Collaborative Research Framework for Automated Driving System Developers and Infrastructure Owners and Operators

December 2021

U.S. Department of Transportation
Federal Highway Administration

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Technical Report Documentation Page

1. Report No. FHWA-HOP-21-012	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Collaborative Research Framework for Automated Driving System Developers and Infrastructure Owners and Operators		5. Report Date December 2021 6. Performing Organization Code
7. Author(s) Martha Eddy, Mohit Mandokhot, Filmon Habtemichael		8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle 505 King Avenue Columbus, OH 43201		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH6116D00049L 693JJ319F000428
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration (FHWA) Office of Operations 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered 14. Sponsoring Agency Code HOP
15. Supplementary Notes		

16. Abstract

The Federal Highway Administration (FHWA) initiated the Testing and Pilot Design, Development, and Evaluation Framework project with the objective of developing a framework that enables collaboration among Automated Driving System (ADS) developers and Infrastructure Owners and Operators (IOO) for research, testing, and development activities. This Framework report is based upon feedback FHWA received through extensive engagement and input from ADS developer and roadway stakeholders, including automotive original equipment manufacturers (OEMs), suppliers, technology companies, and State, and regional government entities. The intent is for the Framework to advance each of the stakeholder's valuable knowledge and information towards the realization of a safe system approach. The findings contained in the Framework support that research and development tests need to be collaborative and thoughtfully structured with regards to goals, design, monitoring mechanisms, and evaluation schemes to advance the state of knowledge gained through these engagements. Additionally, this Framework provides collaboration elements and considerations that apply throughout the research and development testing phases, including aids and checklists, collaboration opportunities, and real-world examples from across the country. While the focus of this Framework is primarily directed toward ADS development and roadway testing—benefits of utilizing the collaboration Framework for higher levels of driving automation can be realized and also extend to development of other types of transportation technologies as well.

17. Key Words Automated Driving Systems, Infrastructure Operators Owners, Testing, Research, Pilot, Collaborative Testing, Autonomous Vehicles, Evaluation Framework		18. Distribution Statement No Restrictions	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 70	22. Price N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Glossary of Terms and Acronyms

Term / Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
ADS	Automated Driving System
ASCE	American Society of Civil Engineers
AUVSI	Association for Unmanned Vehicle Systems International
AVS	Automated Vehicle Symposium
BSM	Basic Safety Message
CCTV	Closed-Circuit Television
DAQ	Data Acquisition System
DDT	Dynamic Driving Task
DMP	Data Management Plan
DOT	Department of Transportation
ECV	Essential Climate Variable
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
INS	Inertial Navigation System
IOO	Infrastructure Owners and Operators
I/O	Institutional and organizational
LiDAR	Light Detection and Ranging
LED	Light-Emitting Diode
MDOT	Michigan Department of Transportation
MDSS	Multi-Domain Sensing System
ML	Machine Learning
MPO	Metropolitan Planning Organization
MUTCD	Manual for Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
OBU	On-Board Unit
ODD	Operational Design Domain

Term / Acronym	Definition
OEM	Original Equipment Manufacturer
PennDOT	Pennsylvania Department of Transportation
RADAR	Radio Detection and Ranging
RAMS	Reliability and Maintainability Symposium
RSU	Roadside Unit
R&D	Research and Development
SAE	SAE International
SPaT	Signal Phasing and Timing
TNC	Transportation Network Company
TMP	Traffic Management Plan
UL	Underwriters Laboratory
V2X	Vehicle-to-Everything
VRU	Vulnerable Road Users
WZDx	Work Zone Data Exchange

1. Introduction

Testing and evaluating of automated driving systems (ADSs) under various roadway scenarios is a critical activity with the intent of creating a successful safe system when deployed. Understanding the capabilities that need to be implemented either in the ADS or roadway domains requires collaboration between ADS developers and Infrastructure Owners and Operators (IOO) to assist in deployment of ADS in a safe and efficient manner. To address this, the Federal Highway Administration (FHWA) initiated the *Testing and Pilot Design, Development, and Evaluation Framework* research project with the objective of developing a framework for ADS/Roadway testing and evaluation.

The objective of this project is to develop a framework that will support ADS developers and roadway stakeholders to actively collaborate on testing and evaluation activities that provide each of the stakeholder's valuable knowledge and information that advances the safe and effective integration of ADS into our roadway system. Collaboration among ADS developers and IOOs[1] has the potential to make testing more comprehensive, enable better identification of issues and potential solutions, accelerate development and deployment of ADSs, and lead to outcomes that benefit both ADS developers and roadway stakeholders. The intent is for the Framework to advance each of the stakeholder's valuable knowledge and information that works to advance the safe and effective integration of ADS into our roadway system. This Framework provides collaboration elements and considerations that apply to all phases of ADS testing, including aids and checklists, collaboration opportunities, and real-world examples from across the United States.

The intended audience for the Framework includes ADS developers, IOOs, first responders, transportation system operators, fleet operators, and other transportation professionals interested in or affected by ADS technologies when tested or ultimately operated within the roadway infrastructure. This Framework is a resource and a learning tool, but it is not formal guidance nor direction from U.S. Department of Transportation. The content of this document does not have the force and effect of law and is not meant to bind the public in any way.

This Framework was developed with extensive engagement and input from both ADS and roadway stakeholders, including automotive original equipment manufacturers (OEMs), suppliers, technology companies, and Federal, State, and regional government entities. Stakeholder engagement included document/concept reviews, webinars, and one-on-one interviews, which allowed the project team to get a perspective on:

- How to foster collaboration among public and private sector ADS/roadway participants.
- Concerns and needs during ADS and roadway infrastructure testing and evaluation.
- Essential elements in collaborative ADS testing and evaluation.

Thanks to the generous time and effort of various IOO, roadway, and ADS developer stakeholders, this resulting Framework includes stakeholder perspectives. The Framework covers all types of ADS/roadway research and development testing – simulation, off-road, and public road testing; and any and all tests (including pilots). Collaboration is necessary to ultimately create a safe roadway network; and collaboration among the various stakeholders is encouraged from the earliest of stages of ADS/roadway research and development testing. This collaborative Framework identifies opportunities for ADS Developers and IOOs to work together to understand the ADS and roadway stakeholder roles during testing in support of safe

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[1] Infrastructure Owners and Operators include the entities involved in the administration, design, implementation, operation and maintenance of transportation system features and elements.

ADS/roadway integration. Several ADS/roadway test elements, such as data sharing, support collaborative research and development testing and the Framework encourages earlier and substantial collaboration through testing. Note that this Framework is not guidance but does provide a basis to conduct collaborative research and development tests independent of the entity or entities initiating the test.

2. Framework Overview

The Collaborative Research Framework for ADS Developers and IOOs (hereinafter referred to as “the Framework”) provides a broad suite of tools, considerations, and approaches that facilitate collaboration between ADS developers and roadway stakeholders. When developing ADS test scenario and testing procedures, readers can refer to this document in developing their test design and development checklists, as well as get additional information on activities to be performed before, during, and after testing. The Framework also presents opportunities for collaboration in the context of typical ADS and roadway test scenarios, methodologies, and procedures, and the associated data management needs (e.g., data collection methodologies, testing parameters/variables, metrics, common data definitions). The intent of the document is for all involved in testing to strive to create a safer transportation network that is inclusive of ADS-equipped vehicles. With a collaborative effort, the expectation is that the timeline to realize a safely integrated fleet will be shorter than it would be otherwise.

As shown in Figure 1, the Framework addresses nine over-arching aspects or themes, which support the four key framework elements. In Section 3, these over-arching elements are then applied to the different test phases along with contextual examples and real-world lessons learned. Developers and roadway stakeholders can use this Framework to collaboratively test ADSs leading ultimately to use on the Nations’ roadways.

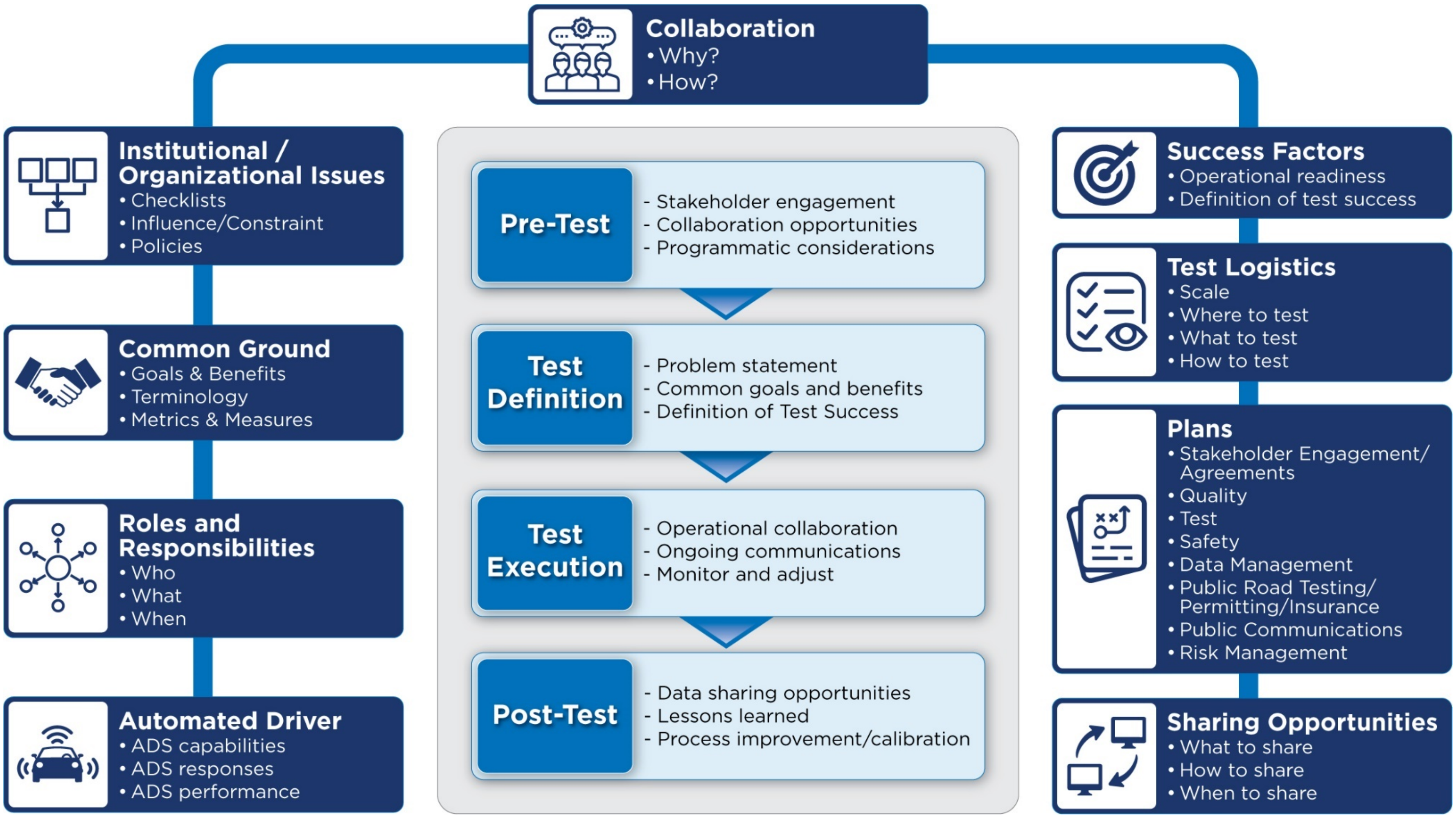

Figure 1. Graphic. Collaborative Testing Framework for ADS Developers and IOOs.

Source: *Federal Highway Administration.*

2.1 Collaboration – Why and How to Collaborate?

There are many reasons why collaboration between ADS and IOO stakeholders is critical for successful testing and evaluation. One prominent reason is that stakeholder collaboration allows for early detection and resolution of ADS issues related to technical, organization, and strategic test implementations. Collaboration allows testing participants from diverse organizations, backgrounds, and skill sets to solve specific ADS/roadway problems. Open and frequent ADS and roadway stakeholder interactions from the start of the test design leads to improved test outcomes. Effective communications also enhances the quality of the testing because input from stakeholders with differing points of view can be collected.

Implementation of ADS testing may carry risk to developers. Early detection of potential issues with ADS testing decreases implementation risk since all stakeholders will have common expectations and work toward the same objectives. Other benefits of ADS and roadway stakeholder collaborations include gathering specialized information from experts in other fields of study; sharing needed data, which can be difficult or expensive to collect; reduced testing costs; and faster execution of the tests.

Partnership to Address ADS Navigation Around Work Zones

The Pennsylvania Department of Transportation (PennDOT) has assembled nine partners to work on a project addressing infrastructure changes required for safe navigation of ADSs in work zones. The project partners include PennDOT, Pennsylvania Turnpike Commission, Pennsylvania State University, Carnegie Mellon University, PPG Paints, and others. The project will develop distinctive coats for work zone pavement markings and barrels for easy detection by ADS sensors. In addition, the project will develop advanced mapping and communication systems for safe ADS navigation at and around work zones. The test will cover 17 different work zone scenarios in urban, rural, and suburban configurations with varying work zone scale, complexity, and duration. The Team's testing will be conducted first in virtual environments followed by track tests at the Pennsylvania State University. Finally, open road tests will be conducted on roads with active work zone sites across the Commonwealth.

Developing meaningful collaboration among ADS and roadway stakeholders will be an iterative process and will take time and diligence. Especially in the area of ADS and transportation technology, stakeholders indicated that collaboration has not been the norm. Many ADS components have been developed by industry with little or no consultation with roadway stakeholders.

When facilitating ADS and roadway stakeholder collaboration, it is beneficial to ensure the appropriate stakeholders are identified and engaged. Collaboration objectives will be clearly communicated to the stakeholders. In addition, the roles and responsibilities of the stakeholders will be clearly laid out so that each stakeholder understands what is expected from them and can focus their effort on delivering their part in a timely manner. Most importantly, to keep ADS and roadway stakeholders engaged, the collaboration should seek to result in added value to the core mission of each stakeholder.

