping equipment will be used to deploy paint and bead line striping and line striping containing the enhanced coating in the work zones. Pavement marking removal equipment will be required to restripe the work zone between scenarios. At LTI, PennDOT District 9-0 may provide the line-striping services for the facility. If District 9-0 is unavailable, another district may be used. If no other districts are available, a vendor would be used to provide line striping. In the live environment, a contractor would be responsible for providing the line-striping services.

Alternatively to the line striping equipment, temporary lane striping tape may be used to create pavement markings.

2.3.6.4 Decommissioned Work Zone Vehicles

Decommissioned work zone vehicles will be provided by PennDOT Districts and Counties to act as shadow vehicles. A shadow vehicle is used upstream of the work area to protect workers on low-speed roadways. Truck-mounted attenuators (TMAs) are required for the shadow vehicle when the work zone is along a freeway or expressway.

For typical work zones in Pennsylvania, the shadow vehicle can be any vehicle on a conventional roadway as long as it is equipped with a flashing, oscillating, or revolving yellow light which is visible from any direction (360° visibility) and is not being used as a work vehicle. The shadow vehicles will be treated with an enhanced coating in some variations of the work zone scenarios.

2.3.6.5 Automated Truck-Mounted Attenuator

In addition to the static traffic control devices, an Autonomous TMA (ATMA) will be procured for the project to deploy in work zones that require a TMA, particularly the mobile work zone scenario. The ATMA will enable a “leader/follower” operation which will allow the ATMA to follow a human-driven maintenance vehicle. In addition to testing the AV’s interaction with TMAs, the ATMA will allow the project team to understand how the automated systems might interact with each other. The ATMA and maintenance vehicle will communicate via V2V communications. The ATMA will be procured and operated by PennDOT Central Office.

2.3.6.6 Other Vehicles

Other vehicles in the work zones will be operated by the owner of the vehicle. The other vehicles will be provided by PSU, PennDOT Central Office, PennDOT Districts, PennDOT counties, and the public. The general public will only be operating vehicles in the live on-road environment. As such, the other vehicles will be made up of a variety of makes and models.

2.3.6.7 GNSS

GNSS refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receiver then uses this data to determine its location (longitude, latitude, elevation) to a degree of precision that can vary from a few centimeters to several meters. There are four global GNSS, with the most well known being the Global Positioning System, as well as several regional GNSS. Project subsystems may use one or several of the available GNSS.

2.3.6.8 Reference Station

Several Reference Stations will be used for the project to provide high-precision location data. As opposed to GNSS, Continuously Operating Reference Stations (CORS) are able to provide sub-centimeter level accuracy with a good connection. There are currently over 1,350 CORS sites as part of the National CORS system, as well as some privately owned CORS. For this project, the RSU will use the CORS operated by PennDOT as part of the National CORS network, the Mapping Van will use the CORS that is owned by PSU and located at LTI, and the AV will utilize a CORS network to which CMU subscribes.

2.3.6.9 Work Zone Data Exchange (WZDx) System

The WZDx System refers to any system that receives the WZDx information from the DMS WZDx page. User systems that may receive the WZDx include map services (e.g. Waze, Google, Apple, etc.) and vehicle OEMs. The information that will be received by the WZDx System will be JavaScript Object Notation (JSON) in the WZDx format established by USDOT's WZDx Program. The WZDx information will be provided in the format that was established at the time of the development of the project and will not be updated as the project progresses. The information that is provided by the DMS will originate in PSU's map processing system and will be sent along with the map information. The API link where the WZDx information will be provided may be available on the USDOT WZDx Program website.

2.4 Software

This section provides a listing of any software and other products/services that are applicable that will be used during the operation and maintenance of the system.

2.4.1 Automated Vehicle

CMU is responsible for developing the software for the ADS to operate the AV. CMU plans to use software from MathWorks, dSPACE, and other open-source software. CMU is responsible for the license and maintenance costs of the software.

- Technical Specifications
    - Operating System: Ubuntu 20.04 LTS
    - Function Code: C/C+

2.4.2 Mapping Van

PSU is responsible for keeping their own custom developed Mapping Van software up to date. Any software updates to the Mapping Van software will be performed by PSU. PSU is responsible for verifying that the Mapping Van software is functioning properly and operational.

PSU will be responsible for obtaining any software required for the final project evaluation. PSU will be responsible for keeping the software up to date. PSU plans to use MATLAB, Python, and C++ development tools to perform the final evaluation and for data processing steps. As well, PSU may temporarily host data on an internal, firewalled PostgreSQL database to facilitate rapid processing and data transfer to the DMS.

- Technical Specifications:
  - Operating System: Ubuntu 20.04 LTS
  - Middleware: ROS Noetic
  - Function Code: Python 2.4 and C/C++
  - Data processing: MATLAB 2021b, data processing is done within Python and C/C++ when speed is needed.
  - Data servers: PostgreSQL 10.12 with the PostGIS 2.5.3 bundle that supports the Spatial Extension subtree, supported by Java Version 1.8.0_202-b08 with Oracle Corp. Java HotSpot 64-Bit Server VM mixed mode and the JDBC 42.2.9 version JAR drivers.

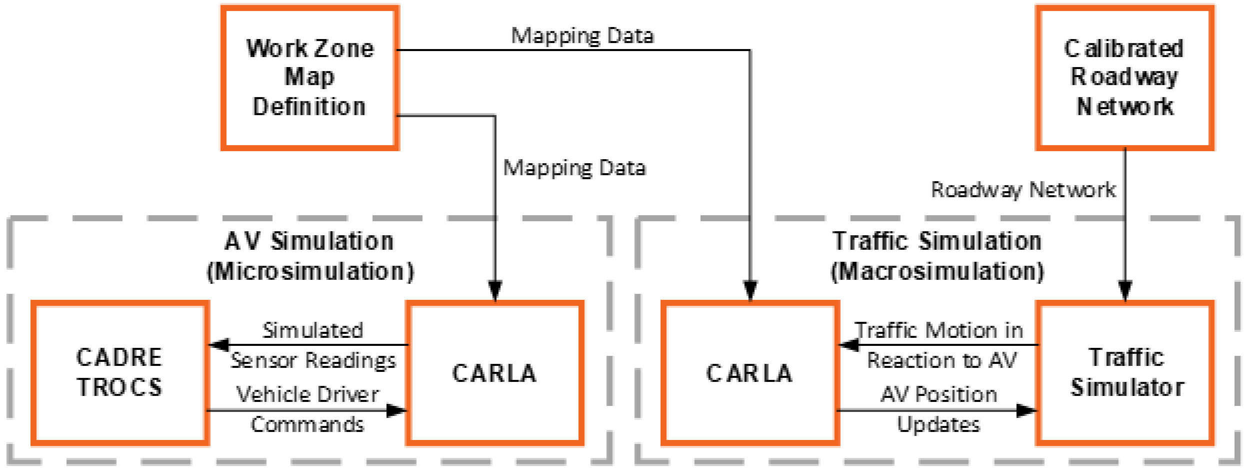
2.4.3 Simulation System

The Simulation System is made up of individual simulation/simulator tools. As shown in **Figure 4** these systems will be integrated using a tool called CARLA. For CMU's simulation of AV behaviors within a construction environment, their subsystem is known as CADRE TROCS and is used to simulate ADS in a virtual environment. For PSU's integration of traffic simulations with motion simulations of vehicle chassis behavior, PSU will most likely use the tool Simulation of Urban MObility (SUMO) as their traffic simulation system due to its open-source availability and ongoing development within the CARLA environment.

Software Description:

- **CARLA** was developed by the Computer Vision Center and is an open-source, 3D simulator that supports the development, training, and validation of ADSs. CARLA allows the flexible specification of sensor suites and environmental conditions, and user-defined elements including instances of other vehicles, pedestrians, and user-defined maps. In order to create the simulation environment, the ADS simulation system and traffic simulation systems will be integrated using APIs that pass data between the systems.
  - Version: 0.9.12
  - Operating System: Ubuntu
- **CADRE TROCS** was developed by CMU and allows the user to determine the path of the vehicle, change the map on the fly, and place obstacles within the simulation. A graphical user interface for CADRE TROCS facilitates real-time monitoring and manipulation. It consists of six main functional components: real-world model plotter, XML-based scenario loading area, historical host vehicle measurement, a zoom/panning tool, simulator/planner stop/go toggle tool and an external trigger control panel.
- **SUMO** is a free and open-source traffic simulation suite developed by the German Aerospace Center and community users. It allows modeling of intermodal traffic systems that includes road vehicles, public transport, and pedestrians. SUMO is licensed under the Eclipse Public License V2 and will be used by PSU.

Figure 4: Simulation System Architecture



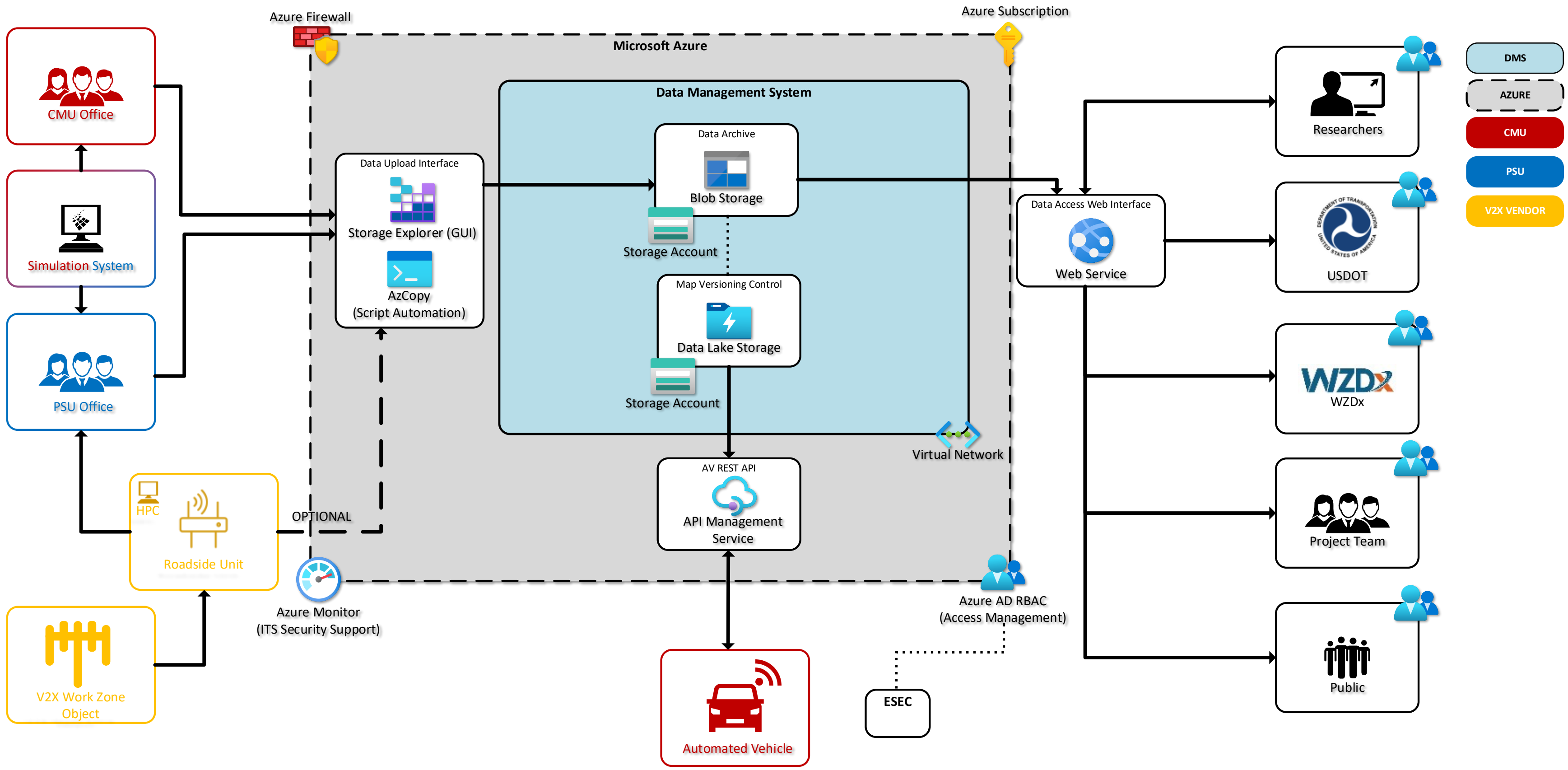
SOURCE: ADS DEMONSTRATION CONCEPT OF OPERATIONS

2.4.4 Data Management System

A graphical user interface will be provided for project members to view, query, and pull data from the DMS. An API will be supplied to enable the USDOT and other researchers to connect and extract data for analysis and research purposes. The API will also be used to push data to a separate repository for sharing with the general public via a publicly accessible WebApp. The APIs in use will be properly documented with sample code and information to make the API interaction seamless. The various APIs enable specific components of the ADS environment to interact with various types of data correlated to matching parameters based on requests and returns a list of all data activities matching filter designations from the requests made to the DMS.

Data will be uploaded by the project team; namely, PSU and CMU, using Azure Storage Explorer. This is a free GUI tool from Microsoft made available on Windows, Mac, and Linux. With this tool the team can access and manage Azure Blob Storage as well as move data to and from Azure Data Lake Storage. An alternative option to uploading data can be achieved using AzCopy, a command-line utility for automation purposes. AzCopy is Microsoft Azure's command-line utility for copying data to or from Azure Blob Storage using simple commands that are designed for optimal performance, which will also be made available to the project team. **Figure 5** provides a diagram of the system architecture for the project's data management system built within the Azure cloud platform.