ADS developers and the IOO stakeholders indicated during project interactions that collaboration is a key need when performing ADS testing that has been missing to date and something to strive to achieve in the future. There are varying degrees of "need" for collaboration among the stakeholders at different points of the ADS test phases. Currently, most of the communication between infrastructure and ADS stakeholders is informal. ADS developers typically engage with other State agencies (e.g., motor vehicle departments), seeking to gain approval to test on the road network—not the State DOTs (IOOs). Proprietary data concerns (and competitive advantage concerns) may be limiting ADS stakeholders from taking a more progressive approach toward data sharing with IOOs. Early engagement of stakeholders, not only during on-road testing, but also during simulation and closed track testing, is critical for developing high-quality fidelity of driving and roadway environments, as well as for quality data collection and mapping of infrastructure. ADS stakeholder collaboration can enable more complete use case selection for ADS application testing. An example of a collaborative testing of roadway features and work zone barrels led by the Pennsylvania Department of Transportation (PennDOT) is discussed in the box on the previous page.[2,3]

Collaboration in the realm of ADS and roadway testing may also include communication with policy makers. To successfully collaborate with policy makers, ADS developers and IOOs need to understand the policy-making process and the environment in which the policy makers operate.

There have been a few instances where ADS developers and IOOs have collaborated to set a foundation for research and development testing. One example is the smart intersection project[4] in Marysville, Ohio—an example of collaboration between ADS developers and IOOs at local and State Department of Transportation (DOT) levels[5]. In the project, the city of Marysville, Ohio DOT, and Honda Research and Development (R&D) Americas, Inc. collaborated to set a foundation for ADS/roadway research and development by equipping all 27 traffic lights in the city of Marysville and 1,200 private and government vehicles (from ODOT, Marysville City, police, fire, and schools) with cameras, sensors, transmitters, and digital displays for enhancing intersection safety. The system transmits warning messages when pedestrians, emergency vehicles, and red-light running are detected.

This Framework addresses collaboration from various stakeholder perspectives throughout the test lifespan and provides examples where collaboration has yielded successful outcomes for both stakeholder groups. Included are benefits of collaboration and information about how and when to collaborate. This overarching theme also introduces recommendations for stakeholders to consider throughout the testing phases.

2.2 Common Ground

"Common Ground" refers to creating a common or shared working environment so that ADS and IOO stakeholders fully understand each other, which is critical for tests to be successful. When executing ADS/roadway tests, all parties will have clearly defined expectations, outcomes, and success criteria. There are three key components of Common Ground: (1) common goals and benefits, (2) common terminology, and (3) common metrics and measures.

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[2] https://www.post-gazette.com/news/transportation/2019/09/18/PennDa8OT-self-driving-vehicles-federal-grant-work-zone-safety/stories/201909180139, accessed September 2020.

[3] https://www.govtech.com/transportation/Pennsylvania-Groups-Partner-to-Test-Autonomous-Vehicles.html, accessed September 2020.

[4] https://www.dispatch.com/news/20181004/honda-demonstrates-smart-intersection-technology-in-marysville; October 4, 2018.

[5] https://statescoop.com/autonomous-vehicles-ohio-four-cities-agreements/; November 29, 2018. "Ohio Cities team up to be autonomous-vehicle testing grounds;" "…a program launched … to promote the development of autonomous vehicles".

Common Goals/Benefits

Common Goals/Benefits starts with identifying the stakeholders' goals and objectives regarding ADS testing and evaluation—and highlighting those that are shared. In some locations, IOOs are testing creative and smart traffic signs and machine-readable pavement markings in collaboration with ADS stakeholders in search of an effective means of sharing road and traffic condition information. One way of developing common goals and identifying benefits among stakeholders is by leveraging public and private organizations [such as the National Highway Traffic Safety Administration (NHTSA), FHWA, SAE International (SAE), American Society of Civil Engineers (ASCE), American Association of State Highway and Transportation Officials (AASHTO), Association for Unmanned Vehicle Systems International (AUVSI), Automated Vehicle Symposium (AVS); changed in 2021 to TRB Automated Road Transportation Symposium] to educate and engage ADS and roadway infrastructure stakeholders. These engagements have led to successful gathering of collective feedback and progressing the practice by sharing the outcomes of the events.

Common Terminology

Effective communication and understanding by all parties involved is paramount. Nomenclatures used by one stakeholder may not be understood or have different meaning by another. In one shared example, the IOO and ADS participants interested in performing on-road testing found that the same words had different meanings among the industries. Developing a common terminology and taxonomy requires effort, but in the long run it will facilitate education of a shared and consistent language, which will aid in minimizing communication failures. Having clearly defined terminologies and taxonomy unifies the languages of both ADS developers and IOO stakeholders. Standards like the SAE J3016 (Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles)[6] and the UL 4600 (Standard for Safety for the Evaluation of Autonomous Products)[7] provide common terminology useful in the realm of ADS technology. Similarly, having a standard communication protocol for information shared between IOOs and ADSs is important.

Interoperability of equipment used in ADS technology and infrastructure adaptations is another concern that challenges ADS/roadway commonality. Therefore, it is important to understand a minimum level of functionality that ADS developers and IOOs must adhere to before, during, and after ADS testing. In early ADS on-road testing, a collective ADS and IOO test team struggled to effectively communicate but was able to find common ground by establishing a test-specific shared vocabulary that was communicated with pictures. As part of this project, an ADS/Roadway testing and evaluation taxonomy was developed to assist in enabling effective communications among testing stakeholders. This taxonomy is included in Appendix A.

Common Metrics and Measures

Metrics and measures refer to techniques for quantitative assessment of ADS test outcomes and success criteria. Having common metrics and measures ensures that all stakeholders will be able to assess, compare, manage, and track performance uniformly and consistently. This component is used throughout the test phases and in other overarching themes, such as in the Plans to be developed, in the Test Definition, Test Execution, and Post Test stages.

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[6] SAE Int. (2021). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. SAE International, J3016_202104.

[7] UL Standards (2020). Standard for Evaluation of Autonomous Products. Underwriters Laboratories 4600.

To ensure commonality, it is beneficial for ADS and IOO stakeholders to openly and frequently discuss, document, and periodically review the goals, objectives, metrics, terminology, and taxonomy of ADS and roadway testing used in simulation, controlled environment, and public roads ADS testing. If ADS testing and evaluation entails assumptions, all assumptions (described in the Test Development phase) are to be discussed and shared or communicated among all stakeholders.

Another aspect of Common Ground is consistency of traffic signs, road marking, and infrastructure design. Specifically, multi-State corridors might consider if any improvements to the corridor infrastructure could be made to achieve common and consistent practices and infrastructure, which can enhance the safe and efficient ADS/roadway tests, ultimately providing seamless movement of goods and people across jurisdictional lines.

Stakeholders shared examples of how ADS and IOO representatives approach problem solving and development (where ADS/roadway testing squarely sits) to highlight the need to establish Common Ground. ADS developers and IOO stakeholders are accustomed to different approaches of problem solving. Stakeholders suggested that ADS developers follow a more agile (iterative and continuous) approach to problem solving, while IOOs typically follow a waterfall (linear and stepwise) approach. Therefore, when the two stakeholder groups come together, the different problem-solving approaches may initially inhibit collaboration, however, an awareness of this difference by those present may facilitate establishing Common Ground.

Numerous organizations have attempted to create this Common Ground, and establishing commonality is still one of the biggest challenges to address at every instance of ADS and roadway testing. To initially address this phenomenon, FHWA initiated an open call for the National Dialogue on Highway Automation. Event participants included stakeholders, such as original equipment manufacturers (OEMs), technology suppliers, transportation network companies (TNCs), associations, State and local agencies, and public and private sector representatives. The National Dialogue outcome led to this project (and many more) in the quest to safely introduce and operate ADSs into the Nation's road network.[8] Other initiatives include the ADS concept of operations that FHWA is currently developing, and the Work Zone Data Exchange (WZDx) that enables IOOs to make harmonized work zone data available to third parties.

2.3 Test Logistics

"Test Logistics" refers to what to test, how to test, and where to test. This includes development of test scenarios, testing methodologies, and test environment. Test logistics is tailored to specific test scenarios and what aspect of ADS/Roadway is being tested. For example, testing the perception system of ADSs has different testing environment needs and logistics, when compared to testing route planning capabilities of ADSs or testing a new LED signal head. A detailed overview of the three steps involved in developing test logistics is presented below.

What to Test

"What to Test" refers to the test objectives, individual component test vs. systems integration test, etc. This also includes testing the reliability of ADS algorithms, for example, verifying that similar results are obtained under similar driving environments. The challenge is that there may

[8] FHWA (2018). National Dialogue on Highway Automation. Federal Highway Administration, FHWA. Available at https://ops.fhwa.dot.gov/automationdialogue/, accessed July 2020.

be endless variations of test scenarios. Selecting representative ADS/roadway testing scenarios and executing a set of steps to validate the selected scenarios are critical. Various tests may be required to verify correct operations of different ADS functionalities (e.g., sensing, perception, World[9] modeling, and navigation and route planning).

How to Test

"How to Test" refers to the testing method, approach, implementation strategy, and logic. The methodological approach of ADS and roadway testing requires detailed documentation of the test environment, test conditions (preconditions), test procedure, expected results, and actual results. In addition, the methodology might also include detailed test cases and testing requirements. The methodological approach for ADS and roadway testing is expected to enable reproducible results.

Where to Test

"Where to Test" refers to whether the test is virtual or physical, and, if physical, if it will be conducted on a closed track or a public road. For physical tests, selection of the testing location and the factors that go into that selection are components of this overarching theme. Depending on the nature of the scenarios and the maturity of the ADS functions to be examined, the following testing methodologies can be used: (1) simulation tests, (2) closed-track tests, and (3) public road (real-world driving on public roads) tests. Simulation and closed-track testing are suitable for examining ADS functions in their early to mid-maturity stages, while public road tests are best suited for ADS functions in their later maturity stage. To save time and money, stakeholders identified that an accelerated hybrid testing approach that combines simulation and public road testing is ideal. Conducting real-world driving tests often requires receiving a permit or permission from a state agency, which creates a possibility for collaboration between ADS and IOO stakeholders. Many states are opening their roads for ADS testing and are seeing the value of collaboration with ADS technology developers. As of the writing of this report, 12 states authorize ADS testing, while 16 states and the District of Columbia authorize full deployment[10]. There are 64 ADS developers with a valid permit to test ADSs on the public roads in the State of California.[11]

This Framework broadens and deepens the topic of test logistics by first addressing the scale of ADS/roadway testing. Scale can including various SAE levels of driving automation, geographic range for the ADS/roadway test, or how a test can be expanded to the next iteration of the original test. This Framework aids test participants in identifying the magnitude of the test throughout the test phases and how that scale changes when the test scale changes within each test phase. Within each change of scale will be example scenarios to present the test logistic aspects of ADS/roadway testing.

[9] See figure 2 and Appendix A – ADS/Roadway Language and Taxonomy for description of "World".

[10] GHSA (nd). Autonomous Vehicles. https://www.ghsa.org/state-laws/issues/autonomous%20vehicles, accessed July 2020.

[11] The Robot Report (2020). Self-driving vehicles drove nearly 2.9M test miles in California. Available at https://www.therobotreport.com/self-driving-vehicles-drove-nearly-2-9m-test-miles-in-california/, accessed July 2020.

2.4 Institutional / Organizational Issues

Institutional and organizational (I/O) issues have been around for as long as institutions and organizations have existed. Since ADSs are a relatively new and evolving set of technologies, testing and evaluation will face challenges from multiple fronts—from inside and outside of the organizations, as well as from those seemingly unrelated to testing. Having organizational experts from both the ADS and IOO organizations participate early and throughout the test phases will greatly aid in navigating challenges.

Safety is Critical

In the realm of ADS/roadway testing and evaluation, safety of all road users is the greatest priority shared by policy makers and all test stakeholders. More states are opening their roads for ADS testing, which is a crucial step toward reaching the full performance potential of ADS technology. However, strict procedures and guidelines have been instituted by many states to minimize safety risk and protect the public's interest, as ADS testing is generally considered a potentially high-risk research environment. For example, in California, ADS developers are required to submit an annual report on the frequency and cause of test vehicles disengagement from automated driving mode.[12] Some stakeholders indicated that developing sound safety standards and requirements of ADS testing on public roads is one approach to resolve concern over safety of ADS/roadway testing.

Development of Consistent and Cross Jurisdictional ADS Policy

In the webinars conducted, ADS stakeholders expressed that on-road test challenges tend to be more regulatory than technical in nature. Policy on testing and deployment of ADSs has been perceived by ADS stakeholders as fragmented and inconsistent since State laws significantly differ by state. The stakeholders recognized that creating clear and consistent national policies and regulations may be challenging due to current differences in policies and regulations among States and other factors such as varying levels of ADS presence and adoption rates between States (and within State localities). Stakeholders indicated that there is an anticipated benefit from coordinating activities, policy development, and regulations for ADS/roadway testing. Stakeholders indicated that a national level organization could host the creation and support of a consistent and cross-jurisdictional policy structure, and such a structure could assist in addressing inconsistencies across jurisdictions. A national level organization could aid State and local jurisdictions in the use of the newly created structure and aid in increasing the consistency of various testing policies and regulations. Stakeholders further suggested that a national roadmap that outlines actions, activities, and milestones for ADS testing and integration at various test phases could minimize critical challenges of ADS adoption.

More Complete Information for State and Local Policy Makers

Stakeholders indicated that policy makers (state and local) may not necessarily have a complete understanding of ADSs and the capabilities they offer. For example, ADS and technology developers research, develop, test, and operate complex software in a complex environment (e.g., the roadway environment). ADS and technology advancements may occur rapidly, while the promise of technological advancements may be promoted while in the early R&D testing stages; therefore, regulators (and the public) may not easily and fully understand

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[12] Favarò, F. M., Eurich, S. O., & Nader, N. (2018, January). Analysis of Disengagements in Autonomous Vehicle Technology. In 2018 Annual Reliability and Maintainability Symposium (RAMS) (pp. 1-7). IEEE.

how ADSs are capable of functioning. Contributing factors to the disconnects may be due to limited exposure, expertise, and resources. Due to the dynamic nature of the industry and number of ADS and technology developers and OEMs, it is not expected that policymakers fully understand the maturity level of ADS technology and the ADS developers' desired time line of ADS testing and deployment. In addition, there may be a misbalance between the rapid evolution of ADSs and updates to certain regulations. Frequent and clear communications regarding ADS technology maturity, potential implications, and testing needs with policymakers has been identified as a means of overcoming this limitation. Collaborative testing and evaluation of ADS/roadway scenarios is beneficial because it leads to production of uniform and consistent information across private and public stakeholders for sound legislations and informed decisions.

Understanding the Roles and Responsibilities of ADS/Roadway Stakeholders

ADS developers may not have a clear understanding of the distinction between the various roles that Federal[13], State, local, and other agencies such as metropolitan planning organizations (MPOs), play in the decision-making process. Similarly, Federal, State, local and other agencies may not have a clear understanding of the roles and responsibilities of individuals working in ADS organizations for implementation of ADS testing. Discussing stakeholder roles is important in that the aim is to understand the transportation decision-making processes and to make sense of the responsibility and authority of agencies in relation to driving automation. For example, involving MPOs can lead to development of a practical procedure for real-world testing of ADS/roadway features with minimal disruptions or negative impacts to the local transportation network and users.

There are a wide number of factors that may influence, constrain, or direct testing due to institutional and organizational issues on the path to ADS/roadway testing. The Framework presents considerations and checklists for each of the test phases. These materials aid in navigating institutional and organizational (I/O) challenges that IOO and ADS representatives encounter when conducting the tests and pilots.

Institute for Automated Mobility (IAM) (Arizona Institute of Automated Mobility, n.d.)

IAM is a public-private consortium that focuses on the liability, regulatory, and safety implications of ADSs. Developing standards and best practices is the core of its mission. The stakeholders are Intel, Arizona DOT, Arizona Commerce Authority, Arizona Department of Public Safety, and academic partners. Intel is offering Mobileye's Responsibility Sensitive Safety (Mobileye Responsibility-Sensitive Safety, n.d.) and other ADS technologies. The Arizona DOT and Department of Public Safety will develop a traffic management center equipped with automated technology that integrates law enforcement and first responders. Academic partners will expand their research capabilities on ADS safety-related topics and liability issues. The Arizona Commerce Authority has committed $1.5 million, Arizona DOT has committed $1 million, and Intel has committed an undisclosed amount.

2.5 Roles and Responsibilities

In the process of ADS/roadway testing and evaluation it is important to identify who from the various organizations needs to participate, what roles within the organizations are needed, and when (which

[13] Note that different Federal agencies (i.e., FMCSA, FHWA, NHTSA and others) have jurisdiction and interest in ADS development.

phases) they need to participate. Some participants may be involved in only one phase, while others may be essential to all phases. An example of identification of roles and responsibilities among the organizations in the Institute of Automated Mobility is discussed in the callout box .

Roles and Responsibilities of ADS Developers

Overall, the role of ADS developers is to provide and mature the ADS technology to achieve safe and efficient ADS operations on public roads. The ADS developer is responsible for making the technology reliable, so that it can be self-sufficient and operational in almost every imaginable scenario. For example, when testing ADSs in a work zone scenario the roles of ADS developers include developing a technology that will accurately detect the presence of construction activities, construction crew, new lane configurations, lane delineation equipment (cones and barrels); developing a test plan; addressing data sharing and data needs; contributing to the development of the necessary supporting plans; securing approval to conduct the test, conducting the test; and more.

Roles and Responsibilities of IOOs

In the context of ADS/roadway research and development testing, the role and responsibility of IOOs is to provide the infrastructure where the vehicles equipped with ADSs will be tested. To enhance safe testing of vehicles equipped with ADSs, IOOs, through collaboration with the test team, may consider incorporating infrastructure adjustments (e.g., equipping traffic signs and road markings so that they are machine readable.) Before incorporation of infrastructure adjustments into ADS/roadway testing, sufficient research and testing of these various roadway environment elements in conjunction with vehicles equipped with ADS technologies may be needed to suggest which adjustments are most effective. When testing ADSs in a work zone scenario, for example, the responsibility of IOOs may be to make reasonable efforts to establish consistency of various work zone infrastructure elements at the testing location. This will lead to a test that identifies ADS perception capabilities of work zone infrastructure elements, resulting in a safe and effective work zone test environment. In the work zone test example, IOO input to the test could include providing the work zone infrastructure layout before, during, and after construction (possibly through detailed HD maps); ensuring clear pavement markings; sharing traffic management plans at and around the work zone test area; providing consent to conduct public-road testing; participating with the ADS developer in test meetings; contributing to test plans and supporting documents; and more.

In this Framework, who to have at the table and each participant's role and responsibility are highlighted for the ADS/roadway test phases. The Framework prompts discussion regarding when stakeholders and participants are required to be engaged in the test phases. The Framework shares novel examples of how tests have been conducted and when participants have been engaged throughout the phases.

2.6 Plans

Efficient and effective ADS/roadway testing and evaluation is an iterative process that benefits from collaboration among multiple stakeholders, particularly the ADS developers and IOOs. The reason for the iterative process is that research and development test and evaluation results are intended to satisfy the needs and expectations of all parties either involved with or affected by ADS technology. The Test Logistics theme focus is on developing scenarios, methodologies, and environment of testing, whereas the Plans theme focus is on documenting approaches, actions, responsibilities, data needs, and what-if scenarios and alternatives for activities involved in ADS/roadway testing. For a collaborative environment to exist, stakeholder participation as part of the test design plan, data collection plan, and evaluation plan can be beneficial in many ways, (e.g., early detection and resolution of issues, enhanced quality of testing, shared implementation risk, reduced testing cost, and faster test execution). In some instances, ADS/roadway testing and evaluation may need to account for roadway adaptations, which can be incorporated through collaboration with IOOs. Consistent stakeholder collaboration has a potential to expedite ADS/roadway testing and evaluations for safe and efficient ADS operations and integration on our Nation’s road transportation system.

Waymo’s First Responder Engagement Plan

The objective of this plan is to provide first responders with the knowledge they need to safely identify, approach, and interact with a vehicle equipped with ADSs in an emergency scenario. Key topics include:

- Location of owner information, vehicle registration, and proof of insurance
- Communicating with a remote operator
- Vehicle capabilities and operational design domain
- Removing and towing the vehicle
- Recognizing vehicle’s autonomous mode
- Disengaging automated driving mode
- Detecting and ensuring automated driving mode has been deactivated
- Safely interacting with electric vehicles and disabling power
- Considerations when in wet locations and extrication situations
- Firefighting considerations and lift and cut zones
- Location of passive restraints, high and low voltage, fluid locations
- Post-incident handling

Developing well-detailed test plans is important because they provide a foundation for achieving the ultimate test goals. Having test plans aids in defining the test scope and assists in setting goals and objectives as well as measuring success and meeting requirements.

Successful execution of the ADS/roadway testing occurs with successful planning for all aspects of tests and pilots. The Framework identifies not only the useful types of plans, but also suggests when and where to execute the actions identified in the plans. Mutual input to and recognition of the plans may aid in progressing the safe operations of the road network with ADS-equipped vehicles operating harmoniously with current-day transportation issues and challenges.

Some of the plans in the ADS/roadway testing and evaluation context include:

Stakeholder Engagement/Agreements Plan

This plan documents the strategies to communicate and effectively engage with stakeholders before, during, and after the ADS/roadway testing and evaluation period. It specifies the communication frequencies and types, as well as activities to enhance engagement. The outline of a stakeholder engagement/agreement plan can include:

- Stakeholder engagement goals and objectives.
- Purpose of stakeholder engagement.
- Stakeholder identification.
- Stakeholder analysis matrix.
- Stakeholder engagement process and approach.
- Stakeholder engagement timeline.
- Stakeholder agreements and disclosures.

Quality Plan

The Quality Plan specifies standards, practices, resources, specifications, and activity sequence for reliable ADS/roadway testing and evaluation. It documents the planning, implementation, and assessment of tests for quality assurance and quality control. In the quality plan, the following topics may be included:

- Quality goals and objectives.
- Purpose of the quality management plan.
- Organizations and their roles and responsibilities.
- Methodology for quality management.
- Quality auditing and performance measures.
- Procedure for quality control.
- Procedure for quality assurance.
- Compliances and certifications.

Test Plan

The Test Plan is a document that details the test objectives, scope, methodology, resources, success criteria, sequence of events, and schedule of intended test activities. At a minimum, the following topics may be discussed in the test plan:

- Introduction, background, and overview.
- Test objective and scope.
- Testing methodologies.
- Test approach and assumptions.
- Roles and responsibilities of parties involved.
- Test environment and scenarios.
- Test schedules and sequence of events.
- Test success criteria.
- Test risk and mitigation plan.

Safety Plan

The Safety Plan embraces a strategy that details the procedure to be followed for safely conducting ADS testing. It addresses how adverse effects of ADS tests can be avoided. Waymo's first responder engagement plan presented in the callout box on the previous page is a good example of a component of a safety plan[14]. An outline of a safety plan can include:

- Safety goals and objectives.
- Safety vision and commitment.
- Roles and responsibilities of personel involved in testing.
- Safety standards, inspections, and certifications.
- Hazard identification, assessment, prevention, and control.
- Emergency response procedure.
- Safety event reporting procedure.
- Safety event investigation procedure.

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[14] Waymo (2019). Waymo Fully Self-Driving Chrysler Pacifica Emergency Response Guide and Law Enforcement Interaction Protocol. Available at https://storage.googleapis.com/sdc-prod/v1/safety-report/waymo_law_enforcement_interaction_protocol_2019-10-11.pdf, accessed July 2020.

- Safety evaluation and improvement.

Data Management Plan

A Data Management Plan (DMP) is a document that outlines how data are acquired or produced during the testing, how they will be managed, described, stored, and shared. It also details data types, sources, formats, and standards. In the DMP, the following topics may be discussed in detail:

- Introduction, background, and overview.
- Roles and responsibilities of all parties.
- Data storage and backup.
- Data standards and best practices.
- Data formats and metadata.
- Working with sensitive data.
- Policies for dissemination, access, and sharing of data.
- Licensing the data.
- Data preservation and retention period.

Public Road Testing/Permitting/Insurance Plan

This Plan outlines the need for public road testing and details the requirements for obtaining permission to use and safety precautions to be taken. At a minimum, the plan may include the following topics:

- Introduction, background, and overview.
- Description of vehicle type and automation level.
- ADSs operational design domain.
- List of public roads used for vehicle testing.
- Date and time of tests.
- Compliance with applicable standards and regulations.
- Cyber risk and security measures.
- Data Acquisition System standards .
- Collision and disengagement reporting.
- Interaction with law enforcement.
- Safety and liability protections.

Public Communications Plan

The Public Communications Plan documents strategies for effectively communicating ideas and information to the target audience, and how to respond as a collaborative team to a variety of potential outcomes. The outline of a public communication plan may include:

- Communication goals and objectives.
- Target audiences.
- Communication platforms.
- Communication protocols.
- Key messages.
- Communication events and schedule.
- Campaigns.
- Feedback collection.

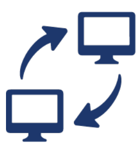
- Benchmarks for success and evaluation.

Risk Management Plan

The Risk Management Plan identifies strategies that aims to reduce the likelihood of a loss or damage occurrence and decreases the consequences of the event if it does occur. The plan will detail the process for maximizing opportunities and minimizing threats by tracking identified risks, identifying new risks and anticipated problems, and developing a mitigation strategy. In the risk management plan, the following topics may include:

- Risk management strategy.
- Risk identification.
- Risk responsibilities.
- Risk assessment procedure.
- Risk response.
- Risk mitigation.
- Risk contingency planning.
- Tracking and reporting.
- Processes to address immediate unforeseen risks.

2.7 Sharing Opportunities



Data are one key issue that requires thorough discussions from IOO and ADS stakeholders to avoid challenges (e.g., proprietary data/information, use of data). Data are critical to evaluate the outcome of tests, and data are key to effective road network operations. It is possible that ADS and IOO stakeholders can share a variety of resources. Resource sharing includes sharing of skills and expertise in addition to sharing of information and existing data.

Sharing of Information and Existing Data

Sharing of test results and existing datasets is important as information and data sharing enhance understanding of the ADS operations, builds trust, and increases transparency among stakeholders. New data collection is expensive and time consuming. Sharing existing data can cut costs and collection time across the board. For example, IOOs can share signal phase and timing (SPaT) data, pavement conditions and hazards, roadway inventories, location and path of emergency vehicles, work zone information, road incidents and planned events, road closure information, and traveler information. ADS developers can use data received from IOOs in the context of route planning, rerouting, etc. Similarly, IOOs can use information received from ADS developers to identify and correct problematic road spots where ADSs frequently disengage. Although it is widely agreed that data sharing is key for successful ADS operations, it is important that specific technical aspects of data sharing be clearly defined, such as the data sharing mechanism, ownership, licenses, and privacy concerns. Data sharing practices have the potential to support development of data management plans that consider the data types that stakeholders already have or are able to collect, and that can support ADS/roadway testing.

Sharing of Skills and Expertise

The primary resources to be shared are skills, knowledge, and expertise that are critical for improving effectiveness of ADS technology and its maturity. Most of the research and development in the context of ADSs is contained with the technology developers. For other stakeholders to come up to speed, the skills and expertise obtained to date from ADS development can be transferred to IOOs and other stakeholders. New learning from ADS tests and pilots can be shared with IOOs so that they stay engaged on how ADSs can be safely and efficiently integrated into the road network. The objective of sharing skills and expertise is not for ADS developers and IOOs to be experts in each other's areas, but to have a level of knowledge to be able to relate each other's area to their areas, e.g., IOOs need enough information so they can relate ADS operations to the roadway.

From the webinars conducted, ADS stakeholders expressed concerns about sharing all data with IOOs due to proprietary nature of the data and possible implications for their competitive advantage. However, there are numerous data elements that are not proprietary in nature that can be exchanged between both parties. For example, ADS developers can share non-business sensitive data such as disengagements of ADSs, crashes and near misses, and consumer adoption rates. Test participants can identify need for and use of shareable metrics by having constructive discussions on the purpose and usefulness of sharing data and clearly define data sharing agreements. In addition, stakeholders can agree on a standard data sharing mechanism to effectively and efficiently communicate the information with IOOs and other vehicles equipped with ADSs on the roadway.

Most in this industry understand that data is a key issue that is likely to cause challenges for both IOO and ADS stakeholders. Data are critical to evaluate the outcome of tests. Data are also key to effective road network operations. This Framework leverages data strategies and presents what, how, and when to share for the various test and pilot phases.

2.8 Success Factors

Many factors influence success of ADS/roadway research and development testing and evaluation. Success Factors include a definition of test success, and operational readiness which includes comprehension of ADS and roadway test elements and process, stakeholder engagement and collaboration, and ongoing public communications.