Figure 5. DMS Reference Architecture



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

2.4.5 Roadside Infrastructure

RSU software includes the device operating system, any applicable software application licenses, and the vendor's head-end management software. The operating system is comprised of the system kernel, core OS applications and utilities, the networking stack (IPv4, IPv6, Ethernet, IEEE 1609, LTE R14 PC5), security stack (SCMS certificate and messaging signing), and V2I stack (applications, J2735 message encoding, and others).

The Commsignia RSU runs a modified version of OpenWRT, the open-source wireless router platform, adapted for use with V2X communications (both DSRC and C-V2X). Having a foundation on OpenWRT means the Commsignia RSU's interface is very similar to a wireless router, featuring a Layer 4 firewall onboard and full routing capabilities in addition to V2X processing.

Commsignia's software stack is self-contained, with the RSU itself capable of generating, receiving, and processing V2I messages. However, external data sources such as the HPC and others may use the RSU as a relay for V2I communications. Depending on use case, the HPC may pre-generate an encoded message for broadcast by the RSU which the RSU does not need to process. Likewise, the RSU may receive some V2X messages which can be forwarded to another system for processing and/or analysis.

Licenses depend on the RSU vendor; Commsignia however does not require any special licensing to use the V2X message sets or applications required for the ADS demonstration; MAP, SPAT, TIM, or (potentially) BSM processing.

Commsignia's head-end software, Commsignia Central, will be used to remotely manage the RSUs by PSU and can perform functions such as message loading, firmware updating, health monitoring, and others. This software will be included as part of Commsignia's participation in the demo and will not require integration within the demo environment.

Should GPS location services be insufficient for the location, a CORS basestation may be required to augment positioning services for the RSU.

2.5 Roles and Responsibilities

Table 4 lists the roles and responsibilities of each stakeholder of the project.

Table 4. Stakeholder Roles and Responsibilities

Stakeholder	Roles and Responsibilities
PennDOT Central Office	• Support DMS development, simulation testing, closed-track testing, and final evaluation report • Manage live on-road testing • Install and maintain V2X equipment
PennDOT Districts	• Set up work zones • Drive other vehicles in the closed-track testing
PennDOT Counties	• Set up work zones • Drive other vehicles in the closed-track testing
HNTB	• Support DMS development, simulation testing, closed-track testing, live on-road testing, and final evaluation report • Project management • Develop safety management plan, systems engineering management plan, system architecture, and standards plan • Visual check of all planning documents

Stakeholder	Roles and Responsibilities
PSU	• Support DMS development, simulation testing, and live on-road testing • Manage closed-track testing • Develop final evaluation report • Integrate, maintain, and operate Mapping Van and Simulation Systems • Prepare and submit for closed-track testing IRB approval, if necessary • Drive other vehicles in the close track testing
CMU	• Support DMS development, closed track testing, live on-road testing, and final evaluation report • Manage simulation testing • Integrate, maintain, and operate AV and Simulation Systems • Prepare and submit for live on-road testing IRB approval
Deloitte	• Develop, maintain and operate DMS
PPG	• Support DMS development, simulation testing, closed-track testing, live on-road testing, and final evaluation report • Provide coating and integrate into work zones
PTC	• Support DMS development, simulation testing, closed-track testing, live on-road testing, and final evaluation report
PTC Maintenance & Construction	• Set up work zones
Michael Baker International (MBI)	• Support DMS development, simulation testing, closed-track testing, live on-road testing, and final evaluation report • Develop O&M plan
Drive	• Support simulation testing, closed-track testing, live on-road testing, and final evaluation report • Coordinate IRB approval • Coordinate communication and outreach efforts
V2X Vendors	• Integrate and configure V2X equipment
Contractor	• Set up work zones

2.6 Security and Privacy

All project equipment must be physically protected to reduce the chance of theft or unauthorized access. Most of the roadside infrastructure used in this project will be stored in garages or storage containers at the end of the day. A small group of roadside infrastructure devices will be located inside locking traffic signal cabinets and RSUs will be mounted high on poles. Project vehicles and traffic control devices will be stored in locking garages and storage containers. PSU and CMU labs will be locked and require card keys, codes, or hard keys to facilitate access.

System and data security is expected to include the network security and the protection of Personally Identifiable Information (PII).

The DMS is built upon Microsoft Azure, protected by an Azure Firewall and provides a secure mechanism (VPN, SSL, etc.) for sources to connect and exchange data securely. An Azure Virtual Network (VNet) will be used to secure the Azure resources, which contain the data within the ADS project. The Azure VNet is essential for a private network in Azure. The VNet enables many types of Azure resources to securely communicate with each other, the internet, and on-premises networks. Other additional benefits of the Azure VNet include filtering network traffic, routing network traffic and integration with Azure services. To filter network traffic to and from Azure resources in a VNet, Azure Network Security groups (NSGs) will be implemented. A network security group contains security rules that allow or deny inbound network traffic to, or outbound network traffic from Azure resources. For each rule, the source and destination, port, and protocol must be specified. Additional security services that will be implemented include TLS 1.2 encryption during data-in-transit, which aims to secure data actively being transferred from one location to another, as well as 256-bit AES encryption for data-at-rest, which aims to secure inactive data stored within the DMS.

The DMS will leverage Azure Active Directory (Azure AD) for access management. Azure AD is Microsoft's cloud-based identity and access management service. Azure role-based access control (RBAC) will be used as the authorization mechanism, which determines what data each stakeholder group will have access to. Using Azure RBAC, each stakeholder group will be granted their respective access (e.g., read, read/write). Azure Key Vault, Microsoft's cloud service for securely storing and accessing secrets, will be used to control access to any passwords, certificates, or API key that will be used within the DMS.

2.7 Training

Any required training will be provided by the stakeholder responsible for providing the staff. The appropriate Staff will be trained on how to use the field equipment and hardware, software, how to operate the AV, how to operate the Mapping Van and equipment, how to use the DMS, and individual duties and responsibilities.

3 OPERATIONS

This section provides an overview of the policies and high-level operational procedures that will govern the operation of the ADS demonstration system. It is intended to govern all operations as described in the ConOps and the activities necessary to obtain the project goals and objectives. It also serves as a guide for addressing and resolving issues that may come up regarding the equipment deployed for the ADS demonstration and the data collection by the DMS.

3.1 Operational Modes

- **Mode 1: Normal Operating Conditions**
  - A normal operating condition exists when all the ADS demonstration systems are online, in service, and operating as designed without system defects or failures of any kind.
- **Mode 2: Degraded/Failure conditions**
  - A degraded condition exists when functionality for any of the ADS demonstration systems capabilities are diminished or lost, the state reflects unavailable, fallback or minimal risk condition. In degraded conditions, an alternative (though less precise) means of accomplishing system functions may exist.
  - A failure condition exists when the system is unable to perform any of the ADS demonstration systems capabilities, the mode of operation is inoperable, and the state reflects offline or unavailable for any reason.
- **Mode 3: Maintenance Conditions**
  - A maintenance condition exists when any of the ADS demonstration systems capabilities are inoperable or offline due to system maintenance state and the condition prevents test activities from progressing.

3.2 Testing Facility Hours of Operations

The testing track facility is open 24 hours 5 days a week from Monday 12:01am to Friday 11:59PM. PSU will make the testing facility available on weekends if requested and with enough advance notice prior to the date needed.

3.3 On-Road testing Hours of Operations

On-road work zone testing will have variable operating hours dictated by the work projects. The on-road testing will work within those operational hours and operational environment.

3.4 Mapping Van

The Mapping Van, including the basic vehicle, sensors, and processing equipment will be operated by PSU. The Mapping Van requires two users to operate – a Mapping Van Driver and Mapping Equipment Operator. The equipment within the vehicle will allow the Mapping Equipment Operator to monitor and operate the sensors and equipment while the Mapping Van Driver focuses on driving the van.

In order to integrate the Mapping Van into the project, there will need to be several modifications to the vehicle. If sensors are not available via the coatings supplier, the Mapping Van will require the integration of infrared and hyperspectral cameras to detect objects and measure spectroscopy for specially-coated surfaces. The LIDAR sensors will be replaced with the same or better model LIDAR that the AV is using for consistency.

Software updates will be required in order to turn the sensor data received into the map format required by the AV. The Mapping Van and associated equipment currently has the ability to map standard roadway environments and turn the sensor data into map files similar to what the AV would ingest, but the formats need to be tested for work zone information, and to match the exact agreed upon format that will be used by the AV.

3.4.1 Operating Procedures

This section describes the operating procedures for the ADS Demonstration System, the procedures in this section are based on the operational scenarios located in the ADS ConOps.

3.4.1.1 Mapping Van in normal operating mode mapping work zone.

1. Mapping Van Driver safely navigates the Mapping Van to the starting point of the work zone scenario testing.
2. Mapping Equipment Operator logs into the Mapping Van equipment and ensures static calibration.
3. Mapping Equipment Operator starts mapping equipment, dynamically calibrates the Mapping Van sensors, and verifies that the mapping equipment is transmitting data.
4. Mapping Equipment Operator notifies the testing team that testing will begin.
5. Mapping Van Driver navigates the Mapping Van multiple times through the work zone.
6. Mapping Van processes and stores sensor data.
7. Mapping Equipment Operator stops mapping equipment and notifies the testing team that the Mapping Van has completed mapping the work zone.
8. Mapping Van Driver navigates Mapping Van to the staging area and stops the Mapping Van.
9. Mapping Equipment Operator removes the Mapping Van's hard drive and connects to Map Processing Equipment (PSU-RMC processing computer) and validates the sets of raw map data collected for each work zone scenario by comparing the datasets collected through multiple mapping runs.
10. The mapping equipment operator verifies successful generation of an HD map from the PSU-RMC.
11. Within 24 hours of HD map generation, the mapping equipment operator sends the HD map file to the DMS via the established virtual private network.
12. The mapping equipment operator coordinates with the data manager to verify the HD map file has been received and is stored on the DMS.

3.5 Automated Vehicle Operations

The AV, including the basic vehicle, sensors, and ADS components, will be operated by CMU. The AV requires two users to operate – a Safety Driver and Safety Associate. The Safety Driver will be responsible for driving the AV and monitoring events that require disengagement, while the Safety Associate will be responsible for providing backup monitoring for disengagement. The on-board 4G-LTE modem will be used to download HD maps. The AV includes a touchscreen user interface that allows users to input a new destination or communicate route information and provides an ethernet port for configuration purposes.

The sensor data and other data are processed in the AV's ADS computer hardware. Processing takes place in real-time and the processed and raw data are stored on the AV's data storage. Note that due to processing capacity, not all sensor data is able to be logged. Once the testing run is complete, the removable hard drive will be removed from the AV and connected to a computer at the testing site where the data can be uploaded to the DMS.

Minor modifications will be required to integrate the AV into the project. A Dual-Mode (DSRC/C-V2X) OBU from Commsignia will be integrated into the vehicle in order to receive messages from V2X Work Zone Objects and RSU. The OBU broadcasts and receives messages to/from RSUs and other (remote) OBUs. The processing unit performs various tasks with the data received from in-vehicle sensors, GNSS, and message data received via the OBU. Finally, the in-vehicle display provides alerts and/or warnings to the Safety Driver based on outputs from the processing unit, all of which will be ingested into the DMS via uploading once each testing run is completed. The OBU will be required to maintain a level of performance and standard of care identified in the requirements and procurement materials.

The existing vehicle software may require updates to receive the map data and WZDx data in the format provided by the DMS. The data received from the DMS will then need to be integrated into the ADS's map that is used to allow the vehicle to navigate. The vehicle does not currently operate using either data format, but the new formats will allow the AV to understand its environment in the work zone area. During normal operations of the automated vehicle, all devices and roadside objects are communicating with the AV.

3.5.1 Operating Procedures

This section describes at a high-level the AV operating procedures for the ADS Demonstration System. The procedures in this section are based on the operational scenarios located in the ADS Concept of Operations. The ADS Demonstration Deployment Plan will describe the steps needed to set up the work zone, prepare for deployment, and deployment procedures. The testing plan will provide detailed steps of the operating procedures during the tests.

3.5.1.1 AV in normal operating mode navigating through a basic work zone.

1. Safety Driver calibrates AV sensors.
2. Safety Driver navigates AV to the starting point of the work zone.
3. Safety Associate notifies the field testing management and support staff that autonomous navigation can commence.
4. Safety Driver activates autonomous mode.
5. AV approaches the work zone.
6. The safety driver allows the AV to navigate through the work zone. The safety associate verifies that the AV detects and responds to work zone objects properly and documents results.
7. The safety driver allows the AV to clear the work zone.
8. The safety driver disengages AV autonomous mode and resumes manual control of the vehicle.
9. The safety driver navigates to the designated vehicle staging area and parks.
10. The safety associate verifies the CMU-AV data logger captured operational data from the test run and is stored on the OBU
11. The safety associate coordinates with the data manager to verify AV BSM and aggregated operational data has been received by the DMS.

3.5.1.2 AV in normal operating mode receiving updated HD map from DMS.

1. AV requests an updated map from the DMS.
2. DMS sends updated map to the AV.
3. AV receives the updated map.
4. AV updates internal map.
5. AV updates route.
6. The safety associate verifies receipt of the HD Map.
7. AV approaches the work zone.

3.5.1.3 AV in normal operating mode navigating through the work zone with V2X objects.

1. AV receives V2X work zone object device location.
2. AV updates internal map.
3. AV updates route.
4. AV approaches the work zone.
5. AV safely navigates through the work zone.