Definition of Testing Success

ADS testing is an iterative process (i.e., each previous test providing an additional improvement opportunity to maturing ADSs). Success factors from a testing point of view focus on the ability to correctly verify that the ADS has made the right (i.e., desired) decisions in each test scenario and environment. Candidate success factors (which are unique to each test) may include:

- Improving perception of the driving environment by ADS sensors.
- Successfully capture and document accurate interpretation of information provided from other parties, e.g., information from IOO.
- Improving the ADS's perception system to appropriately respond to a variety of events with different levels of risk.
- Understanding the factors that the ADS uses to determine whether the ADS is operating within the designated ODD.

Comprehensiveness of ADS/Roadway Test Elements and Process

Success factors from the ADS/roadway test elements and process point of view include test coverage, test outcome reusability, transferability to other roadway environments, value of data generated from the testing, system reliability, ADS performance, scenario representativeness and completeness, test practicality, security of information sharing, and system maintainability.

Stakeholder Engagement and Collaboration

Even if the ADS technology itself is fully mature, its research testing and ultimate deployment would not be successful without engagement and collaboration of key stakeholders, such as IOOs, first responders, policy makers, and the public. Therefore, success criteria from stakeholder engagement and collaboration points of view include:

- Establishing goals for collaboration and achieving them.
- Finding alignment between benchmarks established by public entities, IOOs, and private firms.
- Continuous collaboration.
- Proactive public outreach strategies.
- Community acceptance of the deployments.
- Community use of deployments like automated shuttles.
- No safety issues associated with the deployments.
- Identification of central strategies through collaborative conversations to mitigate issues encountered during research and deployments.

Ongoing Public Communications

This refers to strategic communication process with the core objective of influencing, engaging, and building beneficial relationships with ADS and IOO stakeholders, particularly policy makers, and the general public. Even if the highest possible maturity level of ADSs is obtained, it would not be successful unless it is embraced by policy makers and the general public. Ongoing public communications improves the perceived usefulness, maturity level, attitude, trust, risk, compatibility, and value of ADS testing and evaluation as well as deployment on public roads.

Success comes in many shapes and sizes. Each phase of testing will have desired and anticipated outcomes. The Framework aids in assisting the ADS and IOO participants in defining test success factors within each test phase. The Framework explores options for defining test successes.

2.9 Automated Driver

Today's driver is a human, and the road infrastructure (e.g., traffic signs and road markings) are constructed and designed for a human driver. With ADS-equipped vehicles, the driving task may more frequently be accomplished by the ADS. Stakeholders indicated that ADSs will have a range of driving characteristics, like aggressive or conservative somewhat similar to the range of characteristics inherent in different human drivers. Testing and operation of ADS-equipped vehicles can demonstrate how the vehicles perform and provide insight into what adjustments may be made to the existing road infrastructure to support or enhance the safe operations of the road network of tomorrow—with human-driven vehicles and vehicles equipped with ADS technologies on the same roadways.

This Framework is an instrument that provides considerations for those conducting testing and pilots to prepare for both type of drivers (i.e., human and ADS) on the road.

3. Application of the Framework to the ADS/Roadway Testing Phases

The Framework provides ADS and IOO stakeholders involved in testing and evaluation (referred to as “you” from here on) with knowledge and information to structure collaborative ADS/roadway testing and evaluation programs. The Framework recognizes your need for flexibility in design of test programs, and hence you are encouraged to adapt the knowledge judiciously to satisfy the needs of your collaboration. This approach aims to account for diverse ADS/roadway challenges, while providing information that allows you to glean valuable insights for successful collaboration.

The activities for successful collaborative testing and evaluation can be categorized into four phases as shown in Figure 2. This figure identifies each phase with this Framework.

The Framework identifies a set of activities within each phase. The over-arching themes presented in the Framework Overview section are recognized within these activities. The activities are explained with the use of in-text narratives, a Work Zone test scenario, and real-world examples as appropriate.

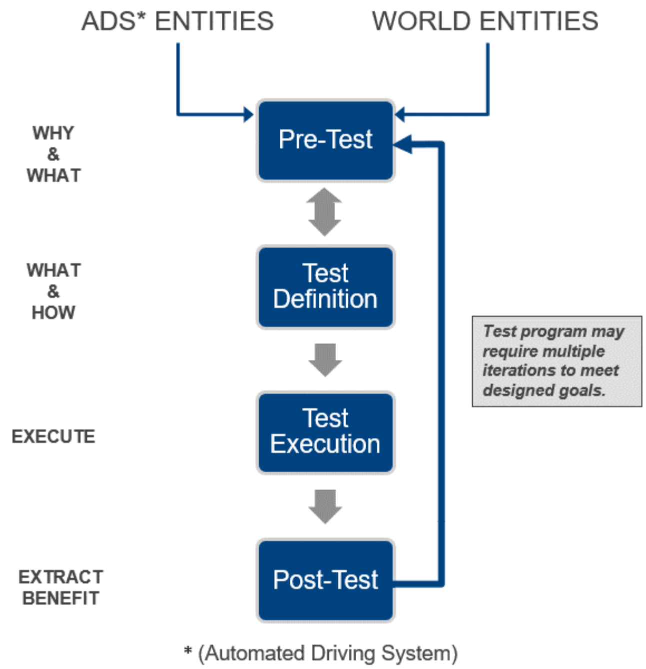


Figure 2. Graphic. Framework for Collaborative Testing and Evaluation.

Considering the in-text narrative, if an ADS sensor manufacturer wants to test on public roads, the Framework highlights facets of collaboration with the IOO entity. For example, the Framework encourages entities to recognize the need to use common terminology when exchanging ideas and discussing test plans and expected test outcomes.

Stakeholders identified that many ADS developers prefer the use of agile program management methodologies in the development of their products as requirements and metrics evolve with each iteration of the agile development process. Whereas roadway entities may tend to rely on a traditional (waterfall or linear) approach toward management of on-road test programs as the requirements are more clearly understood from the beginning of testing. The Framework provides information that outlines the core aspects of testing and evaluation and is applicable to both the agile and waterfall processes. You may seek to use this structure as a common reference between collaborating entities. This may enable diverse stakeholder entities to speak a common language that can satisfy the goals of an effective and efficient collaboration.

3.1 Pre-Test Phase

The objective of the Pre-Test phase is to conduct activities that help discuss a broadly appealing testing and evaluation problem statement and engage with stakeholders over the mechanics of collaboration.

First, you (the test stakeholder) will identify a problem statement with a broad appeal. Next, the stakeholders, their roles, and collaboration opportunities will be identified in the Pre-Test Phase. Finally, the problem definition statement will be created in a collaborative fashion.

Table 1 documents the objectives, activities, and expected outcomes at the completion of the Pre-Test phase. This summary table can be viewed as a model to obtain additional information on an identified activity of interest.

Table 1. Summary of Pre-Test Phase.

Pre-Test:	Details
Objective	• Discuss identified testing and evaluation problem goals with stakeholders. • Evaluate collaboration opportunities for successful testing and evaluation.
Inputs	• Technology of Interest. • Initiating Stakeholder.
Key Activities	• Programmatic considerations. • Stakeholder engagement. • Collaboration opportunities.
Outputs	• Obtain a clear definition of the goals of collaborative testing. • Agreements under which the stakeholders can expect to collaborate.
Plans	• Stakeholder Engagement / Agreements. • Permits, requirements, and insurance. • Preliminary risk management plans. • Preliminary public communications.

3.1.1 Overview of the Pre-Test Phase

ADS and roadway stakeholders may benefit from a review of the following key activities involved in the Pre-Test Phase. The activities are divided into three themes listed below:

- Programmatic considerations:
  - Problem Identification – Identify a broad problem to be tested.
- Stakeholder engagement:
  - Roles and Responsibilities – Identify roles and responsibilities for collaborating entities throughout the testing and evaluation phases.
  - Stakeholder Engagement / Agreements – Determine the engagement and non-disclosure agreements that facilitate and govern the collaboration.

- Collaboration opportunities:
  - Preliminary Risk Assessment – Conduct a preliminary risk assessment to capture the risks involved in various facets of collaboration.
  - Permits, requirements, and insurance – Review permits needed for public road testing. Review safety, operation, and technical requirements for other methods.
  - Public Communications – Develop a coherent public communications strategy to inform users affected directly or in-directly by the testing and evaluation.

Figure 3 outlines the typical sequence for execution of the proposed Pre-Test Phase activities. You may start by identifying the problem statement. However, the activities within the stakeholder engagement and collaboration opportunities may be done at any time. You may iteratively define these items in conjunction with the Test Definition phase for a complete definition of all activities needed before commencement of Test Execution.

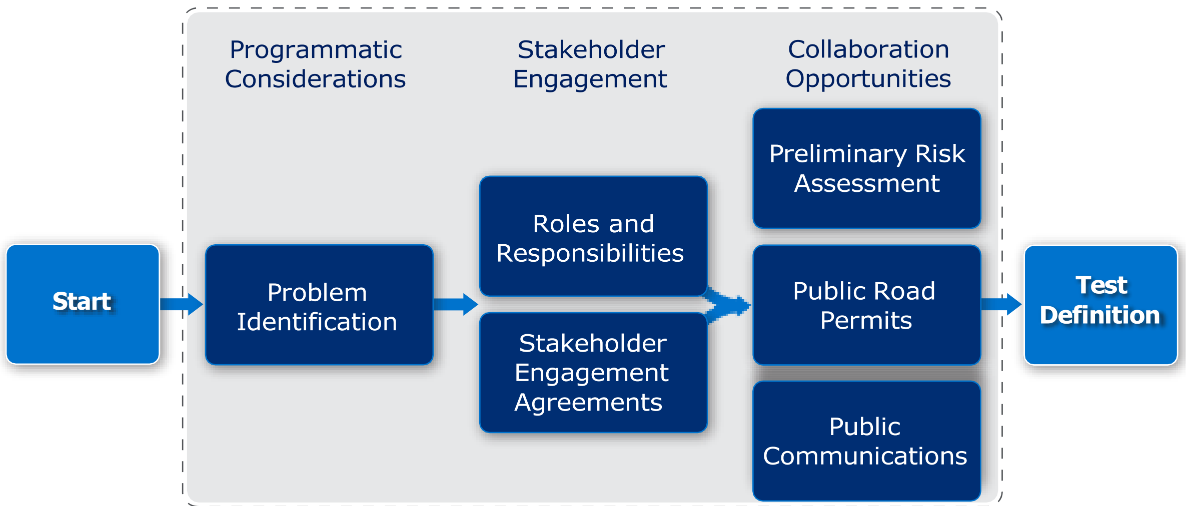


Figure 3. Graphic. Activities during the Pre-Test Phase of Collaborative ADS/Roadway Testing and Evaluation.

Source: *Federal Highway Administration.*

3.1.2 Key Activities within the Pre-Test Phase

Problem Identification

As a stakeholder who is interested in collaborative testing and evaluation, you must first identify a problem of interest.

The problem statement can be identified using an established internal mechanism. ADS stakeholders may identify the problem using their own product development cycle. The product development process may point to a feature that needs to be tested in a collaborative environment before the feature is incorporated into the development of a production vehicle. The infrastructure stakeholders may identify problems of interest by reviewing the changing landscape of demands from roadway users, due to the presence of an ADS serving as the driver.

Let us take the example of an ADS developer who identifies the need to test their prototype traffic sign recognition feature. Collaborative testing of the Traffic Sign Recognition feature performance can broadly interest other stakeholders such as IOOs and City Authorities. In the

Pre-Test phase, the ADS developer can broadly define the problem, and identify IOO representatives to collaborate throughout testing. Such testing may occur in simulation, when developing algorithms for the traffic sign recognition feature. The IOOs and ADS developers may collaborate to model the traffic signs correctly within simulation. If testing on public roads, the IOOs may be able to provide route and traffic sign inventory information that leads to effective execution of the test program. The insights obtained from the testing and evaluation of the feature can improve both the ADS feature performance and provide IOOs with design insights.

Roles and Responsibilities

Once stakeholders identify an agreed-to problem statement, they deconstruct it further to develop value propositions for each participating organization. This step formalizes the expected tangible and intangible benefits of collaboration.

Stakeholders may recognize tangible benefits such as sharing of resources, expertise, and costs; development of shared insights among collaborating stakeholders; and improved ADS or infrastructure system performance. Stakeholders may also recognize intangible benefits such as development of key partnerships with organizations and improved public branding and relationships for your organization and participating stakeholders.

Stakeholder Engagement / Agreements

A clear identification of roles and responsibilities among participating stakeholders will enable extraction of outlined benefits. In the Pre-Test Phase, stakeholders may define each organization’s role throughout all four phases of the collaboration. They may also seek to outline resources needed to execute the identified organizational responsibilities. The stakeholders may define engagement agreements that formalize these roles and responsibilities.

According to stakeholders, ADS development is competitive in nature. Protection of proprietary information is of paramount importance for all stakeholders. Non-disclosure agreements could be used in protecting sensitive information. This information could include, but is not limited to ADS architecture, performance, and testing results. Test participants may use both the stakeholder engagement agreements and the non-disclosure agreements to establish policies that govern mechanics of the research and development test collaboration.

Preliminary Risk Assessment

Next, the stakeholders perform a preliminary assessment of risks. The preliminary risk assessment is designed to be a broad, working document that is iteratively updated throughout the test program. The assessment can highlight any technical and data issues expected to occur as a part of the collaboration. These risks may also relate to the outlined scope of work, resources, technical expertise, and protection of proprietary information throughout the course of the test program. The risk assessment can also include, when necessary, a readiness assessment of the participating group of stakeholders. Readiness for collaboration may also be influenced by legal, financial, and organizational factors.

Let us consider a hypothetical data risk in a collaborative test program between an IOO and an ADS developer. IOOs collaborating with ADS developers for public roadway testing may need to procure access to a secure data management solution to manage any proprietary ADS data. The solution may need to demonstrate the capability to provide controlled access to sensitive information. It is critical to capture such risks to facilitate collaboration with confidence. The stakeholders may also review if these data collection and storage risks are pertinent to collaboration in the simulation and controlled environment proving ground test methods.

Permits, Requirements and Insurance

In many States,[15] [16] [17] a permit process governs the deployment of ADS-equipped vehicles on public roadways. Stakeholders may collaboratively determine the information needed to acquire such permits. Permits broadly govern four facets of public road testing of ADS-equipped vehicles: presence of a safety operator, development of safety management plans, data reporting, and liability. Stakeholders may also need to review insurance and liability requirements appropriate to their tests.

Example AV Testing Permit Requirements

Permit requirements may vary across states. Requirements may vary when testing with or without a safety operator. As an example, you may review CalTrans[15], Maryland DOT[16], and Arizona DOT[17] AV Testing Permit requirements.

Stakeholders may collaborate to review permit requirements as applicable to their testing and evaluation. In cases where permit requirements are not formalized, stakeholders may seek to inform, and consult with representative roadway authorities to determine such requirements. Establishment of Common Ground and a recognition of collaboration benefits may aid in the approval of public roadway testing and evaluation.

When testing in a controlled environment, stakeholders may review applicable insurance and safety requirements that need to be satisfied to allow execution of testing. These requirements may relate to the ADS developers or the safety operator designated to execute these tests.

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[15] CalTrans requirements:

- Without Driver - Autonomous Vehicles Tests without a Driver – https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/testing-autonomous-vehicles-without-a-driver/
- With Driver - Autonomous Vehicles Testing with a Driver – https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/testing-autonomous-vehicles-with-a-driver/

[16] Maryland DOT's permit process for Highly automated Vehicles – Permit Process for Testing HAVs (maryland.gov) and Expression of Interest to collaborate on connected and automated vehicle technology and/or test highly automated vehicles in Maryland

[17] Arizona DOT's Autonomous Vehicles Testing and Operating in the State of Arizona | ADOT (azdot.gov)

Develop Preliminary Public Communications Plan

When seeking to test ADS-equipped vehicles in a collaborative fashion on public roadways, it is important to determine a coherent public communication strategy. ADS and roadway stakeholders can develop a preliminary public communications plan that targets stakeholders directly or indirectly impacted by the testing and evaluation.

> **Public Communications Strategy**
>
> Timely and coherent communications can build public trust and outline roadway safety measures. When new risks arise (e.g., AV crashes), a coherent strategy can enable communication among key public stakeholders, legislators, and technology companies.

When testing in a controlled environment or when collaborating using simulation, the public communications plan may focus on outlining the benefits of collaboration. Stakeholders may choose to outline the key facets of the testing and evaluation and illustrate benefits that roadway users may experience from the results of testing and evaluation. One example of execution of a public communications plan may be when IOOs and ADS developers collaborate to test in a controlled environment the use of integrating vehicle-to-everything (V2X) technology with ADS-equipped vehicles to make pedestrian crossings safer, the methodology and results may be shared with the public. Information shared can encourage interest from other local governments and facilitate adoption of the tested V2X technologies.

A focus on the benefits, a recognition of risks, and an establishment of mitigation strategies are three key pillars of a public communications plan. The use of a single point of contact and a coherent message approved by collaborating partners may mitigate public risks as they arise during testing and evaluation.

3.1.3 Outputs for the Pre-Test Phase

On completion of the Pre-Test phase, you will have a clearly identified problem statement.

Next, the stakeholders can formalize established partnerships by acknowledging the roles and responsibilities of each entity in the collaboration. Stakeholder engagement and confidentiality agreements are an important outcome of this phase.

Finally, you may capture program risks in the preliminary risk assessment. These risks include but are not limited to operational, technical, data, legal, and financial facets of the collaboration. You will also outline a Public Communications Plan and determine permits and requirements that govern access to public road facilities and controlled environments.

3.2 Test Definition Phase

The objective of the Test Definition Phase is to conduct activities that help define the technical and data facets of a collaborative test program. The completion of the Test Definition Phase produces a Test Plan, a Data Management Plan (DMP), and a Quality Plan, which facilitates subsequent test execution.

Table 2 documents the objectives, activities, and expected outputs you may obtain on completion of the Test Definition Phase. You may review this summary table as a model to obtain additional information on an identified activity of interest.

Table 2. Summary of Test Definition Phase.

Test Definition:	Details
Objective	• Develop a comprehensive test plan that captures the technical, data, evaluation, and quality facets of collaborative ADS/roadway testing.
Inputs	• Problem Definition from the Pre-Test Phase. • Stakeholder Collaboration Assessment.
Key Activities	• Common Goals and Benefits. • Problem Statement. • Definition of Test Success.
Outputs	• Comprehensive ADS/Roadway Test Plan. • DMP, a Quality Plan, and definition of Test Success.
Plans	• Test Plan. • Data Management Plan. • Quality Plan.

3.2.1 Overview of the Test Definition Phase

ADS and roadway stakeholders may benefit from a review of the following key activities involved in the Test Definition Phase. The activities are grouped under three key themes:

- Common Goals and Benefits:
  - Start Problem Definition – Collaboratively identify the goals and objectives of testing and define a test program to achieve identified goals.
  - Establish common language – Generically describe the ADS and World elements (see Figure 2 and Appendix A – ADS/Roadway Language and Taxonomy) involved in the collaborative testing to facilitate exchange of ideas.
- Problem Statement:
  - Test Scenario Definition – Collectively define the test scenario by describing the assumptions, roles, and state of relevant ADS and World elements that influence performance. Determine appropriate method for testing and evaluation, i.e., simulation, controlled environment, public road testing, or a combination of methods.
  - Data Definition – Identify relevant data sources and elements and develop a data management plan.
- Definition of Test Success – Collaboratively determine the metrics and criteria for evaluation of ADS/roadway test performance. The success can be measured at a technical, organizational, and public perception level.

Figure 4 outlines the sequence of proposed activities in the Test Definition Phase. First, you may start to define the problem in a greater level of detail. You may benefit from the use of common language before developing the technical and data definition of the Problem Statement. Finally, you define the technical and organizational test success criteria relevant to the collaboration. These activities may be executed concurrently with the Pre-Test Phase.

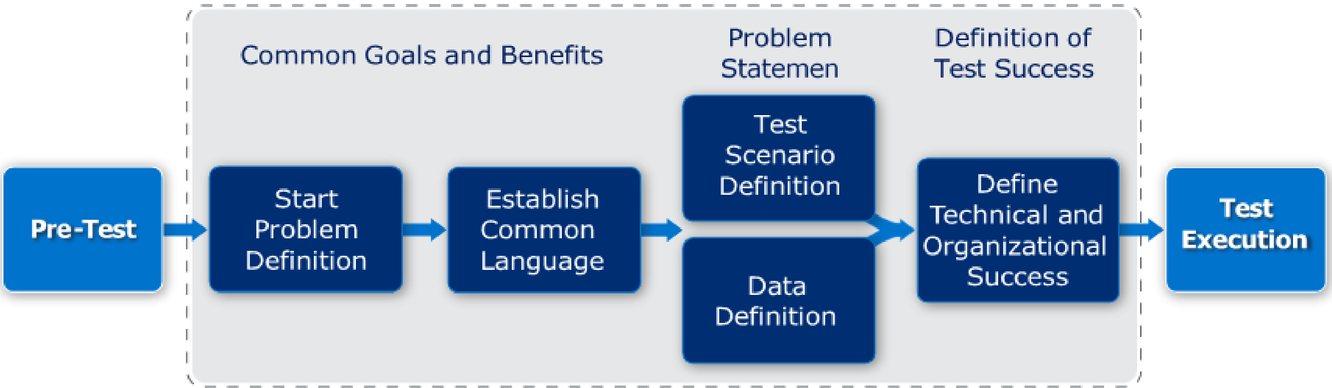


Figure 4. Graphic. Activities during the Test Definition Phase of Collaborative ADS/Roadway Testing and Evaluation.

Source: *Federal Highway Administration.*

3.2.2 Key Activities within the Test Definition Phase

Start Problem Definition

In the Test Definition Phase, the stakeholders start to define the collaborative ADS/roadway test program. Inputs from a diverse set of stakeholders help formalize the problem statement[18]. The stakeholders determine the goals of collaboration. You may need to define more than one objective and numerous clarifying assumptions to achieve the outlined goals. Each objective may require the conceptualization of a separate test program.

Scenario Example 1 – Table 3 provides a problem definition template and captures the relevant stakeholders, goals, objective, and test program for an example Work Zone Navigation Feature test scenario.

Michigan DOT/3M Connected Roads I-75 Test Corridor

Michigan DOT (MDOT) collaborated with 3M to deploy a 100-day test of 3M Connected Roads prototype solutions in a 3.3-mile construction work zone[12]. The collaboration took place between 3M, MDOT, and a variety of automotive OEMs and sensor suppliers. This is a good example of collaboration to achieve roadway safety goals.

Table 3. Scenario Example 1: Problem Definition Template.

Scenario Ex.1	Details
Stakeholders	• ADS Manufacturers. • State or local DOT Operations.
Goal	• Increase ADS navigation capability. • Understand features that lend to success of ADS operations.
Objective	If within ODD, ensure successful navigation, even in adverse weather
Test Program	Baseline Evaluation of Work Zone Navigation Feature

In this phase, the stakeholders may start to consider the appropriate test method to achieve their goals. There are three recognized, high-level, test environment categories including simulation, closed track, and public road to test systems that influence the ADS/roadway

[18] "Motor City" Detroit Merging Automotive & Infrastructure Innovation with 3M Connected Roads I-75 Test Corridor (https://multimedia.3m.com/mws/media/1572737O/michigan-test-corridor-case-study.pdf)

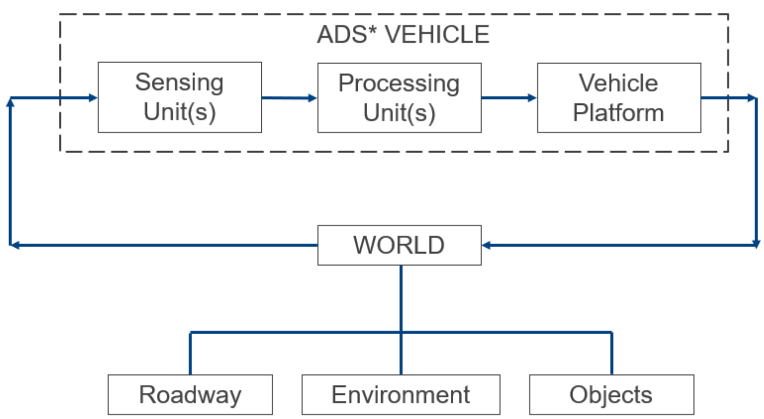
performance. The stakeholders may collaborate in one of the test methods or in a combination of all three methods to meet their needs.

Establish a Common Language Between Stakeholders

A collaborative definition of the test program builds on shared expertise of the ADS and roadway stakeholders. However, the lack of knowledge of each other's technical space and inconsistent use of nomenclature may hinder this effort. The ADS and roadway stakeholders can use agreed upon language to establish common ground between all participating entities.

First, you may define the level of automation for the ADS feature to be evaluated under collaborative testing. You may use the recommendations within the SAE J3016 Recommended Practice[19] to determine the level of automation to identify the feature under test. Next, you may seek to describe the ADS-equipped vehicle and relevant World elements that influence ADS performance and test scenario outcomes. The language used to describe the ADS-equipped vehicle and relevant World elements can be generic, functional, and modular. A review of the collaboration's goals and scope can help you determine the level of detail needed for the description and satisfy objectives.

ADS and roadway stakeholders can use published references (e.g., NHTSA, 2018) to discuss ADS features and define the ODD. Figure 5 provides an overview of the language created as a part of the Framework and describes the ADS Vehicle and constituent World elements. Appendix A presents a summary of the language.



* Automated Driving System

Figure 5. Graphic. Generic Description of the ADS Vehicle and Constituent World Elements.

Source: *Federal Highway Administration.*

In case of an ADS developer seeking to collaborate with an IOO to test their Traffic Sign Recognition algorithm, the stakeholders can use generic language to communicate with the IOO. In this case, the ADS feature relies on a visual-camera-based sensor that looks for sign objects in the observed scene. The Processing Unit for the feature relies on Machine Learning

[19] SAE Int. (2021). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. Society of Automotive Engineers International, J3016_202104. Available at https://www.sae.org/standards/content/j3016_202104/, accessed September 2021.

(ML) based object detection algorithm to identify presence of traffic signs. The ML method may rely on the use of a database of traffic signs to help identify the type of sign detected.

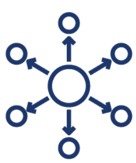
Test Scenario Definition

Stakeholders may seek to define the test scenario. Test scenarios allow for a categorical evaluation of the ADS feature under test.

First, the stakeholders determine an appropriate test method. Stakeholders may choose to test in the virtual environment via simulation, in a controlled environment, on public roads, or a combination of these. Each test method offers its unique advantages and disadvantages. The three test methods offer varying degree of control, fidelity, and data extraction possibilities.

The Framework has been developed to support and encourage collaboration between the ADS/roadway entities in all testing methods. The choice of testing method may depend on the phase of the product development cycle for the ADS or Roadway feature under evaluation. However, the stakeholders need to evaluate and judiciously apply the various framework elements, as not all elements may be needed for each test method. Stakeholders interested in a more detailed exploration of simulation and controlled environment test methods may benefit from a review of Chapter 5 of the Framework for Automated Driving System Testable Cases and Scenarios.[20]

As a part of the test program, you may like to assess the feature's performance under diverse but relevant roadway, environmental, and object conditions. You may also need to test under varying traffic volume and in the presence of diverse road users. The ADS and roadway stakeholders can play unique roles in the collaborative design of test scenarios.



The ADS stakeholders may broadly outline the role of the ADS-equipped vehicle, safety operator, and expected behavior of the ADSs within the defined scenario. You may also define the parameters and assumptions of the ADS-equipped vehicle under test. You may specify the role of the test operator. The safety operator may need to monitor the environment and take over the dynamic driving task (DDT) either willingly or when prompted by the ADS. Finally, you identify the intended behavior of the ADS under the designed test scenario. This allows you to make a judgement of risks involved in test execution.

Scenario Example 2 – The baseline test scenario for a Work Zone Navigation feature is conducted in a controlled environment. In this scenario, the test operator drives the vehicle at 45 mph, and activates the SAE Level 4 system before entering a construction zone with a lane shift. The test operator cannot provide manual inputs to the vehicle accelerator, brake, or steering wheel, if present. Figure 6 demonstrates the baseline test scenario, in which a lane shift is designated using construction barrels. IOOs and ADS developers may choose to model the scenario first in simulation and then transition to a controlled environment testing.