3.5.1.4 AV in normal operating mode navigating through the work zone that utilizes a temporary traffic signal.

1. AV receives a MAP from an RSU.
2. AV approaches the work zone.
3. AV detects that is on a signalized approach.

4. AV detects the signal state of the AV's approach.
5. AV responds appropriately to the current traffic signal.
6. AV safely proceeds through the intersection and continues its route.

3.5.1.5 AV in normal operating mode detects an object in the roadway.

1. AV approaches an object in its path.
2. AV detects the object.
3. AV determines that object is obstructing its path, but it can be passed.
4. AV determines the best course of action (stays in current lane to pass or needs to safely encroach into another lane of traffic without affecting traffic)
5. AV passes the object
6. AV continues along route.

3.6 Simulation System

CMU is responsible for developing the CADRE TROCS software and integrating with the CARLA software. CADRE TROCS will be integrated with CARLA for enhanced visualization within the project. CARLA allows the user to visualize the environment in an enhanced 3D environment and allows the system to import real maps from Open Street Maps. Any software updates to the ADS simulation software will be performed by CMU. CMU is responsible for verifying that the ADS simulation software is functioning properly and operational. CMU will observe, collect, process, and analyze the behavior of the AV in the simulation environment. Collected data in the simulation environment will include the virtual camera and LIDAR data, safety data, and operations data from the vehicles.

PSU is responsible for keeping the traffic simulation software, SUMO, up-to-date and procuring any necessary add-ons required for the simulation. PSU will develop custom modules as needed to create the traffic simulation. PSU is responsible for verifying that the traffic simulation software is functioning properly and is operational.

The simulation tools (CARLA, CADRE TROCS, and SUMO) need to be coordinated to receive the same map in the same format so that all vehicles in the network are operating on the same paths. All the programs may be able to receive OpenStreetMap XML, but further testing will be required to ensure that they can be integrated using this format in order to be ingested into the DMS.

3.6.1 Operating Procedures

This section describes the operating procedures for the ADS Demonstration System simulation.

3.6.1.1 Simulated AV in normal operating mode navigation through work zones

1. Simulated AV CADRE simulator is connected to the CARLA simulator.
2. Simulation operator loads work zone maps.
3. CARLA outputs simulated sensor reading to the CADRE simulator.
4. Simulated AV navigates through simulated work zones scenarios.
5. Simulation data is collected and uploaded to DMS.

3.6.1.2 Simulated AV in normal operating mode traffic interactions while navigating through a work zone

1. SUMO and CARLA simulators are loaded.
2. Simulation operator loads work zone maps.
3. Simulated AV navigates through simulated work zones scenarios.
4. Simulation data is collected and uploaded to DMS.

3.7 Data Management System (DMS)

The cloud hardware and software will be operated by Microsoft per the Azure service agreement. The software used to operate the DMS will be operated by Deloitte.

The DMS will be able to carry out the following functions:

- Data evaluation and checking
- Data aggregation from multiple sources
- Propagation of data for near real-time archiving
- Propagation of data to other data exchanges (such as the USDOT WZDx)
- Data storage
- Controlled access of data from multiple platforms
- Map download via API

The APIs in use will be properly documented with sample code and information to make the interactions through the APIs seamless. The various APIs enable the components of the ADS environment to interact with various types of data as they correlate to matching parameters based on requests and returns a list of all data activities matching filter designations from the requests from the DMS.

Access to blob data requires proper authentication and user authorization in order to ensure the integrity of data within the DMS remains intact. Azure AD is a cloud-based identity and access management services which will help users sign in and access datasets within the DMS. System administrators will be able to utilize Azure AD to enable custom access requirements for the DMS.

3.7.1 Operating Procedures

This section describes the operating procedures for the ADS Demonstration System DMS. This section provides a high-level overview of the operating steps, Appendix B provides more detailed steps. These operating procedures describe how the CMU-RMS and PSU-RMS will be able to upload data into the DMS using Microsoft Azure Storage Explorer via Azure Active Directory and/or using a shared access signature (SAS) token. A SAS token provides secure delegated access to resources in a storage account. With a SAS, system administrators can provide granular control over how data is accessed.

3.7.1.1 Upload data by CMU-RMS and PSU-RMS using Azure Active Directory in a new container

1. Data user will open Azure Storage Explorer.
2. Data user will select Azure environment.
3. Data user will enter their previously created credential information.
4. Data user will attach a resource (ADLS Gen 2 container or directory).
5. Data user will select Azure active directory in connection method.
6. Data user will enter connection info.
7. Data user will open explorer and access blob container.
8. Data user will create a container and upload blob to the container.

3.7.1.2 Data retrieval using SAS token

1. Data user will open Azure Storage Explorer.
2. Data user will select ADLS Gen 2 container or directory
3. Data user will select SAS as the connection method.

3.8 Roadside Infrastructure

The ADS roadside infrastructure collectively supports AV operations in the work zone by providing location-specific, contextual information to the AV over V2X communications. This infrastructure ecosystem incorporates several components which work together to make this possible:

- RSUs will broadcast relevant information to the AV, including MAP, SPAT, TIM, and other J2735 message types, and forward any messages received from the AV to the local HPC for logging.
- V2X Work Zone Objects capable of broadcasting their type, position and status will populate the work zone, disseminating relevant information.
- Traffic Signal Controllers will disseminate SPaT messages to the local HPC for logging and forwarding to the RSU for broadcast.

- Temporary Traffic Signals may play a role in the ADS environment, but this is yet to be determined. The HPC will integrate all of the roadside infrastructure together, aggregating and processing data produced by the V2X Work Zone Objects and other systems, generating appropriate V2I messages which will then be broadcast out of the RSU to the AV.

3.8.1 Roadside Unit (RSU)

Under most test scenarios, the RSU will function strictly as a radio, with other systems such as the HPC feeding it pre-encoded messages for broadcast. The V2X Work Zone Objects will report their location data via Zigbee messages, which the HPC will receive. The HPC will then compile relevant positioning messages about those devices for re-broadcast by the RSU over V2X to the AV. Additionally, the HPC will store and broadcast MAP messages about the workzone lanes via the RSU, combined with SPaT messages from the local traffic controller if present.

The RSU will also be integrated with Commsignia's software, Commsignia Central, for remote management, firmware updates, monitoring, manual message configuration, and other functions. Should the use case call for it, the RSU may also forward BSMs or other received V2X messages to the HPC or some other backend system, which can then be aggregated and analyzed for positioning, speed, and vehicle operation metrics such as breaking patterns or erratic behavior.

Most scenarios will require the RSU to simply remain operational and relay messages via V2X when instructed to do so by other automated systems and should not require any manual operation by human participants. Since the RSU will operate in close proximity to the other roadside components, high-bandwidth communications to the RSU from the backend should not be necessary. Should the RSU require manual operation, the Commsignia RSU can be operated either via HTTP(S) web interface, SSH, and/or the Commsignia Central software. Both HTTP(S) and SSH interfaces provide full configuration options and can be used for rebooting, updating firmware, enabling/disabling V2X broadcast, enabling/disabling V2X applications, manual message configuration, and other operations relevant to the ADS demo.

As described in section **Error! Reference source not found.**, operations of the RSU will be the r esponsibility of Penn State University (Sean Brennan) for the closed track areas of the ADS demo, with PennDOT (Gunnar Rhone) taking over operations once testing moves to a live work zone environment.

3.8.2 V2X Work Zone Objects

V2X work zone objects include cones and barrels instrumented with GPS and Zigbee radios for establishing a connected environment. The objects serve as beacons to provide precise position and time data. If the devices procured support position correction, the GPS receiver may use PennDOT's reference stations to receive position correction data to improve its accuracy.

3.8.3 Traffic Signal Controller (TSC)

TSCs are the source of the SPaT information broadcast by RSUs at equipped locations. TSCs are designed to be fully automated, executing the pre-set timing patterns based on the time of day and other parameters. Operations staff also have the ability to override current timing plans in instances where a plan change is necessary. The AV will automatically react to the SPaT message when received by the OBU.

3.8.4 Temporary Traffic Signal

At the time of this writing, PennDOT is evaluating the procurement of the Temporary Traffic Signal. Details will be added to this section once it is procured.

3.8.5 HPC

The edge HPC is responsible for two primary functions. First, it shall serve as a central connectivity hub. Using wired and wireless network interfaces, the HPC will enable transmissions to and from sources (RSU, MS Azure Cloud, PSU) having different communication profiles, including C-V2X, DSRC, GPS, 4/5G cellular, Zigbee, Wi-Fi, and Ethernet. Second, the HPC shall serve as a data broker, collecting, aggregating, logging, and sending data to and from configured network interfaces. The broker is responsible for facilitating information exchanges between the four types of (architectural) elements in this research project:

- AV
- RSU field devices
- DMS support system in Azure cloud
- The back-office processing Centers (PSU, CMU)

At the time of this writing, the project is evaluating BSM, TIM, and SPaT/MAP applications in support of data transmits for meeting use case objectives. If these (or other) CV apps are deemed necessary during research and testing, the HPC shall be capable of deploying off-the-shelf CV applications that read, write, create, and transmit the necessary SAE formatted data messages that enable the desired functionality. Should connectivity to the DMS exist, which may be possible for the track testing portions of the project, the HPC may manage to push data updates (in a non-real-time manner) to the DMS, or pull data from the DMS for distribution to the AV.

3.8.6 Digital Worker Vest

The digital worker vests will broadcast system inputs specific to maintenance and construction operations. Information provided to Maintenance and Construction Field Personnel includes dispatch requests, maintenance, and construction actions to be performed, and work zone safety warnings.

3.9 ATMA

At the time of this writing, PennDOT is evaluating the procurement of the ATMA. Details will be added to this section once it is procured.

3.10 Utilities

Utilities will be required to support the equipment and staff at the facilities on the project. The PSU laboratory and LTI will require electricity, gas, water, communications, and sewer. Additionally, LTI will require that the on-site gasoline fueling stations be maintained and supplied with gasoline. PSU will be responsible for providing the utilities at the PSU laboratory and LTI.

The construction sites will require electricity and communications capabilities. It is not typical for construction trailers to have water, sewer, and gas hooked up, but water bottles and portable restrooms will be supplied. The contractor will be responsible for providing the utility connections at the construction site.

4 OPERATIONAL POLICIES AND CONSTRAINTS

Operational policies and constraints listed in Table 5 were identified as constraints on the design and implementation of the proposed system in the ADS Demonstration ConOps.

Operational policies are pre-determined decisions regarding the operations of each component or sub-component of the system, typically in the form of general decisions or understandings that guide development and decision-making activities. Operational policies inform decisions made in the design of the system. Constraints are impediments outside of policy that restrict the system from achieving its goal with respect to objectives.

Table 5: Operational Policies and Constraints of Proposed System

Category	Operational Policies and Constraints
Policy	Pennsylvania has passed a law that allows automated truck-mounted attenuators to be used on public roadways (PA Code, Title 75, Chapter 85, Subchapter B, § 8502).
Policy	Pennsylvania code allows AVs on public roadways given that a safety driver is present (PA Code, Title 75, Chapter 85, Subchapter B, § 8502 and Pennsylvania AV Testing Guidance).
Policy	The municipalities own all traffic signals in the Commonwealth of Pennsylvania. If a work zone is constructed at a signalized intersection, the municipality must be consulted before installing any RSU in the traffic signal controller cabinet.
Policy	Stakeholders managing data have IT and data security policies that must be accommodated when designing, planning, delivering, operating, and controlling the DMS and its data inputs.
Constraint	C-V2X/DSRC interfaces should follow the National ITS Architecture standards for subsystems and interfaces that are not intentionally being modified for research purposes.
Constraint	C-V2X/DSRC devices may need to be licensed by the FCC.
Constraint	The system architecture that is deployed should meet applicable ITS standards.
Constraint	Testing must be conducted in a manner that does not impact on the safety of other road users.
Constraint	There are limited locations that already have CV infrastructure in place for on-road testing.
Constraint	Design constraints and considerations will limit the locations where C-V2X/DSRC RSU may be installed.
Constraint	The effective distance of C-V2X/DSRC coverage will limit where the RSUs may be placed.
Constraint	Work zone setups will come from PennDOT Publication 213.
Constraint	ADS will utilize CMU's already-built AV with limited modifications.
Constraint	The Operational Design Domain of the AV during the course of the project will be the same as the existing Operational Design Domain of the AV.
Constraint	The Mapping Van will utilize PSU's already-built Mapping Van with limited modifications.
Constraint	LTI does not have every roadway element that needs to be tested (i.e., highway on-ramps/off-ramps and roads to create detours).
Constraint	The Simulation System has perfect lane level accuracy.
Constraint	The Mapping Van generates large quantities of data (10+ Gb/s) and cannot process all the data in real time. The data must be physically offloaded by removing the hard drive and processed offline before sending to the DMS.
Constraint	The AV generates large amounts of data and cannot send all of the data back via 4G. The data must be physically off loaded by removing the hard drive and transferred to the DMS.

Category	Operational Policies and Constraints
Constraint	Testing will require day and night testing, therefore staffing resources and track scheduling may be constrained.

Source: ADS Demonstration Concept of Operations

5 MAINTENANCE

This section provides an overview of the maintenance approach for all the system components, as well as the facilities to be used for the ADS Demonstrations. Many of the activities and steps associated with maintenance are captured in vendor-supplied manuals and guides, so that information is not duplicated here.

5.1 Mapping Van

PSU is responsible for the maintenance of the mapping vehicle and is expected to maintain the Mapping Van in accordance with its own standard operating procedures, hardware/software configurations processes, OEM recall processes and spare parts/warranty plans (Mapping Van is still under OEM warranty). PSU will be responsible for maintenance of the OBU.

5.1.1 Preventive Maintenance

PSU will be responsible for the Mapping Van preventive maintenance (e.g., oil and coolant levels, air filters, tire pressure and tread depth, etc.) by following OEM recommendations.

5.1.2 Vehicle Inspection and Maintenance Routine

PSU will be responsible for inspecting and maintaining its Mapping Van on a regular basis. The Mapping Van Driver and Mapping Equipment Driver will be responsible for checking the vehicle at the beginning of each run for its safety and maintenance features. Any issues found during inspection and maintenance of the vehicle should be logged in writing and reported to the respective testing lead from PennDOT and project manager.

5.1.3 In-Vehicle Equipment Maintenance

PSU will be responsible for inspecting and maintaining the vehicle equipment and components. At the beginning of each run the mapping equipment driver will be responsible for checking that the vehicle equipment and mapping equipment are operating correctly. Any issues found during inspection should be logged in writing and reported to the respective testing lead from PennDOT and project manager.

5.1.4 Hardware/Software Systems

PSU will be responsible for the vehicle's hardware/software system configuration. The mapping equipment operator will be responsible for checking that the mapping equipment software is functioning without conflicts or changes as a result of the vehicle hardware/software system configuration upgrade. If the mapping equipment is not able to operate, then the mapping equipment operator is to notify the issue to the testing lead from PennDOT and project manager.

5.2 Automated Vehicle

CMU is responsible for the maintenance of the automated vehicle and is expected to maintain the AV in accordance with its own standard operating procedures, hardware/software configurations processes, OEM recall processes and spare parts/warranty plans.

5.2.1 Preventive Maintenance

CMU will be responsible for the AV preventive maintenance (e.g., oil and coolant levels, air filters, tire pressure and tread depth, etc.) by following OEM recommendations.

5.2.2 Vehicle Inspection and Maintenance Routine

CMU will be responsible for inspecting and maintaining its AV on a regular basis. The safety driver will be responsible for checking the vehicle at the beginning of each run for its safety and maintenance features. Any issues found during inspection and maintenance of the vehicle should be logged in writing and reported to the respective testing lead from PennDOT and project manager.

5.2.3 In-Vehicle Equipment

CMU will be responsible for inspecting and maintaining the vehicle equipment and components. At the beginning of each run the safety driver will be responsible for checking that the vehicle equipment and components are operating correctly. Any issues found during inspection and maintenance of the vehicle equipment and components should be logged in writing and reported to the respective testing lead from PennDOT and project manager.

Inspection items to verify:

- HMI
  - Wires are not broken or wearing out
  - Visual and Audio alerts are provided successfully
  - HMI is connected to a power source and successfully connects to the other systems.
- Sensors
  - Wires are not broken or wearing out.
  - Connections are secure and not loose
  - Information is being transmitted successfully to their destinations

5.2.4 Hardware/Software Systems

CMU will be responsible for the vehicle's hardware/software system configuration. The safety driver will be responsible for checking that the ADS is functioning without conflicts or changes as a result of the vehicle hardware/software system configuration upgrade. Also, the ADS stack will be updated as needed by connecting a laptop. If the ADS is not able to operate, then the safety driver is to notify the issue to the testing lead from PennDOT and project manager.

5.2.5 Communications

CMU will be responsible for the vehicle's OBU and 4G LTE modem. The safety driver will be responsible at the beginning of each run to verify that communications are functioning, and that the vehicle is able to communicate with RSU and DMS. If the communications are not functioning, then safety driver is to notify the issue to testing lead from PennDOT and project manager, who will then communicate with the DMS, and infrastructure leads to coordinate troubleshooting activities.

Inspection items to verify:

- OBU
  - Antenna is secure and position correctly on top of vehicle and cables are connected
  - Wires are not broken or wearing out
  - Power source is connected securely
  - OBU connection to laptop is available

5.2.6 Vehicle Replacement

If the AV is severely damaged during operations, CMU has a backup AV that can be used as a replacement. The change management strategy defined in the Project Management Plan will be used to pivot the project from the original vehicle to the new vehicle. In order to create a fair comparison for the Final Evaluation Report, work zone scenarios may need to be re-run with the new vehicle.

5.3 Simulation System

The CMU lab will be supported by the CMU Facilities department and the PSU lab will be supported by the PSU Office of Physical Plant. They will be responsible for the following:

- Maintaining the computers and making sure that the computers have access to the internet and the correct software to run the Simulation System
- Verifying that the simulation team has access to the lab and log-on access to the computers in the lab

- Cleaning and other day-to-day maintenance activities

5.4 Data Management System

The cloud hardware and software will be maintained by Microsoft per the Azure service agreement. Deloitte will be responsible for keeping the DMS up-to-date and installing any software updates. The Azure platform on which the DMS runs may occasionally be updated and the DMS may require updates in order to remain fully operational. Deloitte will backup data weekly. System status will be monitored by Deloitte to verify that the system is operational.

5.4.1 Data Access Control

5.4.1.1 New Account Creation and Requests

If a new CoPA account is needed for a new user email Partha Talluri (ptalluri@pa.gov) and he will create a ticket to submit the new account request

5.4.1.2 Azure Role-Based Access Control (RBAC)

Azure RBAC will help administrators manage user, access to the DMS, what actions and functions they can perform within the DMs, and what areas of the DMS they access to. This feature is included within Azure Resource Manager and will be essential to implementing access controls for the DMS in order to maintain data security.

Administrators can identify role assignments for all users within the system, which assigns a role definition to a user or group. Access is granted by creating a role assignment, and access is revoked by removing a role assignment. Similar to role assignment, administrators can add a deny assignment option to a user. This feature defines a set of actions that are not allowed within the DMS and will bloc users from performing that specific action within the system. For this project, users will be assigned to roles according to the access level that they need in order to perform their jobs. Table 6 below contains a list of roles that administrators will be able to assign to users.

Table 6: Azure RBAC Role Assignments

Role	Access Description
Owner	Grants full access to manage all resources, including the ability to assign roles in Azure RBAC.
Contributor	Grants full access to manage all resources but does not allow you to assign roles in Azure RBAC, manage assignments in Azure Blueprints, or share image galleries.
Reader	View all resources but does not allow you to make any changes.
User Access Administrator	Let's you manage user access to Azure resources.

5.4.1.3 Access Control Lists (ACLs)

Azure Data Lake Storage Gen2 implements an access control model that supports both Azure role-based access control (Azure RBAC) and POSIX-like access control lists (ACLs).

5.4.2 Data Archiving

The demonstration will use readily available and redundant services for all its data storage and archives. The cloud infrastructure of the demonstration's DMS will provide multiple redundant copies of static files, structured and unstructured data through their respective services. The cloud environment services will provide managed backup services, which are customizable and configurable. High-value datasets will be enabled to take advantage of this feature. In the event of data corruption, a valid copy of the data may be retrieved from a backup copy and applied to the corrupt copy to correct any corruption.

The data collected by this demonstration will be made available through the DMS maintained by PennDOT at least 5 years after the completion of the period of performance to allow researcher and rulemaking groups to analyze the data collected under the various operational scenarios and operating conditions.

Data integrity over time will be ensured by building digital preservation practices into the system. These include functions such as auto-recovery, integrity monitoring, and redundancy. All long-term preservation efforts will endeavor to comply with the International Organization for Standardization (ISO) Technical Report (ISO/TR) 18492:2005 standard (long-term preservation of electronic-document-based information). The success of any long-term preservation efforts will be dependent on the entity that owns the Project post-grant. For data that do not have a contractual archival requirement, the decision to retain a dataset will primarily be at the discretion of the data curator. As the DMS matures, the data usage statistics and user ratings will determine the desire for the data curator to retain a given dataset.

5.4.3 Key Vault Management

Azure Key Vault is a cloud service for securely storing and accessing secrets. A secret is anything that you want to tightly control access to, such as API keys, passwords, certificates, or cryptographic keys.

5.4.3.1 Key Rotations

Automated key rotation in Key Vault allows users to configure Key Vault to automatically generate a new key version at a specified frequency. You can use rotation policy to configure rotation for each individual key.

5.4.4 Back-up and Recovery Policies and Procedures

The DMS will rely on the geographically redundant and distributed nature of the cloud-based data storage repository. Whenever a change or update occurs, a copy of the original data will move asynchronously to a data archive assuming this remains feasible given storage costs. The Project team will work with the cloud-based data storage provider to retrieve an archive should core data become corrupt or require a restore. If it is determined in the future as a requirement, it is possible for the DMS to store its data in multiple regions to ensure higher redundancy of the data.

5.4.5 Azure Policy

Azure Policy helps to enforce organizational standards and to assess compliance at-scale. Through its compliance dashboard, it provides an aggregated view to evaluate the overall state of the environment, with the ability to drill down to the per-resource, per-policy granularity.

5.4.6 Threat Detection

Azure offers built in threat protection functionality through services such as Azure Active Directory (Azure AD), Azure Monitor logs, and Microsoft Defender for Cloud. This collection of security services and capabilities provides a simple and fast way to understand what is happening within your Azure deployments.

5.4.7 Monitoring and Logging

It is important monitor and track system performance data within the DMS to see if any areas of the system can be optimized or updated to improve overall functionality. Azure Monitor allows project team leadership to collect, analyze, and act on telemetry data from the DMS, which will help to maximize system performance and operability. This will also help to identify potential problems within the system that can be dealt with before they can affect DMS operations.

5.4.7.1 Azure Monitor Logs

Azure Monitor Logs are a feature of Azure Monitor that collects and organizes log and performance data from monitored areas within the DMS. Sources of data that can be consolidated into a single workspace include platform logs from Azure services, log and performance data from virtual machine agents, and usage and performance data from the actual DMS. Administrators can use log analytics to analyze and query captured monitoring data for insight and performance optimization. They can also create system alerts and automated actions when certain events occur, and develop dashboards with visual interpretations of data to highlight system performance.

5.4.8 Azure Blob Storage – Best Practices

5.4.8.1 Identifying the security principal used to authorize a request

Any request that has been authenticated by using Azure AD, the RequesterObjectId field provides the security principal identification. The friendly name of that security principal can be found by taking the value of the RequesterObjectId field and searching for the security principal in Azure AD page of the Azure portal.

5.4.8.2 Identifying the SAS token used to authorize a request

Operations that were authorized by using a SAS token can be queried. For security reasons, SAS tokens do not appear in logs. The SHA-256 hash of the SAS token will appear in the AuthenticationHash field that is returned by this query.

5.4.8.3 Azure Resource Manager deployment model

All new storage accounts will be created using the Azure Resource Manager deployment model for important security enhancements, including superior Azure role-based access control (Azure RBAC) and auditing, Resource Manager-based deployment and governance, access to managed identities, access to Azure Key Vault for secrets, and Azure AD-based authentication and authorization for access to Azure Storage data and resources.

5.4.8.4 Locking storage accounts to prevent accidental or malicious deletion or configuration changes

An Azure Resource Manager lock will be applied to all storage accounts to protect the account from accidental or malicious deletion or configuration change. A storage account lock does not prevent data within that account from being deleted. It only prevents the account itself from being deleted.

5.4.8.5 Least privilege permissions to an Azure AD security principal via Azure RBAC

Assigning a role to a user, group, or application, that security principal will only be granted those permissions that are necessary for them to perform their tasks.

5.4.8.6 Securing account access keys with Azure Key Vault

Azure AD will be used to authorize requests to Azure Storage. If a Shared Key authorization is to be used, then the account keys will be secured using Azure Key Vault.

5.4.8.7 Periodically regenerating account keys

In order to reduce the risk of exposing data to malicious actors, the accounts keys will be periodically regenerated.

5.4.8.8 Least privilege SAS permissions

When a Shared Access Signature (SAS) is created, only the permissions that are required by the client to perform its function will be applied.

5.4.8.9 Disabling anonymous public read access to containers and blobs

Unless for a scenario that requires it, public read access to all containers and blobs will be disabled.

5.4.8.10 Storage account minimum required version configuration of Transport Layer Security (TLS)

Clients will be required to use a more secure version of TLS to make requests against an Azure Storage account by configuring the minimum version of TLS for that account.

5.4.8.11 Enable the Secure transfer required option on all your storage accounts

Enabling the Secure transfer required option will be required as all requests made against the storage account must take place over secure connections. Any requests made over HTTP will fail.

5.5 Roadside Infrastructure

PennDOT and PSU will be responsible for maintenance of the RSU. The V2X Work Zone Objects maintenance will be the responsibility of their respective vendor or provider. The RSU and V2X Work Zone Objects will be required to maintain a level of performance and standard of care identified in the requirements and procurement materials. The V2X Vendors will work with PennDOT to integrate the RSU with the DMS, Traffic Signal Controller and TMC, as necessary, and perform testing.

5.5.1 RSU

The RSU, as a form of wireless radio, requires many of the same maintenance procedures as other wireless infrastructure radio types. Preventative and corrective maintenance procedures must be defined to ensure continued and reliable operation of the RSU.

5.5.1.1 Preventative Maintenance

Preventative maintenance procedures include both physical and software elements. Externally, the RSU has N-type coaxial interfaces for its various antennas and a weatherproof grommet for the CAT6 Ethernet backhaul/PoE connection. PennDOT and PSU will take care to ensure that all these external interfaces are appropriately sealed with waterproof butyl tape to prevent water intrusion. While many manufacturers claim their interface connections do not need additional weatherproofing, the harsh environments found in the upper Midwest and upper eastern climates with large temperature fluctuations and heavy precipitation have been known to wear down these interfaces over time.