[20] NHTSA (2018). "A Framework for Automated Driving Systems Testable Cases and Scenarios."` Available at https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf Accessed September 2021.

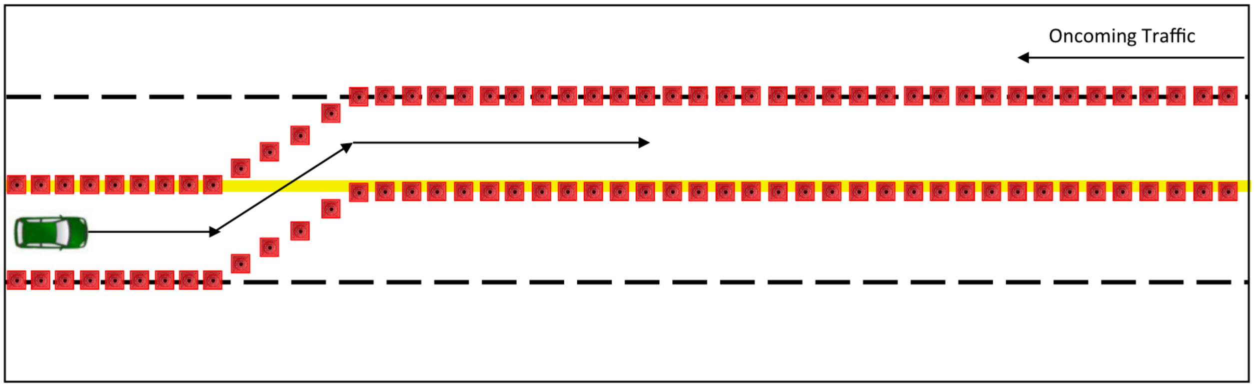


Figure 6. Graphic. Scenario 2: Work Zone Navigation Feature Baseline Test. Construction Barrels are Used to Denote Shifted Lanes.

Source: *Federal Highway Administration.*

The roadway stakeholders can help identify relevant test sites and aid in the definition of environmental conditions and expected behavior of other roadway users within a test scenario. You may also outline the state of Objects (debris, barrels, stop signs, cones, etc.) relevant to the ADS feature's performance in the test scenario. When testing on public roads you may have low control over the observed objects or the ability to acquire information from observed entities.

Finally, the ADS and roadway stakeholders may collaboratively determine other relevant Roadway and Environmental elements that impact the ADS feature performance. For the Roadway, this may include information about its design characteristics, geometry, edges, or traffic control devices. For the Environment, this may include information about atmospherics, road-weather, or connectivity elements relevant to the test.

Scenario Example 3 – Table 4 defines the state of Roadway – Traffic Control Devices in the baseline test scenario used for Work Zone Navigation feature. Refer to figure 6 for a visual representation.

Table 4. Scenario Example 3: Define the State of Roadway for Traffic Control Devices.

Signing / Marking	Work Zone Ahead Sign Reduced Speed Limit (45 mph)
Pavement Marking Type	Solid White and Barrels
Pavement Marking Condition	Retro-reflectivity of pavement markings are degraded, other aspects meet or exceed recommendation
Pavement Marking Color	Yellow and White mentioned as above. Acceptable per NIST Reference
Pavement Marker Width	4-6 inches

Such a categorical identification of ADSs, Roadway, Environment, and Object parameters allows for the conception of parameterization of test programs.

When testing on public roads, your ability to define and control such parameters is limited. In these settings, you are encouraged to identify both parameters relevant to the ADS feature's performance and their expected values. As you execute testing, you may record the observed values of the parameter for each test run of a particular scenario. This information forms the basis of test coverage analysis that may be conducted when testing on public roads. This method allows stakeholders to benefit from the dynamism of public-road testing, while assessing the robustness of ADS feature's performance. You may seek to strategically test under varying environments to improve test coverage and feature robustness. Test coverage analysis may form a part of the quality requirements of a test program.

Testing and evaluation conducted in simulation or controlled environment offers both ADS and Roadway entities an additional degree of control on variation of relevant parameters. The ADS developers and IOOs may collaboratively define parameters of interest and vary the values under simulation. When testing a lane keeping assistance feature performance in simulation, the IOOs and ADS developers may identify the importance of pavement marking parameters, such as color, type, retro-reflectivity, quality, etc. The ADS and IOO entities may collaboratively model these elements. Next, they may run simulations by varying these parameters and identify impact on ADS performance. The simulations can be later validated collaboratively either in a controlled environment or an identified stretch of public roads.

Data Definition

Finally, stakeholders can collaboratively define a Data Management Plan (DMP) to capture the data facets for testing and evaluation. A DMP is a written document that describes the data you expect to acquire or generate during the course of testing; how you will manage, describe, analyze, and store the data; and what mechanisms you will use at the end of your test to share and preserve your data[21]. Table 5 summarizes the key facets of a DMP. You may use this plan to track data activities through the Test Execution and Post-Test Phase. (See Appendix B – Summary of ADS/Roadway Data Sources.)

Table 5. Test Definition: Summary of a Data Management Plan.

Data Aspect	Sub-Topic	Comments
Collection and Documentation	Generation	Identify data sources and data needs
	Acquisition	For data sources in the program, identify intrinsic and extrinsic data acquisition methods to satisfy needs
	Processing	Define raw data processing methods and identify stakeholders responsible for this activity
	Organization	Define data organization techniques used in test program
	Quality Requirements	Define data quality requirements to meet defined evaluation criteria needs
Data Storage and Sharing	Storage	Define data storage methods used in test program
	Sharing	Define data sharing among stakeholders
	Preservation	Define protocols and responsibilities for long-term data storage

[21] Stanford Libraries (nd), *Data Management Plans.* https://library.stanford.edu/research/data-management-services/data-management-plans

The DMP also focuses on identification of data sources relevant to the testing and evaluation. The data sources may come from both the ADS vehicle and relevant roadway, user, and environmental elements. You may need to capture data from these sources using the embedded sensors or via an external sensor package. These sensors may capture live data or provide a static snapshot of the elements of interest. An example of Arizona's Institute of Automated Mobility (IAM) consortium project[22] that leverages data from ADS and roadway stakeholders to advance the safety, science, and policy associated with ADSs is discussed in the callout box.

Arizona IAM Consortium Collaborative Data Sharing

Arizona's IAM consortium is leveraging existing infrastructure to collect performance data on public roads. The research relies on a low data ask from collaborating partners. This may encourage greater openness and participation from ADS stakeholders.

Scenario Example 4 – Table 6 outlines some data sources for Work Zone Navigation feature assessment, and Appendix A has more information regarding the taxonomy for the data sources.

Table 6. Scenario Example 4: Identification of Data Sources for Work Zone Navigation Feature Assessment.

Data Source	Parameter	Comment	Data Needs
ADS Vehicle[23] / Sensing Unit / State Information	GNSS Location	Live source, inherent to ADS Vehicle	Separate reference for location outside of full localization, may replace with independent GNSS
World[24] / Objects / Other Objects /Non- Roadway Users	Work Zone Barrel – Location	Static information, Surveyed at start of test	Establish object locations for all evaluation criteria

The ability to collect and capture appropriate data elements is an important facet of collaboration, even in the simulation domain. A commonly asked question about ADS testing and evaluation is "How many miles of testing is required to develop an ADS?" Many ADS and roadway stakeholders have collaborated in an attempt to address this question by defining a wide spectrum of scenarios and using simulation tests on the various scenarios. However, it is important to investigate the scope and data needs from simulation testing and use the simulation results to guide further verification of ADSs before carrying out physical testing (controlled or public road). In a simulation environment, the data collected from some sensor modalities capture the World around the ADS Vehicle. Combining these data with the localized data of the vehicle may provide useful data for ADS/roadway entities. The ADS developers working collaboratively with IOOs can verify the vehicle and driving environmental models to be used during simulation testing. The models need to be built with enough fidelity to facilitate data acquisition that can satisfy outlined goals.

[22] https://www.azcommerce.com/big-ideas/automated-vehicles/

[23] See Appendix A, Figure 12 in this Framework for Taxonomy

[24] See Appendix A, Figure 15 in this Framework for Taxonomy

Definition of Test Success

The participating stakeholders can define the success criteria to evaluate the collaborative test program. Success factors for the testing and evaluation may be technical and organizational in nature.

The technical success factors depend on the expected outcome of the ADS feature's performance in the defined test scenarios. Evaluation metrics can be developed from a joint understanding of the feature's design intent and expected outcomes under testing. Additionally, you may establish criteria on these metrics to determine acceptability of test performance. Quality requirements can be established based on the evaluation and validity criteria.

For ADS stakeholders, success may depend on whether adequate performance data for the ADS feature were gathered during the test. The data may allow for progress of the feature along the product development cycle, and hence an improved technological readiness. Additionally, ADS stakeholders may obtain valuable user-interaction feedback by public road testing. When testing in controlled environments, the test success depends on the ability to collect correct data variables that may be used to determine the feature's performance. In a simulation setting, the test can be deemed successful if the model allows for preliminary evaluation of performance, and hence the product development cycle to progress to the next stage.

> **Success Factors for ADS and Roadway Entities**
>
> Success factors may vary for each stakeholder. For Roadway entities, this may depend on factors such as community acceptance, occurrence of safety issues, and community use of deployed technology. For ADS entities, these factors may depend closely on technical achievements during testing. It is important to find a common definition of success through collaborative conversations.

For roadway stakeholders, success may depend on safe execution of public roadway testing. The public road testing may also facilitate increased organizational readiness and enable smoother incorporation of ADS-equipped vehicles on the Nation's roadway system. When roadway stakeholders collaborate with ADS entities in simulation methods, the definition of success is more technical in nature. The roadway entities may gain knowledge and information that helps them glean macroscopic and microscopic traffic behavior insights when ADS-equipped vehicles are integrated on our Nation's roadways. The findings from this testing and evaluation may inform transportation policy development. When testing in a controlled environment, the roadway stakeholders can evaluate their program's success based on their capability to structure collaborations at the organizational level. Table 7 outlines the facets of success for ADS/roadway stakeholders under the three test methods.

Table 7. Measures of ADS/Roadway Test Success Across Test Methods.

Stakeholders	Test Method		
	Simulation	Controlled Environment	Public Road
ADS	Technical performance of ADS system	Technical performance, Organizational collaboration	Technical performance, Organizational collaboration, User-interaction feedback
Roadway	Technical feedback for proposed solutions	Technical feedback, Organizational readiness and collaboration	Technical feedback, Organizational readiness, Public acceptance

3.2.3 Outputs and Considerations for the Test Definition Phase

On completion of this phase, you will have a defined Test Plan that includes test scenarios that evaluate ADS feature performance against outlined objectives. The Test Plan outlines the roles of the ADS-equipped vehicle, other roadway users, and state of relevant roadway and environmental elements for each test scenario. Next, you may also obtain a DMP that allows you to track data activities during the Test Execution and Post-Test Phases. Finally, you will develop a definition of test success by review of appropriate metrics and criteria. These form an essential part of the test quality management plans that facilitates Test Execution.

You may review the Test Plan, the DMP, and Quality Plans developed in the Test Definition Phase to determine if the collaboration can progress to the next phase.

Decision Factors include**:**

- Does the Test Plan comprehensively address the goals and objectives of the collaboration?
- Are the test scenarios adequately defined with regards to the roles of ADS and relevant Roadway and Environment elements?
- Is the level of test effort commensurate with the outlined stakeholder collaboration assessment findings?
- Do the outcomes from execution of the Test Plan achieve outlined benefits?
- Is there a clear definition of evaluation metrics? Are evaluation criteria for ADS/roadway performance established? Are test validity criteria established?
- Does the DMP inform relevant data activities in the Test Execution and Post-Test Phases?

3.3 Test Execution Phase

In the Test Execution Phase, you execute testing as defined in the Test Plan. In this phase, you will execute both technical and data facets of the collaborative ADS/roadway testing and evaluation. Collaboration among the diverse stakeholder groups is important during execution and monitoring activities of the testing to satisfy outlined requirements.

Table 8 documents the objectives, activities, and expected outputs that can be obtained by completion of the Test Execution Phase. Use this summary table as a model to obtain additional information on an activity of interest.

Table 8. Summary of Test Execution Phase.

Test Execution:	Details
Objectives	• Execute testing per the defined Test Plan. • Monitor and adjust program direction to meet defined goals, and communication on an ongoing basis.
Inputs	• Test Plan, DMP, Quality Plans. • Permits and insurance.
Key Activities	• Operational collaboration. • Ongoing communications. • Monitor and adjust program direction.
Outputs	• Collaborative ADS/roadway testing and evaluation data. • Deviations in ADS performance and test execution.

3.3.1 Overview of Test Execution Phase

ADS and roadway stakeholders may benefit from a review of the following key activities involved in the Test Execution Phase. The activities are grouped under three key themes.

- Operational Collaboration:
  - Test Logistics – Stakeholders review established Test Plan, identify roles, and plan support for the execution. They review compliance with permits and requirements and conform access to test sites. Stakeholders may collaboratively configure the test environment for the ADS-equipped vehicle as described in the Test Plan.
  - Test Execution – Stakeholders set up data collection methods from sources outlined in the Test Plan. They execute testing and collect ADS performance data under operating conditions outlined in the Test Plan.
- Ongoing Communications – Stakeholders communicate internally with the established multi-disciplinary team on a periodic basis. They may also communicate with external parties, per the established public communications plan.
- Monitor and Adjust Program Direction – Stakeholders monitor compliance of test execution against requirements established in the Test Plan, Quality Plan, and DMP.

Figure 7 demonstrates a sequence of execution of these activities. First, stakeholders may review the test logistics needed for the execution. Next, those stakeholders involved conduct Test Execution per the defined plans. The test stakeholders will conduct ongoing communications and continue to monitor and adjust program direction in parallel with Test Execution. The test stakeholders will rely on status information from the Test Execution activity to provide direction to the test program.

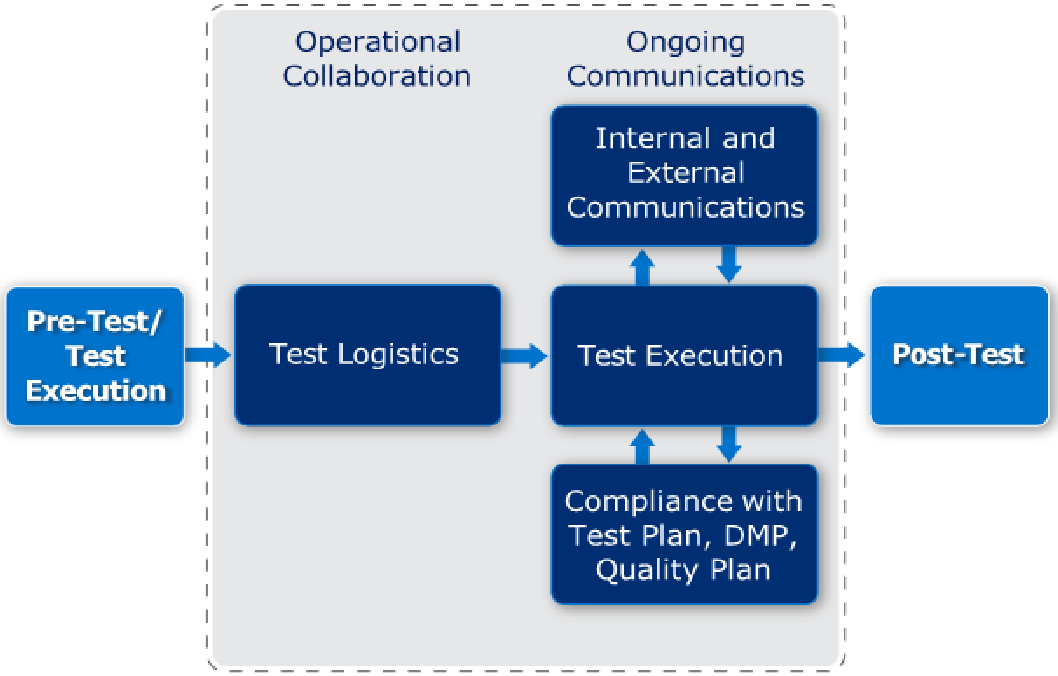


Figure 7. Graphic. Activities in the Test Execution Phase.

Source: *Federal Highway Administration.*

3.3.2 Key Activities within the Test Execution Phase

<u>Test Logistics</u>

In the Test Execution Phase, the ADS and roadway stakeholders review the developed Test Plan. The Test Plan outlines the test program and defines roles for the ADS and roadway stakeholders. The stakeholders can identify resources needed to execute assigned roles within the planned time duration.

When testing on public roads, the ADS stakeholders are responsible for ensuring that they meet requirements outlined in the established permit process. These requirements may relate to the need for safety operators and the presence of a certificate of insurance on file with the permit authority.

When ADS/roadway testing is executed in controlled environments, the entities may need to determine the logistics of three-way collaborations. The three entities are the ADS stakeholder, relevant roadway entity, and a controlled environment operator that facilitates the testing. First, they need to identify proving grounds with appropriate infrastructure that can satisfy the goals of their test program. Next, both the ADS and roadway entities need to ensure that logistics and coordination can occur between the three independent stakeholders that can facilitate safe and efficient execution of outlined testing and evaluation. The ADS and roadway stakeholders may need to become familiar with the proving ground facility operating guidelines and safety requirements that govern the test facilities' use. There may be additional logistics needed around scheduling and personnel availability and support needed for efficient test execution.

Next, the stakeholders can collaborate to configure both the ADS-equipped vehicle and the test sites, per characteristics needed to execute testing outlined in the program.

The roadway stakeholders, by virtue of the knowledge of the roadway system, can aid in the selection of test sites appropriate for the design intent of the test program. The Test Plan may define roadway, environmental, and road-user characteristics needed for successful execution of testing. Roadway characteristics may include the presence of design elements such as ramps or a defined roadway curvature. It may also include the presence of traffic control devices (signs, markings, etc.), and other relevant traffic operation elements (variable traffic signage, etc.) as stated by the Test Plan. The Test Plan may also define the environmental conditions needed for the test. This may include a preferred time of day, presence of illumination, defined atmospheric conditions, or existing road-weather conditions such as, standing water, ice on the roadway, etc.

The ADS stakeholders can set up the ADS feature hardware and software configurations, as defined in the Test Plan. The stakeholders may also review software and personnel support needs required for a smooth execution of the on-road testing and evaluation.

The stakeholders may create a Test Logistics Plan that allows for identification and transport of equipment and resources needed for the test. Execution of some tests may require coordination with other agencies such as state police, DOT maintenance, and emergency responders to maintain roadway safety and cause least disruption of public roadways.

Test Execution

The Test Plan and DMP identify ADS and roadway data sources from which data may be acquired to meet evaluation needs. Before any testing is executed, it is important to review your ability to acquire data from these sources.

Acquiring a high-fidelity data acquisition system may be a first step toward satisfying the data needs of a test plan. The data acquisition system must be flexible and accommodate a wide variety of data sources, both from the ADS-equipped vehicle and relevant infrastructure elements. For the ADS-equipped vehicle, a robust in-vehicle data acquisition system (DAQ) may be used to record raw sensor data and internal vehicle data needed to satisfy evaluation metrics. The same DAQ may be used to acquire data from other sources (roadway, environmental, roadway-users, etc.) relevant to the testing and evaluation. However, when live acquisition of such data is infeasible, it may be integrated externally later. The DMP is your guiding document, as it outlines the strategy for data acquisition through the test execution phase.

Scenario Example 5 – Table 9 details some of the data acquired in the testing and evaluation of a Work Zone Navigation feature. Some critical data sources for this example are the ADS Vehicle, barrels, and atmospherics. Based on the data needs specified by the evaluation metrics, only a subset of the vehicle’s sensors and relevant World variables are collected to satisfy test goals and objectives.

Table 9. Example Test Data Logged During a Work Zone Navigation Feature Performance Evaluation Test Scenario.

Data Source	Parameter	How to Collect	Data Needs
ADS Vehicle – Sensing Unit – State Information	GNSS Location	DAQ connected to ADS INS/GNSS via splitter (ethernet)	Separate reference for location outside of full localization, may replace with independent GNSS
World – Objects – Other Objects – Non-Roadway User Obstacles	Work Zone Barrel – Location	GNSS survey by DOT operations	Established object locations for all evaluation criteria
Environment – Atmospherics – Essential Climate Variables (ECVs)	Precipitation	Measured at nearby weather station by DOT operations	Relevant parameters to ADS performance

The stakeholders may then execute the test. The focus during the execution phase is on efficient collection of ADS/roadway performance data, under operating conditions outlined in the Test Plan.

The test execution team may maintain a data log to capture the ADS/roadway performance. The data log register may be designed to be easy in comprehension and capture specific elements such as test run number, time of day, ADS disengagement reasons, and safety operator commentary. The test execution team may also periodically review the data acquired by the DAQ. The data log can aid in establishing a correlation between observations and acquired data. The stakeholders may observe performance challenges during testing of ADS vehicles. The ADS stakeholders may benefit from the presence of software support staff to analyze collected data and change parameters on the fly to promote efficient use of test facility (controlled environment or public roads) and simulation software and conditions.

<u>Ongoing Communications</u>

During the Test Execution Phase, the stakeholders may benefit from periodic communication within the collaboration. The stakeholders may establish inter-organizational execution status reports to inform collaborators of testing activities, accomplishments, or bottlenecks. These reports can highlight any support needed to resolve identified challenges. The ADS stakeholders can review the collected data and resolve any open action items. The roadway stakeholders can review these status reports to identify support needed for efficient execution of testing.

The collaborators may also seek to inform the public on the status of testing and evaluation, per the established public communications plan. It is critical that messaging is in line with collaborator agreements. A coherent message around the safe testing of ADS vehicles and a recognition of collaborative efforts from ADS and roadway stakeholders may inspire public confidence and enable safe integration of ADS-equipped vehicles on public roads.

Monitor and Adjust Program Direction

The ADS and roadway stakeholders must continually monitor the test program and promote communication between the interdisciplinary teams. The information contained within the execution status reports must be viewed against original test design intent. Such a review allows for early detection of deviations regarding ADS performance and test environment implementation from the Test Plan. Timely identification of deviations in expected test performance can help stakeholders adapt test plans based on observed performance. The test program managers may review the status reports to gain immediate insight into the progress of testing and evaluation. This allows program managers to evaluate if additional resources need to be allocated for completion of the test program within the established deadlines.

Stakeholders can review the test execution data logs and ADS performance data to determine compliance with the Quality Plan. The validity of test runs within a scenario may depend on the state of the ADS, actions of the safety operator, and relevant roadway or environment parameters. The DAQ used during test execution may be able to identify variances to set validity criteria in both ADS performance and test execution. Such test runs may be classified as “fails to meet performance criteria.” The ability to classify and flag when ADSs do not perform as intended automatically after collection of data can help the test execution team identify if a particular scenario needs to be repeated immediately. This can lead to more efficient test execution.

The development, evaluation, and testing of ADS features typically occurs in multiple environments. Features may be first evaluated in simulation, then in closed-track environment, and finally on public roads. Such a multi-faceted approach toward development of ADS features allows for avenues to modify and adapt a test program’s direction throughout ADS testing on closed tracks or public roads.

Scenario Example 6 – In testing the ADS operation in a work zone setup in a controlled environment, the ADS Vehicle may fail to correctly identify traffic barrels used to mark the work zone under adverse atmospheric conditions at night. If the ADS feature is designed to operate under such conditions and fails to do so, the test execution team can classify such observations as not meeting the performance intent. The ADS developer can use this information to improve product development.

Finally, stakeholders may also seek to monitor the data facets of the technical program. The success of the testing and evaluation may depend on the fidelity of data collected and its ability to satisfy needs established by the evaluation metrics. It is also critical to review the data processing methods used to extract insights relevant to the goals of the testing and evaluation.

3.3.3 Outputs and Considerations for the Test Execution Phase

After the successful completion of test execution phase, you obtain ADS test performance data as needed by the Test Plan. The test performance data are acquired and processed in compliance with the DMP. You may also obtain a record of testing to indicate cases where intended performance was not met. These deviations may relate to ADS performance or deviation in test execution.

You may review the quality of test execution in this phase to determine if the activity can progress to the next phase of the test program.

Decision Factors include:

- Does the test execution conform to the requirements enforced in the Test Plan?
- Are data facets of testing and evaluation in agreement with the established DMP?
- Does the quality of test execution conform to requirements established in the Quality Plan?

3.4 Post-Test Phase

In the Post-Test Phase, stakeholders aim to close the collaborative testing and evaluation activity. They review data insights, store data, and discuss any lessons learned from the collaboration.

Table 10 documents the objectives, activities, and expected outputs you may obtain at the end of Post-Test Phase. You may review this summary table as a model to obtain additional information on an identified activity of interest.

Table 10. Summary of Post-Test Phase.

Post-Test:	Details
Objective	• Extract and share insights from testing and evaluation activities. • Conduct project closeout activities to end this collaborative testing and evaluation.
Inputs	• Collaborative ADS/roadway testing and evaluation data. • ADS/roadway performance and test execution not meeting designated performance criteria.
Key Activities	• Data sharing. • Process improvement and calibration. • Lessons learned.
Outputs	• Testing and evaluation data insights. • Lessons learned for future collaborations.

3.4.1 Overview of the Post-Test Phase

ADS and roadway stakeholders may benefit from a review of the following key activities involved in the Post-Test Phase. The activities are grouped under three key themes:

- Data Sharing – Stakeholders review the facets of data storage and sharing as applicable to the collected testing and evaluation data.
- Process Improvement and Calibration – Stakeholders review the process used for the collaboration and identify areas of improvement based on their experiences.
- Lessons Learned – Stakeholders seek to close the collaboration by reviewing lessons learned from the testing and evaluation activity.

Figure 8 outlines the activities conducted in the Post-Test Phase. First, you may review the data storage and sharing facets involved in the collaborative testing. Next, you conduct a review of processes used for the testing and evaluation. Finally, you share lessons learned with involved stakeholders to enable improved future collaborations.

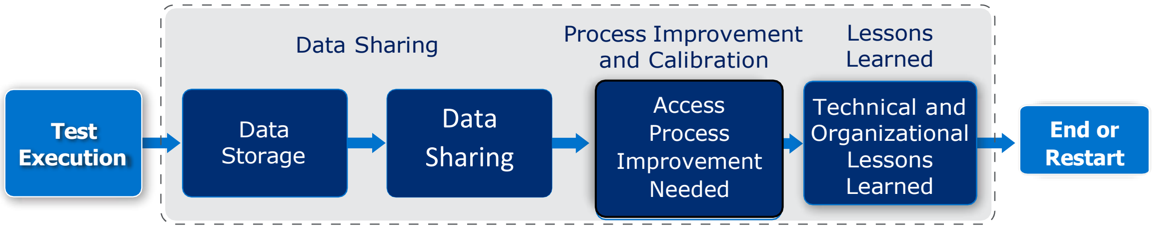


Figure 8. Graphic. Activities in the Post-Test Phase.

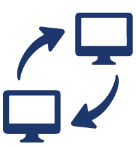
Source: *Federal Highway Administration.*

3.4.2 Key Activities within the Post-Test Phase

<u>Data Sharing</u>

On completion of Test Execution, the ADS and roadway stakeholders may obtain test performance data in both raw and processed form. It is important for both the ADS and IOO stakeholders to be cognizant of the nature of their data requests. The ADS/roadway testing and evaluation programs have the ability to produce vast datasets that need to be managed effectively. A data exchange request made with due consideration to the data needs of the testing and evaluation program helps facilitate increased trust between collaborating entities. The organizations may wish to review their ability to access, use, and store confidential information that may be exchanged during the Post-Test Phase. In the Post-Test Phase, first you seek to store the data in an organized form. Next, you may share test data and insights among relevant stakeholders. You may also seek to implement solutions that facilitate long-term storage and preservation of all relevant data per your established DMP.

The data from testing needs to be stored in an organized fashion to allow for easy retrieval and analysis. Format for the databases used for storage can be such that they describe the data and help identify relationships among the datasets. You may use the test data logs as a reference to indicate relationships among collected data. The format of database can be reviewed to satisfy the stakeholder's information needs as outlined in the DMP.



Collaborating stakeholders may share raw and processed data using necessary access control features available in the selected storage solution. The raw data may be shared only with key stakeholders. Stakeholders may choose to use proprietary processing methods to develop key insights. Proprietary technical information, test plans, quality plans, DMPs may be shared with identified stakeholders on a need-to-know basis. Compliance with the DMP provides stakeholders confidence on the security of proprietary technical and ADS performance data.