An additional step of preventative maintenance is regular verification of the external PoE+ injector (if present). Many PoE injectors fail in outdoor environments and are often sensitive to power fluctuations often found in traffic cabinets and other roadside infrastructure. PennDOT and PSU will perform periodic testing of the injector to confirm that the expected voltage is present on the correct Ethernet pins can prevent unexpected outages. Likewise, surge arrestors will be used in all installations and periodically tested for the correct resistance and voltage passthrough.

Firmware updates are possible on Commsignia RSUs either via the Commsignia Central management software, the HTTP(S) web interface, or via SSH. A firmware package must be present on the user's computer for upload to the RSU if either of the two latter methods are chosen. Firmware updates will be made regularly per the manufacturer's recommendations and may be required to fix any bugs or malfunctions observed during testing.

5.5.1.2 Corrective Maintenance

RSU failures can take on many forms; isolating the issue is the first step in being able to perform corrective measures and restore functionality. The most effective way to do this is by starting from the "edge" of the RSU's domain, the RSU maintenance team will working inward, using the AV or some other device capable of receiving V2X messages:

- Confirm the correct V2X message is being broadcast over the air
- Confirm the broadcasted message is coming from the correct RSU
- Confirm the message content is correct (MAP lanes, SPaT signal groups, etc.)

If messages are received but do not contain the correct information, the RSU maintenance team will work upstream to identify the system pushing the incorrect messages, components to verify include:

- Confirm the HPC configured with the correct MAP.
- Confirm SPaT configured correctly in the signal controller.

If messages are not received at all, the RSU maintenance team will work inward to identify the cause. The following are items to verify when isolating a problem with a malfunctioning RSU:

- Confirm the RSU is enabled and in broadcast mode.

- Confirm the RSU is correctly configured for either DSRC or C-V2X, whichever is needed for the use case.
- Verify if the RSU is attempting to sign its messages with certificates when it should be broadcasting unsigned messages, or vice versa.
- Verify if the RSU is receiving messages for broadcast from the HPC or other systems, or is there a disconnect somewhere farther upstream.

Sometimes, the issue is more subtle and difficult to notice. If the AV is receiving messages but appears to be missing some, it could be that the RSU is not broadcasting messages at the rate it should be (10 messages per second for SPaT, 1 message per second for MAP or TIM, etc.). Identifying this problem requires the RSU maintenance team to use a software tool that can log the number of messages received over time, separated by message type. The following are items to verify:

- Faulty or incorrectly attached antenna interfaces.
- Obstruction between the RSU and the receiving device
- Misconfiguration of the message itself.

Should the RSU fail completely and not power up, multiple causes could be to blame. PoE injectors are a common failure point, as are CAT6 surge protectors. Both of those components will be validated by the RSU maintenance team before troubleshooting the CAT6 outdoor cable or the RSU itself. If both PoE injector and surge protector are functional, there could be corruption in the RJ45 termination at either end of the outdoor cable. Likewise, the jumper between the PoE injector and surge arrestor could be faulty. Finally, as a last resort, the RSU maintenance team will remove the RSU from its mount and powered directly on the ground using a known good PoE injector to diagnose a faulty unit. Replacement of an RSU is straightforward as the only requirements are to install the RSU on the existing mount and re-configure the unit appropriately.

5.5.1.3 V2X Work Zone Objects

5.5.1.3.1 Portable Changeable Message Signs (PCMS)

PennDOT will be responsible for the maintenance of the PCMS. Routine maintenance will be performed to preserve the life of the PCMS and to ensure that is running safely and properly.

- Maintenance steps include:
  - Have an extra battery available (if the PCMS is battery-powered).
    - Clean and inspect the following components:
    - Screen (monthly).
    - Sign door panel(s) (monthly).
    - Solar panel(s) (monthly).
    - Batteries (three or four times per year).
  - Verify that an extra set of programming instructions are stored in the PCMS for emergency use or for "in-the-field" programming.

5.5.1.3.2 Barrel/Cones/Barriers

PennDOT will be responsible for the physical maintenance of the barrels, cones and barriers and PSU will be responsible for the maintenance of any electronic add on made to enhance these items like adding connectivity to the HPC.

5.5.1.3.3 Smart Vest

PSU will be responsible for maintaining the smart vest with support of VT.

5.5.1.3.4 Small C-V2X RSU/OBU

Qualcomm will be responsible for maintaining this equipment.

5.5.1.3.5 HPC

PSU will be responsible for maintaining the HPC.

5.6 Facilities

5.6.1 Test Track Facility

LTI is supported by the PSU Facilities department which maintains the facility. The maintenance crew has the ability to perform minor track repair, lawnmowing, gravel brushing/removal, snowplowing, and other day-to-day maintenance activities. PSU will facilitate access to LTI for the closed-course testing team. It should be noted that this facility is near an airport and the use of 5G radios might need special permission from FCC or FAA.

5.6.2 Construction Site Facilities

The construction site facilities will need to be supported by the contractor of the project. The contractor will be responsible for performing maintenance on the construction trailer, cleaning the facility restrooms, snowplowing access to the facilities, and making sure that the staging and stockpile area is clear for the testing team. The contractor will verify that the team has access to their secured trailer. Supplies and materials that are not able to be provided by the Contractor will be provided by PennDOT.

6 CONFIGURATION & INVENTORY MANAGEMENT

This section describes the configuration management procedures that will be followed for the software and hardware. Also, the inventory management approach and tools to manage how inventory will be tracked.

6.1 Configuration Management

6.1.1 Software Configuration Management

This process is used to manage and control changes in the evolution of a software system and supporting documentation. The effective and efficient performance of this process is achieved by using automated tools to track all modifications to the software system.

- CMU uses internal Linux repositories for software version control.
- PSU uses private GitHub repositories for software version control.
- Versioning of DMS datasets will be handled by internal file versioning following major/minor changes in a table used explicitly for logging purposes (Log Table) capturing information such as modification type, modifying party, modified date/time, etc.
    - Ingestion scripts (scripts reading external data sources) will be managed via version control and will follow semantic versioning practices.
    - Major versions will be marked by fundamental changes in the Log Table (such as fundamental Application Programming Interface [API] structure).
    - Minor versions will be marked by minor changes (such as adding or removing topics).
    - Patch versions will be defined by bug fixes.

6.1.2 Software Code Freeze

This process is used to freeze the software code, meaning there will not be any further modification from the developers. The source freeze will happen at the end of phase 1 but the freeze will be revaluated if critical defects are found, or major additional functionality is added to the source code. Any updates to the source code will need the approval of project stakeholders.

6.1.3 Document Management

The process is used for creating and delivering documentation, and specifications required for the design, procurement, installation, commissioning, and acceptance of hardware and/or software. The official project repository will be hosted by HNTB in their internal server using the Microsoft Team

Site/SharePoint platform. The following are stakeholder's existing document management systems that will also host project documentation.

- CMU will use their internal Linux repository for document management.
- PSU will use a combination of internal Wikis, internal share network drive and external public websites for documentation, maintaining specifications and document management.

6.1.4 Inventory Management

The PSU staff will maintain inventory spreadsheets of the equipment used for the test track portion of the project. PSU staff will take photos of any borrowed equipment to document conditions on arrival. Each project team will follow their internal inventory management processes.

APPENDIX A. ACRONYMS AND DEFINITIONS

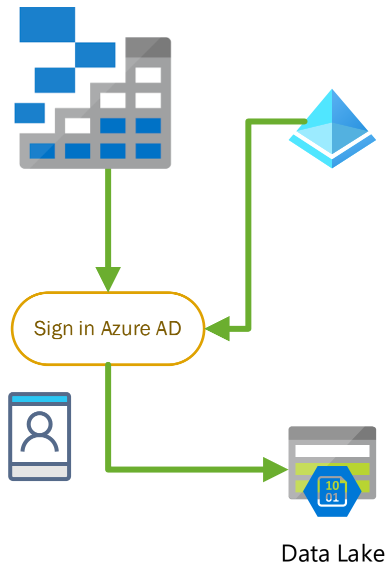
Acronym/Abbreviation	Definition
ADS	Automated Driving System
API	Application Programming Interface
ATMA	Autonomous Truck-Mounted Attenuator
AV	Automated Vehicle
BSM	Basic Safety Message
CADRE	Connected and Autonomous Driving Research and Engineering
CMU	Carnegie Mellon University
CMU-RMC	CMU Research Management Center (Back-Office Research Lab Computer)
ConOps	Concept of Operations
CORS	Continuously Operating Reference Station
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Everything
Deloitte	Deloitte Consulting LLP
DMS	Data Management System
DSRC	Dedicated Short-Range Communications
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
HPC	High Performance Computer
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ITS	Intelligent Transportation Systems
LiDAR	Light Detection and Ranging
LTI	Larson Transportation Institute
MAP	Map Message
OBU	Onboard Unit
PCMS	Portable Changeable Message Sign
PennDOT	Pennsylvania Department of Transportation
PPG	PPG Industries, Incorporated
PSU	Pennsylvania State University
PSU-RMC	PSU Research Management Center (Back-Office Research Lab Computer)
RADAR	Radio Detection and Ranging
RF	Radio Frequency
ROS	Robot Operating System
RSU	Roadside Unit
SAE	SAE International
SPaT	Signal Phasing and Timing
SUMO	Simulation of Urban Mobility
TMA	Truck-Mounted Attenuator
TROCS	Tartan Racing Operator Control Station
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
VRU	Vulnerable Road Users
VT	Virginia Tech University
WZDx	Work Zone Data Exchange
XML	eXtensible Markup Language

APPENDIX B. DMS PROCEDURES

1 DATA RETRIEVAL – STORAGE EXPLORER VIA AZURE AD

This section describes how the CMU-RMS and PSU-RMS will be able to upload data into the Data Management System using Microsoft Azure Storage Explorer via Azure Active Directory

1.1 Launch Storage Explorer

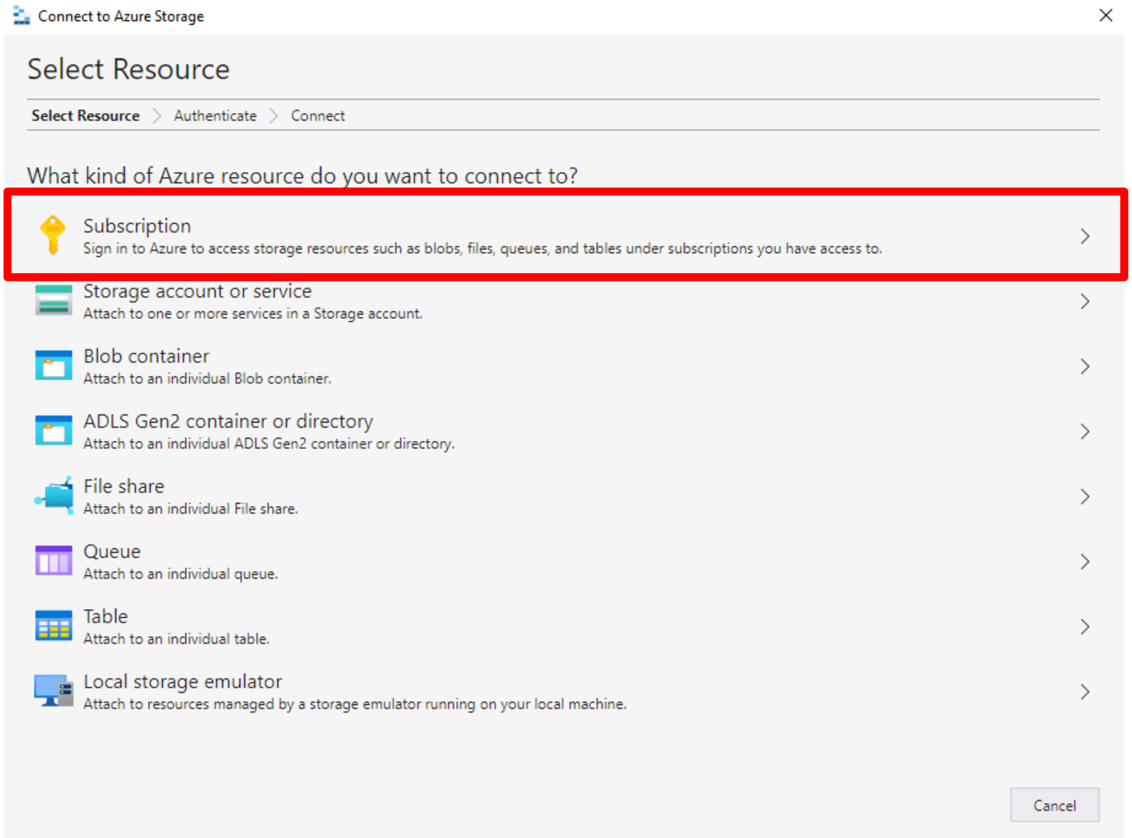


SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

On first launch, the **Microsoft Azure Storage Explorer - Connect to Azure Storage dialog** is shown. Several resource options are displayed to which you can connect:

1.2 Select Subscription

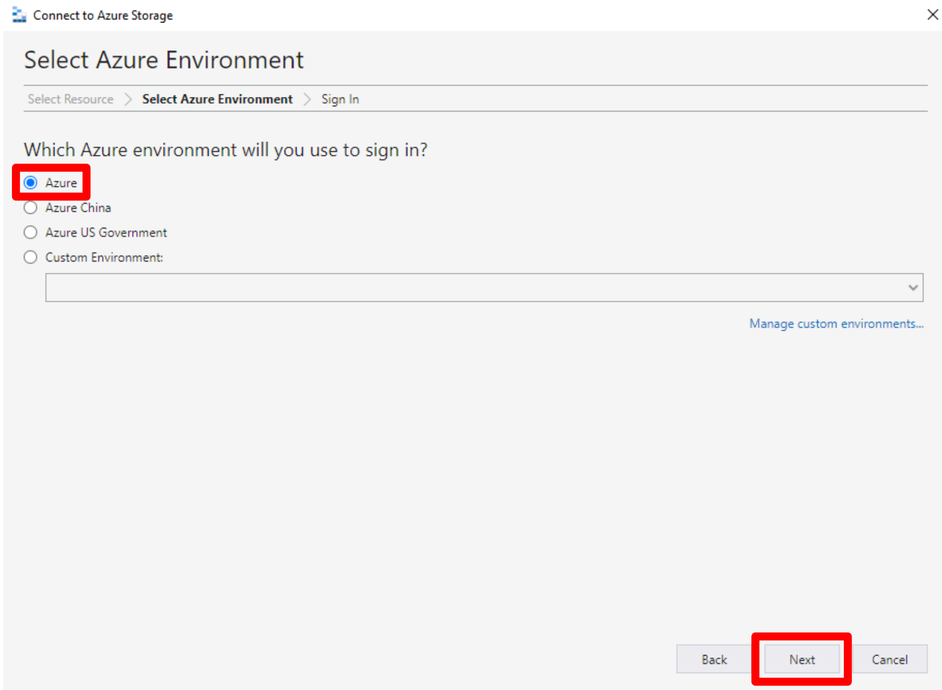
In the **Select Resource** panel, select **Subscription**.



Source: The ADS Demonstration Data Management Plan

1.3 Select Azure

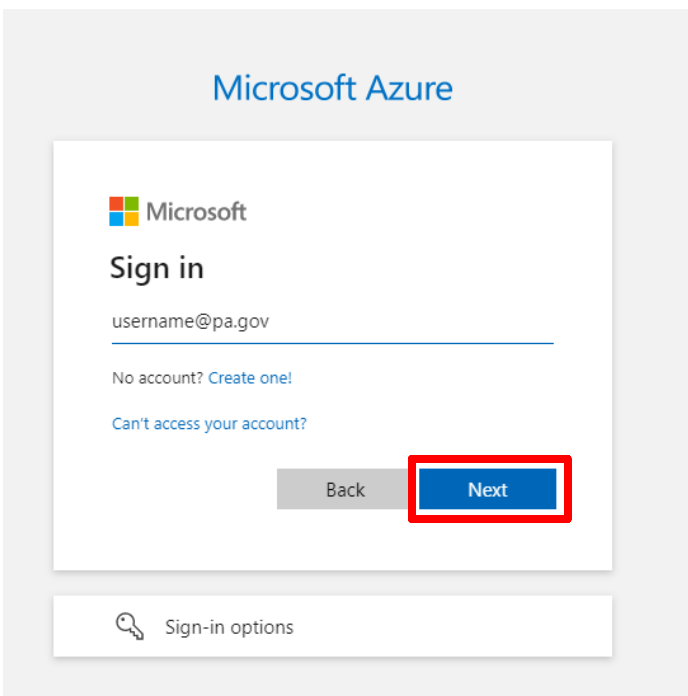
In the **Select Azure Environment** panel, select **Azure**, then **Next**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.4 Enter Credentials and Authenticate

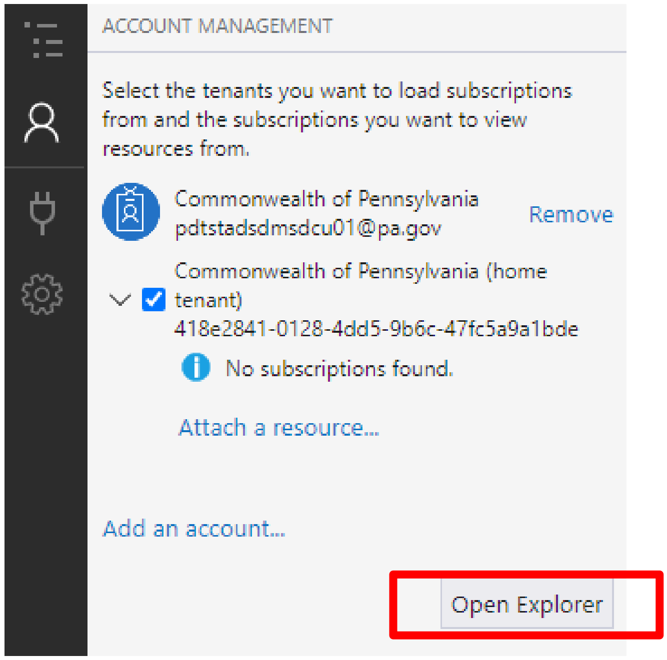
A browser will open and redirect to login page to perform authentication. Enter your username and select **Next**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.5 Attach a Resource

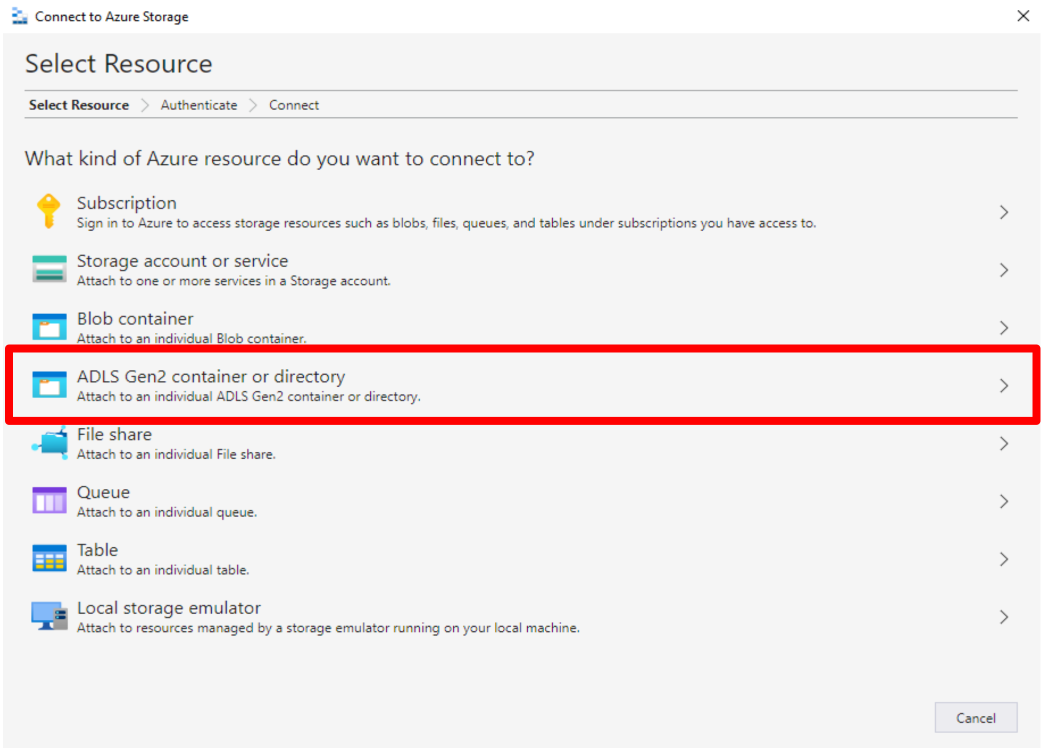
After you successfully sign in with your CoPA account, under **ACCOUNT MANAGEMENT** click **Attach a resource…**



Source: The ADS Demonstration Data Management Plan

1.6 Select ADLS Gen2 container or directory

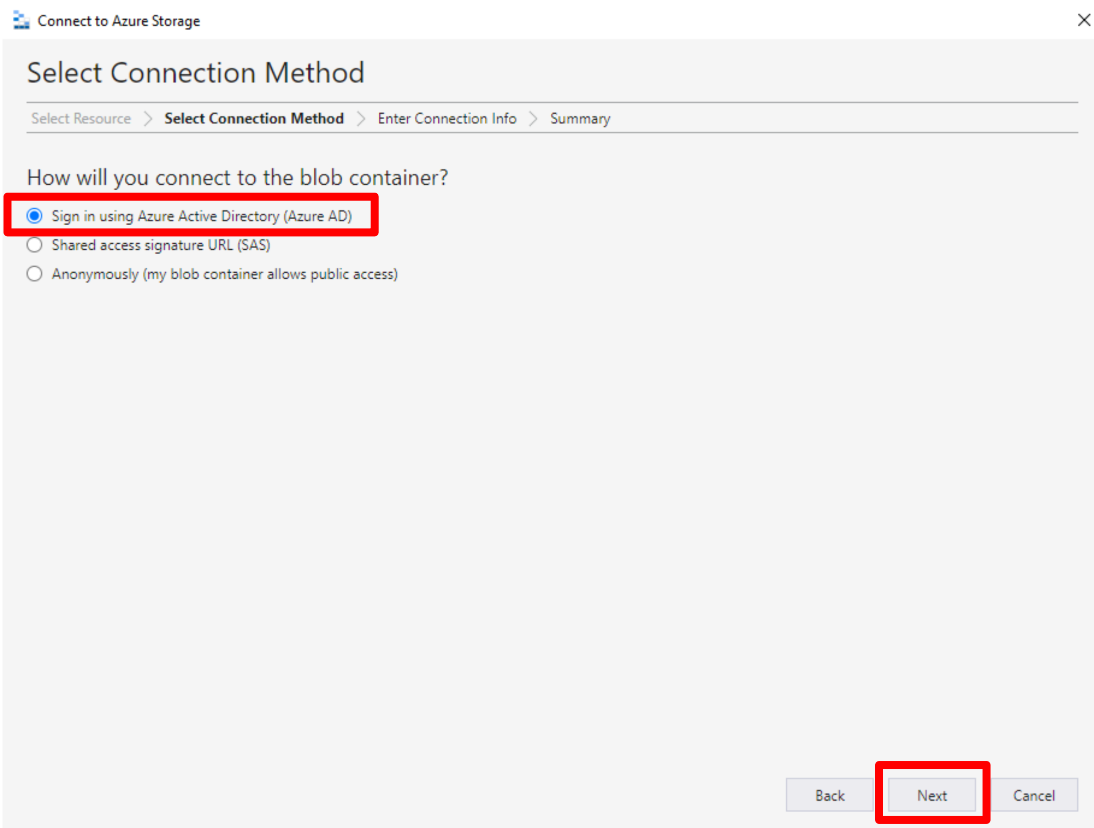
In the **Select Resource** panel, select **ADLS Gen2 container or directory**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.7 Sign in using Azure Active Directory (Azure AD)

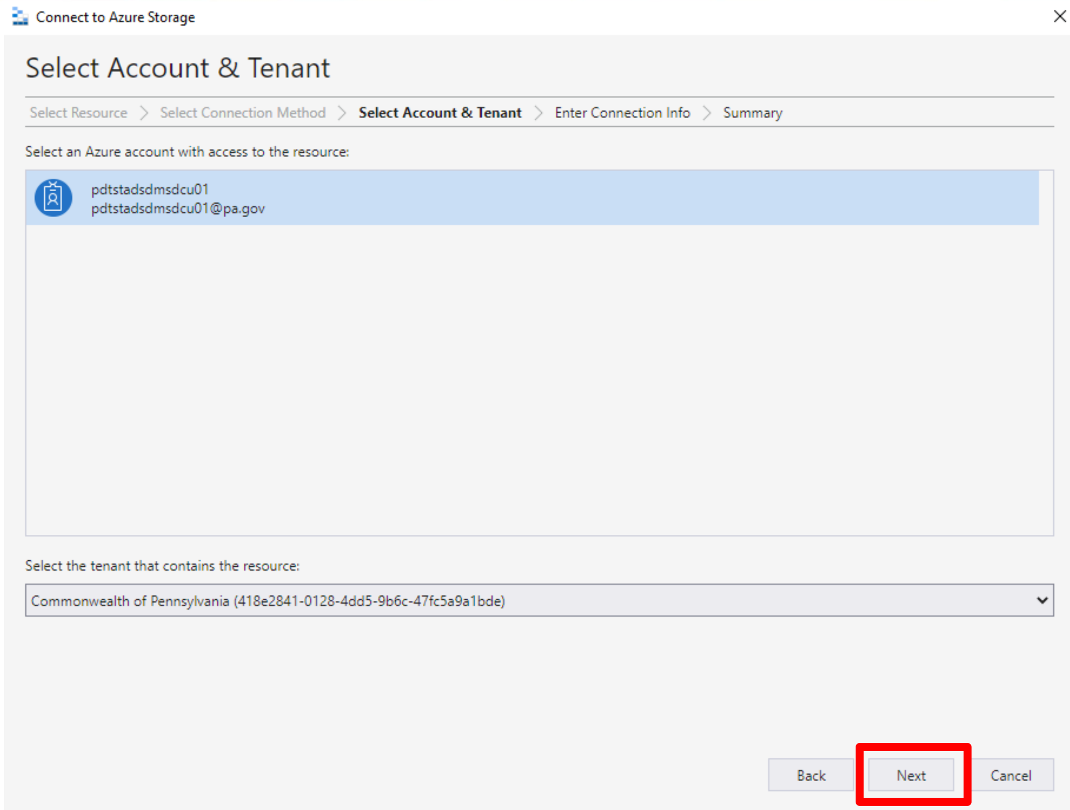
In the **Select Connection Method** panel, select **Sign in using Azure Active Directory (Azure AD)** and click **Next.**



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.8 Select Azure Account

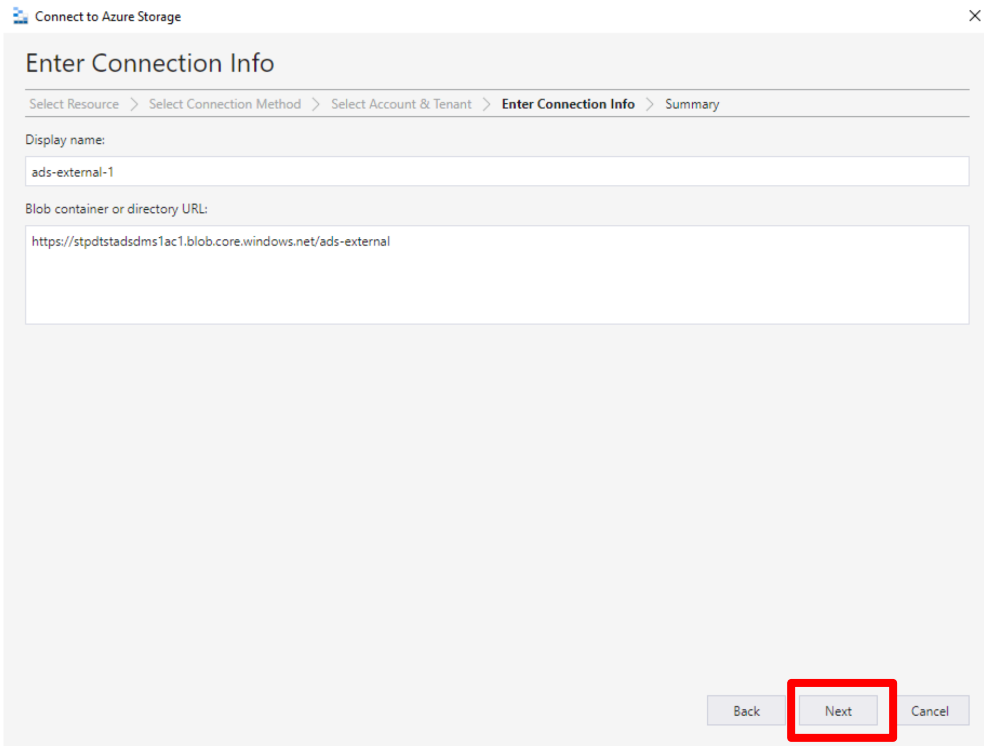
Confirm you see your account in the **Select Account & Tenant** panel and click **Next.**



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.9 Enter Connection Info

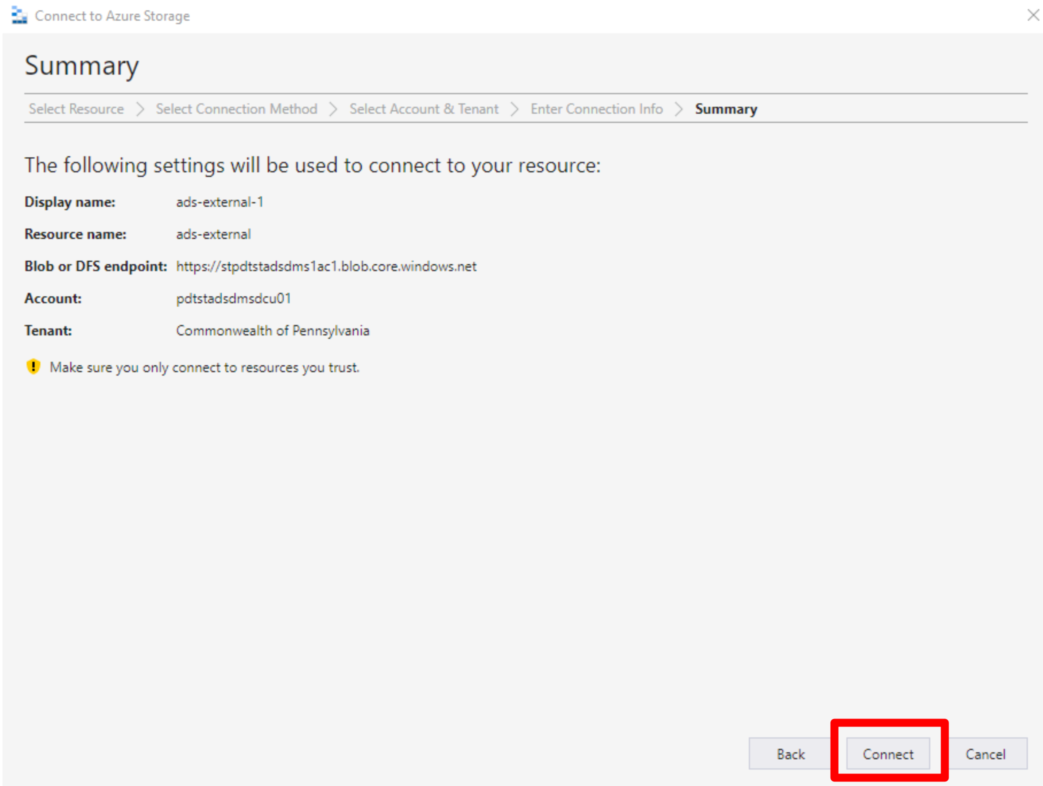
In the **Enter Connection Info** panel enter the blob container URL into the **Blob container or directory URL:** and click **Next**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.10 Confirm Connection

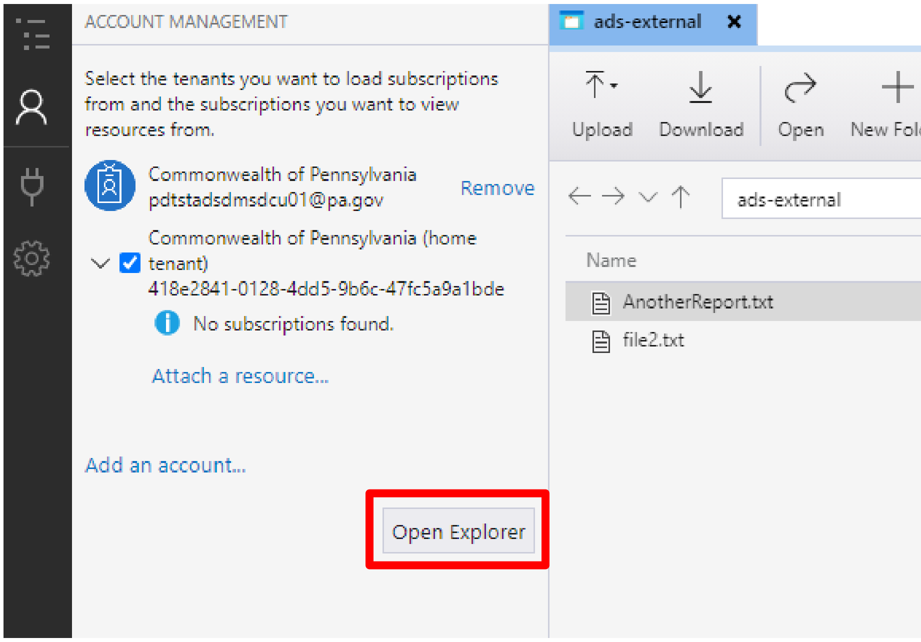
In the **Summary** panel click **Connect**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.11 Open Explorer

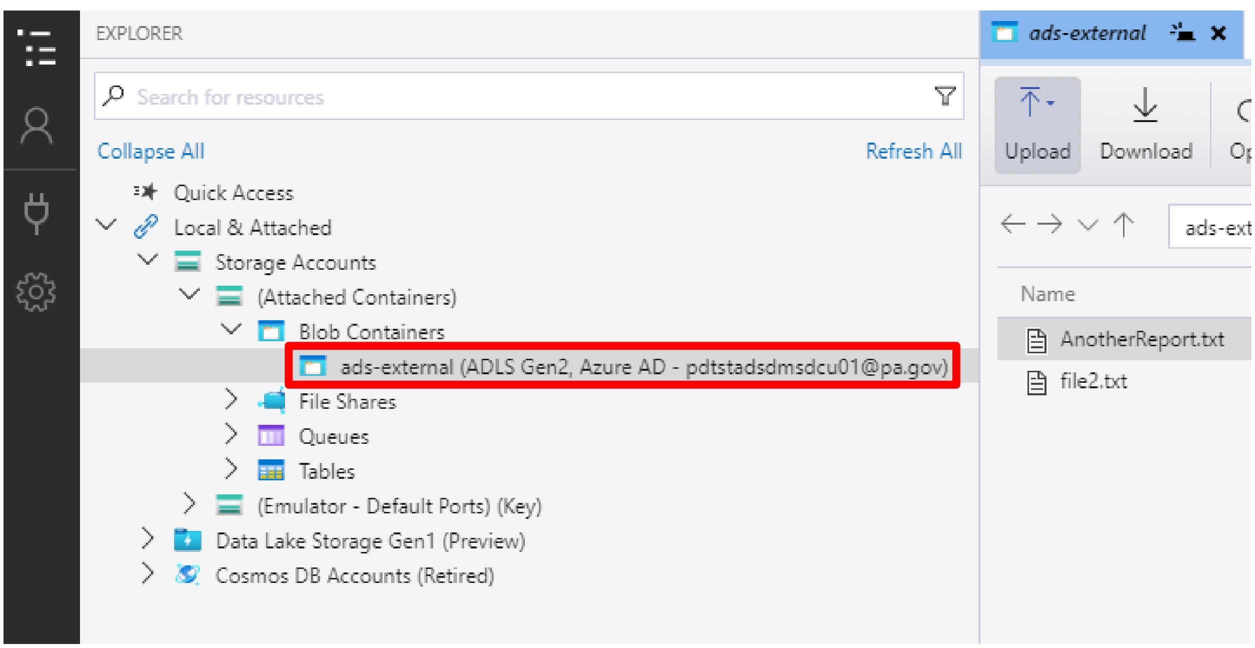
Click **Open Explorer** under **ACCOUNT MANAGEMENT**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

1.12 Access Blob Container

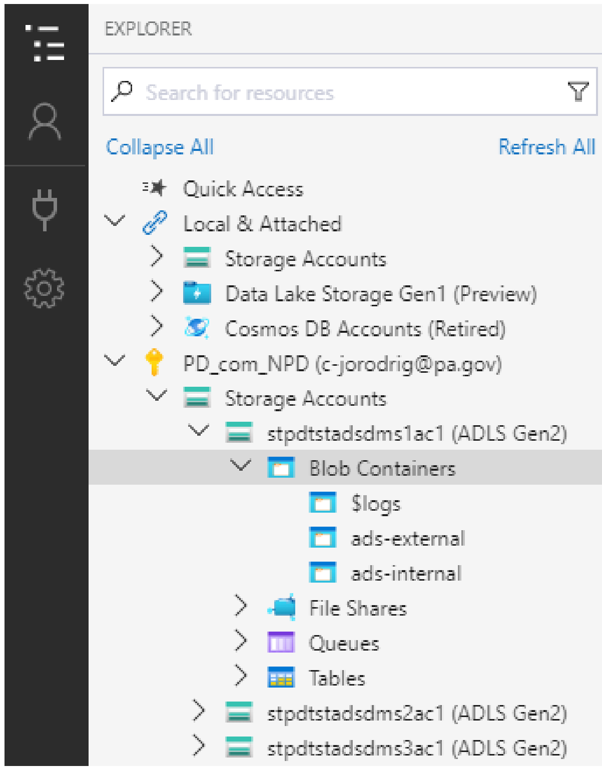
Under **Explorer** view blob under **Blob Containers**



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

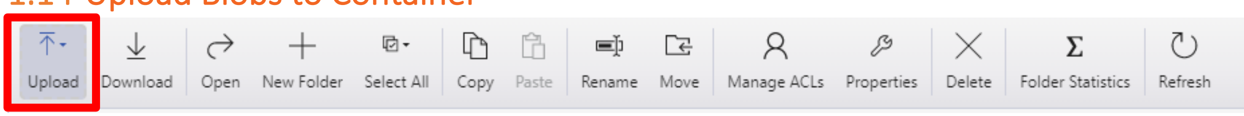
1.13 Create a Container

To create a container, expand the storage account you created in the proceeding step. Select **Blob Containers**, right-click and select **Create Blob Container**. Enter the name for your blob container. When complete, press **Enter** to create the blob container. Once the blob container has been successfully created, it is displayed under the **Blob Containers** folder for the selected storage account.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

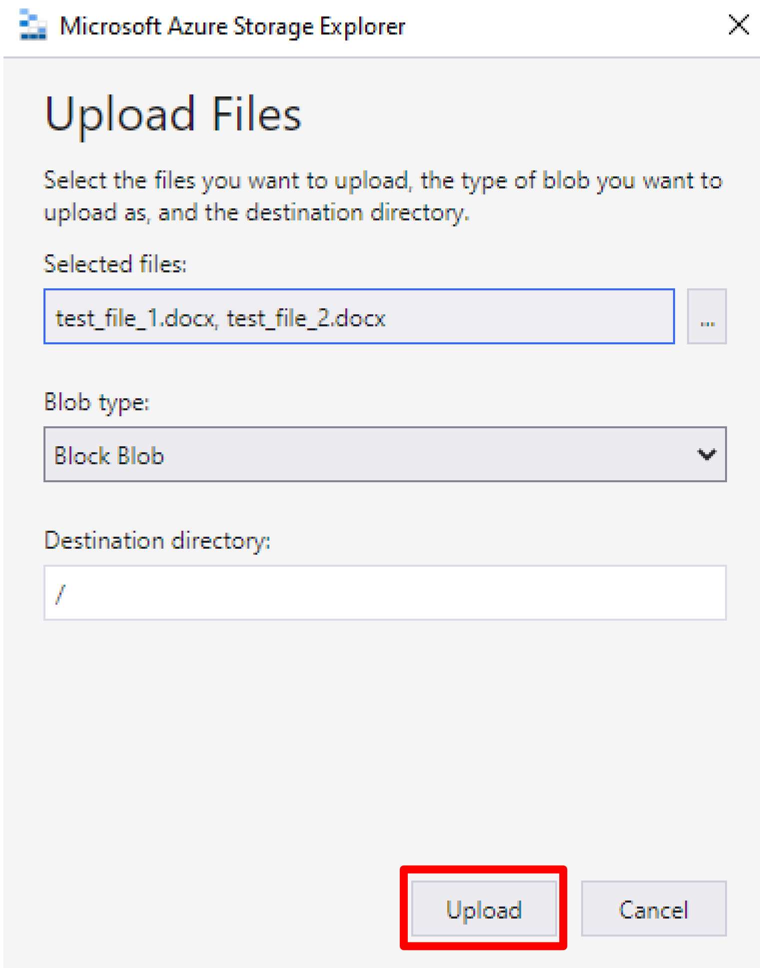
1.14 Upload Blobs to Container



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

Choose the files or folder to upload. Select the **Block Blob** as **Blob type**.

In the Upload to folder (optional) field either a folder name to store the files or folders in a folder under the container. If no folder is chosen, the files are uploaded directly under the container.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

When you select **Upload**, the files selected are queued to upload, each file is uploaded. When the upload is complete, the results are shown in the **Activities** window.

1.15 Download Blobs or Containers

With a blob or container selected, select **Download** from the ribbon. A file dialog opens and provides you the ability to enter a file name. Select **Save** to start the download of a blob to the local location.

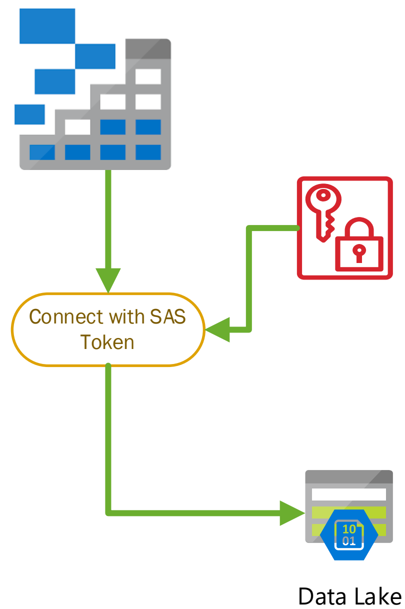
SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

2 DATA RETRIEVAL – STORAGE EXPLORER VIA SAS TOKEN

This section describes how the CMU-RMS and PSU-RMS will be able to upload data into the Data Management System using Microsoft Azure Storage Explorer via a SAS token.

A shared access signature (SAS) provides secure delegated access to resources in a storage account. With a SAS, system administrators can provide granular control over how data is accessed.

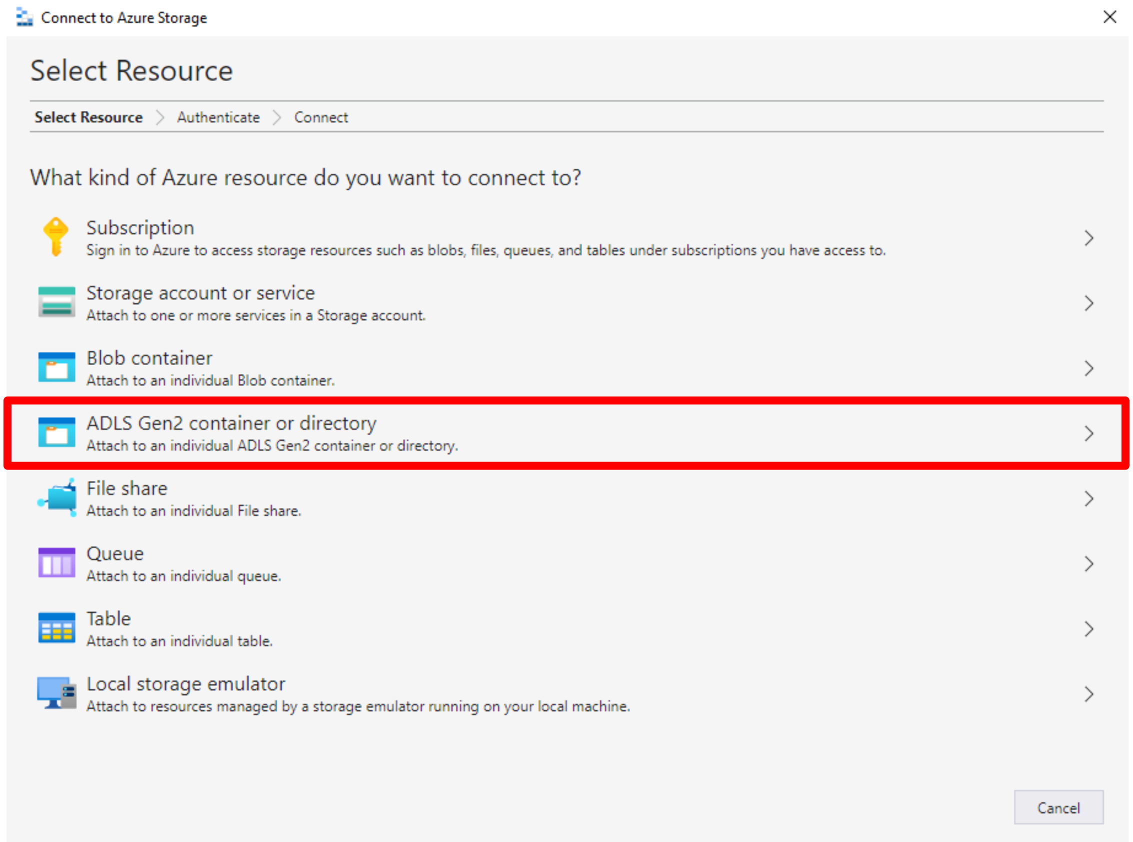
2.1 Launch Storage Explorer



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

On first launch, the **Microsoft Azure Storage Explorer - Connect to Azure Storage** dialog is shown. Several resource options are displayed to which you can connect:

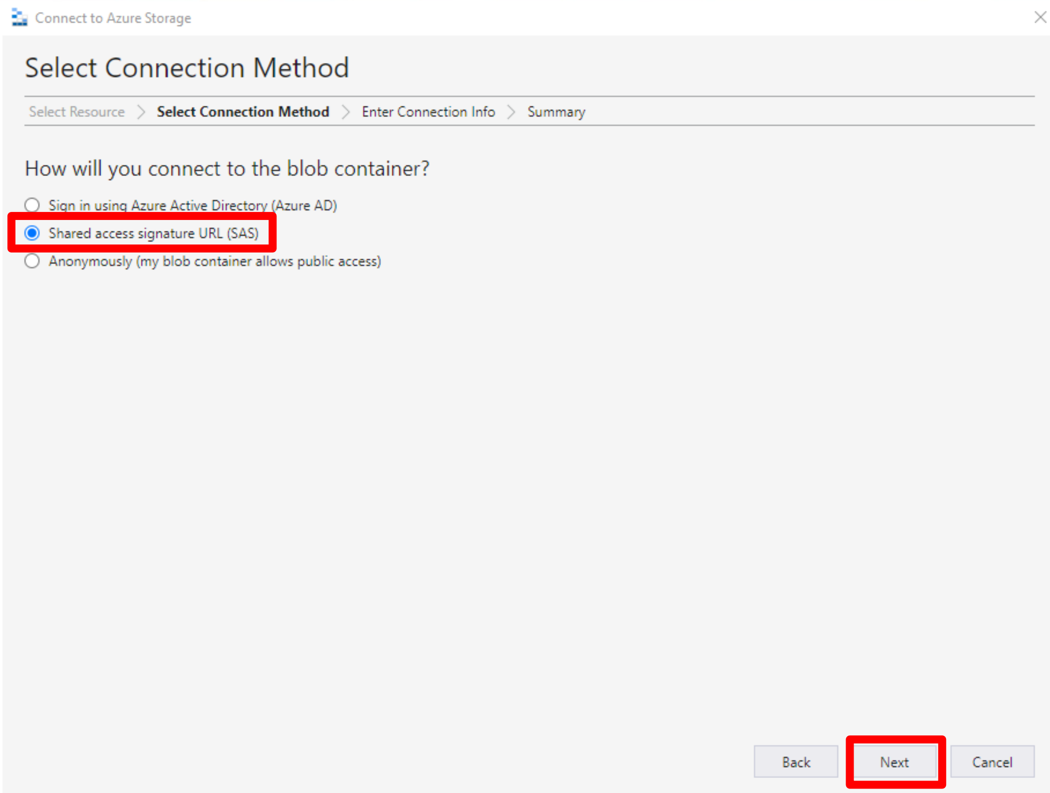
2.2 Select ADLS Gen2 container or directory



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

2.3 Select Shared Access Signature (SAS)

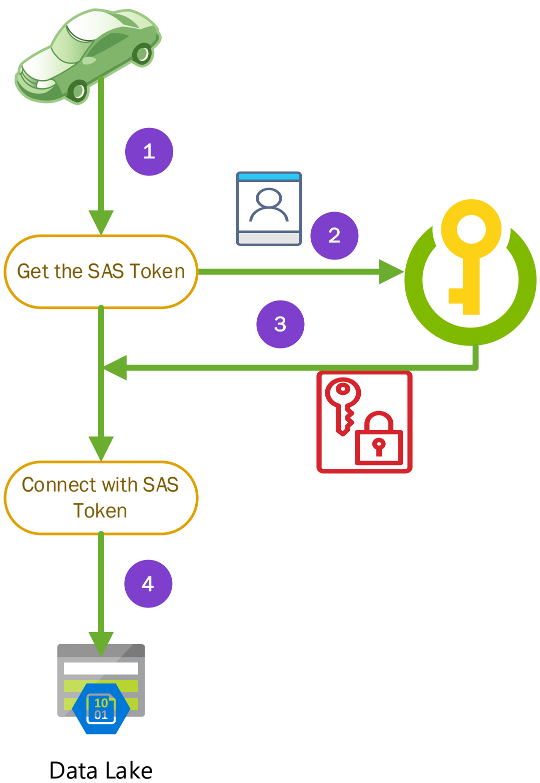
In the **Select Connection Method** panel, select **Shared access signature URL (SAS)** and click **Next**.



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

Use the SAS URL shared to connect the container or directory.

2.4 Data Retrieval – Service Principal and Key Vault



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

2.4.1 Generate SAS token

For the AV to initiate a data access within the Data Management System, (**1**) a SAS token with *Read-Only* permissions is generated.

2.4.2 Retrieve Token from Azure AD

That SAS token (**2**) will be placed securely in Key Vault with *Get* permissions to access data.

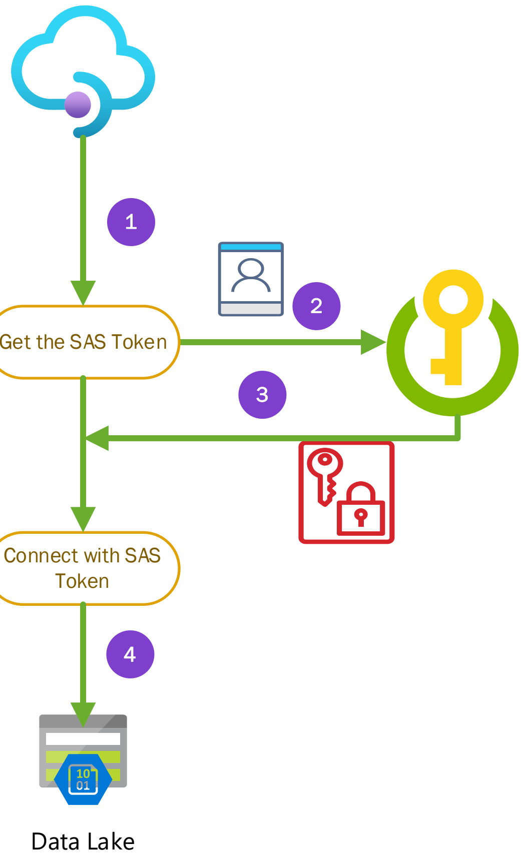
2.4.3 Receive Secret from Key Vault

Once the SAS token is secured in Key Vault with *Get* permissions (**3**) the service principal object retrieves the secret from Key Vault.

2.4.4 AV Receives Files from Data Lake Container

From there, the AV is given the Client ID and Secret to (**4**) connect to the SAS token and is now able to access and read the files from the Data Lake Container.

2.5 Data Retrieval – Service Principal or Managed Identity and Key Vault



SOURCE: THE ADS DEMONSTRATION DATA MANAGEMENT PLAN

2.5.1 Generate SAS token

For an API to initiate a data access within the Data Management System, (**1**) a SAS token with *Read-Only* permissions is generated.

2.5.2 Retrieve Token from Azure AD

That SAS token (**2**) will be placed securely in Key Vault with *Get* permissions to access data.

2.5.3 Receive Secret from Key Vault

Once the SAS token is secured in Key Vault with *Get* permissions (**3**) the service principal object retrieves the secret from Key Vault.

2.5.4 API Receives Files from Data Lake Container

From there, the API is given the Client ID and Secret to (**4**) connect to the SAS token and is now able to access and read the files from the Data Lake Container.