Long-term storage of data and maintenance of collected datasets are additional facets that need to be considered in the collaborative testing and evaluation program. The stakeholders can identify entities or personnel responsible for the effort. The storage of data, proprietary processing methods, test hardware, and plans can promote reuse and efficient execution of future test programs.

<u>Process Improvement and Calibration</u>

While some technical performance issues (e.g., not meeting performance criteria, test protocol/procedure issues, data collection issues) are reviewed and addressed during the Test

Execution Phase, the Post-Test Phase offers an opportunity to review these process/technical issues.

Stakeholders can revisit their experiences during each phase of the Framework and identify areas of improvement. They can map their collaboration experiences against original expectations to identify gaps. You may analyze these gaps by asking simple questions, such as:

- Are there any phases that required a larger commitment of resources than was originally planned?
- Are there any phases or steps in the collaboration process that took longer than expected? What were the key reasons for delays?

Stakeholders may seek to improve the collaborative testing and evaluation process continually by accommodating feedback from a wide range of participating personnel. This includes people involved in test planning and execution, legal authorities, and public representation.

<u>Lessons Learned</u>

Finally, stakeholders may seek to wrap up the collaboration by discussing lessons learned from the collaborative testing and evaluation activity. This activity leads to the formal closure of testing and evaluation.

As a part of the lessons learned activity, the stakeholders review if the insights obtained from processed data satisfy the Test Plan objectives. These insights may be presented in the form of a Test Evaluation Report. The stakeholders may identify lessons learned by asking questions such as:

- What was done well as a part of this collaboration?
- What could be improved to facilitate smoother testing and evaluation collaboration?

Collaborative ADS and roadway testing and evaluation is a new field. The review may lead to the identification of organizational issues that hinder collaboration. It may also lead to the identification of issues such as lack of expertise, limited resource availability, difficult legal agreements, or infeasible data collaboration requests. The review may also identify challenges and ingenuity of stakeholders that lead to the resolution and achievement of common goals.

Take the example of project closeout activities between the ADS developers and city authorities, who collaborate on testing and evaluation of the Traffic Sign Recognition Feature. The stakeholders discuss findings from this testing that may improve the system performance. The ADS developers may share the environmental conditions under which the Traffic Sign Recognition algorithm performance exceeded evaluation criteria. Similarly, ADS developers can share insights that help city authorities determine the location/orientation of traffic signs for optimal detection performance. Finally, the ADS developers and city authorities may work to maintain established relationships to execute future testing.

3.4.3 Outputs and Considerations for Post-Test Phase

On completion of Post-Test Phase activities, stakeholders may judge the success of the collaboration. The stakeholders may review defined Test Success Criteria to determine if outlined goals have been met per defined metrics.

It is also critical that the lessons learned and process improvement findings from this activity are shared among stakeholders to assist in the planning and execution of collaborative testing activities in the future.

You may review the outputs in the Post-Test Phase to determine if the testing is complete.

Decision Factors include:

- Does the collaborative testing and evaluation meet objectives outlined in the Pre-Test Phase?
- How does the collaborative test activity rate per the test success criteria defined in the Pre-Test Phase? Does it satisfy stakeholder expectations?
- Are the data insights adequate to satisfy the collaboration goals of each stakeholder?
- Are there any lessons that may be shared to improve stakeholder experience during future collaborative ADS/roadway testing and evaluation?

4. Next Steps

This Framework aims to create a path toward encouragement of ADS and roadway stakeholders to come together to create a collaborative test program, but the work is not fully completed. This project included broadly disseminating, educating, and encouraging use of this Framework. Actions moving forward include dissemination of outreach materials, use of the Framework by related projects, and interaction with stakeholders to understand how improvements to the Framework may be incorporated.

Appendix A. ADS/Roadway Language and Taxonomy

A review of existing work in the joint ADS/Roadway testing and evaluation has highlighted the need to foster an increased conversation between entities in the ADS technology domain and the Infrastructure domain. The first step to fostering collaboration is to help ADS developers and infrastructure entities build a functional understanding of each other's technical space. It is from such an understanding that a joint vision of ADS/Roadway testing and evaluation activities can be developed.

This appendix summarizes the language developed to enable both ADS developers and infrastructure owners exchange ideas in a generic fashion. The language described here is functional, modular, and generic, which facilitates the exchange of ideas while protecting proprietary information. The "ADS Vehicle" is engaged in a bi-directional exchange of information with the World (Figure 9). The ADS-equipped vehicle gathers information about the World and performs an action. The ADS's action influences the World.

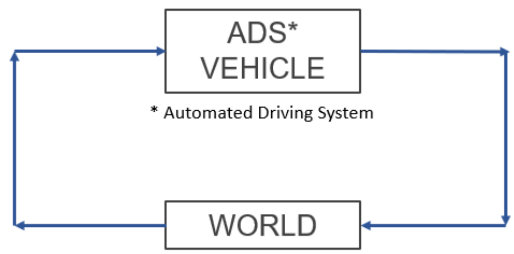


Figure 9. Graphic. Joint ADS/World System.

Source*: Federal Highway Administration*.

This appendix develops this idea further and provides you with information to help develop a functional understanding of the ADS and World elements which engage in information exchange.

Elements of ADS/World Interaction

The ADS Vehicle can be described as a functional combination of three key modules: (1) Sensing Unit(s), (2) Processing Unit(s), and (3) Vehicle Platform (Figure 10). Most ADSs rely on a suite of sensors, which includes cameras, radar, LiDAR, Ultrasonic, V2X Sensors to gather information about the World. The ADSs then ingest this information and use computing hardware and software to build a model of the World. The ADSs then process this information to make decisions that satisfy its mission objectives. The ADSs then send the decision to the vehicle platform in order to execute an intended action.

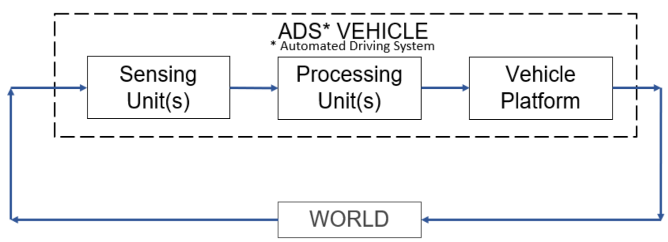


Figure 10. Graphic. ADS Vehicle with Three Functional Modules.

Source: *Federal Highway Administration.*

All elements in the World surrounding an ADS Vehicle may be classified into three key modules: (1) Roadway, (2) Environment, and (3) Objects (Figure 11). For an ADS Vehicle to operate

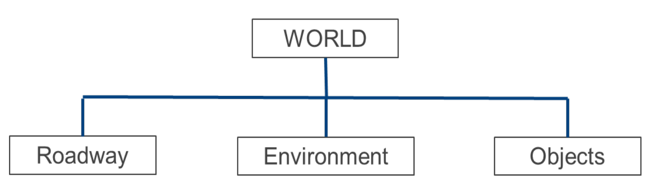


Figure 11. Graphic. World with the Three Categorical Elements.

Source: *Federal Highway Administration.*

in the World, it seeks to absorb both subjective and objective information about all elements contained within these categories.

Modular Description of ADS Elements

The ADS developers may choose to describe their systems in a generic fashion. Figure 12 provides an overview of the functional elements involved in the three modules.

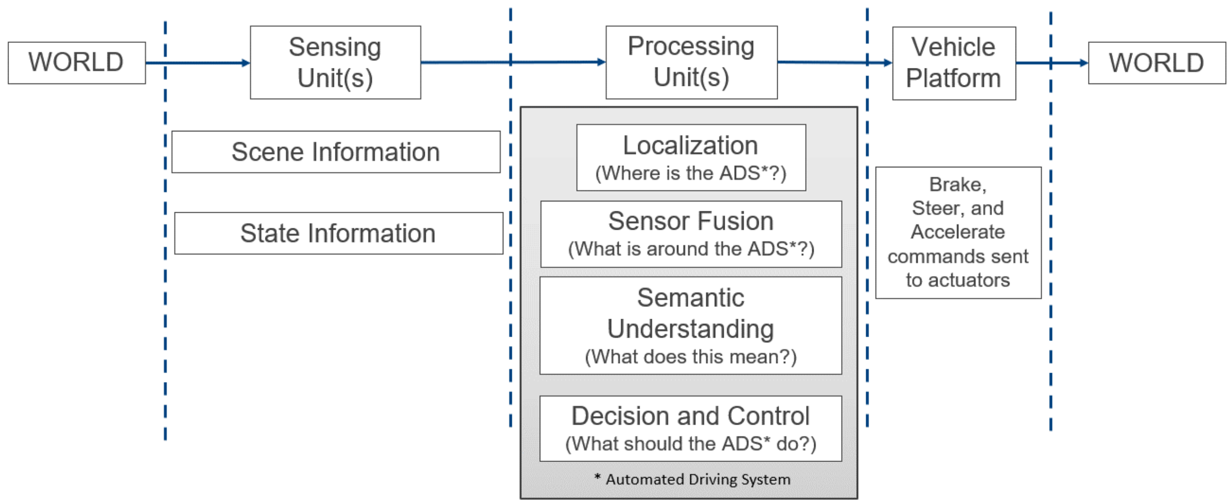


Figure 12. Graphic. An Overview of Various Functional Elements of the ADS Vehicle.

Source: *Federal Highway Administration*.

The field of ADS development is still nascent. There exists a wide variety in technical implementation of these functional modules. These functions may be achieved in a categorical manner (traditional) or all at once (artificial intelligence and deep learning techniques). The proposed language focuses on functional aspects of these ADS units, and admittedly does not intend to cover variations that may arise due to diverse technical implementation choices.

The ADS developers may choose to describe these systems in a level of detail deemed necessary to meet collaborative testing and evaluation objectives.

Sensing Units

An ADS may use multiple sensing units to gather information about all relevant World elements. The ADS developers may describe these sensors generically as modules, which detect changes in environment by observing and ingesting scene and state information.

Table 11 outlines types of Scene and State information which may be observed by a sensing unit for each type of World element. Figure 11 describes the three elements which constitute the World.

Table 11. Information gathered by a Sensing Unit.

Category	Information Types
Type of Scene Information	Shape, Size, Pose, Features, Unique Information, Subjective Features
Type of State Information	Location, Orientation, Form, Motion, Condition

Such a generic description of sensing units allows for the protection of proprietary information, while providing the roadway entities adequate information on World elements which may influence the ADS performance.

Processing Units

The role of the processing unit of an ADS is to filter, assess, and process the information gathered by the Sensing Unit for relevance and make sense of the World in which the ADS Vehicle operates. Broadly, the functions performed by the ADS Processing Units can be described as stated below:

- Sensor Fusion: Ingest, filter, and fuse information from varied sources of sensing unit(s) to help answer the question *What is around the ADS Vehicle?* The sensor fusion unit(s) may be tasked to play the following roles in an ADS Vehicle:
  - Filter raw data obtained from data sources.
  - Fuse sensor data streams.
  - Detect, associate and pre-classify objects.
- Localization: Locate all entities in the World and ADS Vehicle with respect to a common frame of reference. This helps answer the question *Where is the ADS Vehicle?*
- Semantic Understanding: Ingest information from sensor fusion and localization blocks. This helps answer the question *What does this situation mean?*
- Decision and Control: Based on the semantic understanding of the situation *What can the ADS Vehicle do to meet its objectives?*

For ease of comprehension, the roles of a vehicle's processing unit can be divided into three layers, as outlined in Table 12. The ADS may conduct these functional roles in a fused manner.

Table 12. A Model to Comprehend Functions Performed by the ADSs' Processing Units.

Functions Performed by Each Module at Designated Layers	Processing Unit(s)		
	Localization	Semantic Understanding	Decision and Control
Operational Layer	Determine in-lane position of ADS Vehicle and other objects.	Perform object classification. Estimate motion. Understand roadway characteristics.	Longitudinal and lateral motion plan. Vehicle stabilization assessment. Fault Monitoring.
Tactical Layer	Determine if ADS Vehicle is in correct lane to meet objectives. Determine position of other objects in non-travel lanes	Model and predict stationary and dynamic environment around the vehicle. Perform situation analysis.	Behavior planning. Trajectory generation. Path Planning.
Strategic Layer	Determine appropriate route and waypoint information for ADS Vehicle to meet defined objectives.	Model road network and traffic flow analysis.	Global Route Plan. Navigation – Waypoint generation.

Vehicle Platform

While there are a wide range of technical implementations of the vehicle platform, the platform described in this research primarily houses the propulsion, brake, and steering actuators. It also provides an interface to the ADS's decision and control module. Secondly, the vehicle platform houses vehicle state and condition sensors, which feed relevant information to help the ADS decide its capabilities. The vehicle platform receives commands and executes trajectory demanded by the ADS's Processing Unit(s).

Modular Description of World Elements

The World Elements can be categorized into the three modules: (1) Roadway, (2) Environment, and (3) Objects, as noted earlier. An Infrastructure entity may use this classification structure to generically describe their roadway system to the level of detail necessary to facilitate ADS/roadway collaboration.

The Roadway module can be further divided into three subcategories: (1) Roadway Design Information, (2) Traffic Control Devices, and (3) Roadway Operations, as shown in Figure 13. This classification provides a clean approach to distinguish between the design aspects of a roadway, the devices used to regulate vehicular traffic flow, and the information necessary to maintain efficient operations.

Figure 13 outlines elements housed within the Roadway Design and Traffic Control Devices categories. Table 13 provides a brief list of parameters which may be used to describe a roadway system.

Table 13. Parameters within the World – Roadway Category.

Category	Sub-category	Parameters
Roadway Design Information	Roadway Types	Type of roadway, number of travel lanes, roadway width, lane width, access control
	Roadway Surfaces	Surface type, color, surface friction
	Roadway Edges	Shoulder type, shoulder presence, width
	Roadway Geometry	Radius of curvature, grade, rate of change of grade, super-elevation rate
Roadway Operations	Active Traffic Management Signing	Location, information type, roadway restrictions, dynamic design
	Variable Speed Limits	Location, dynamic design (speed, time of day, etc.)
	Managed Lanes	Location, dynamic design (toll info., travel time information, vehicle restrictions, etc.)
Traffic Control Devices	Signing	Priority, required action, condition type (permanent, situational, temporary)
	Marking	Type, quality, color, required action
	Traffic Signals	Location, required action, spat

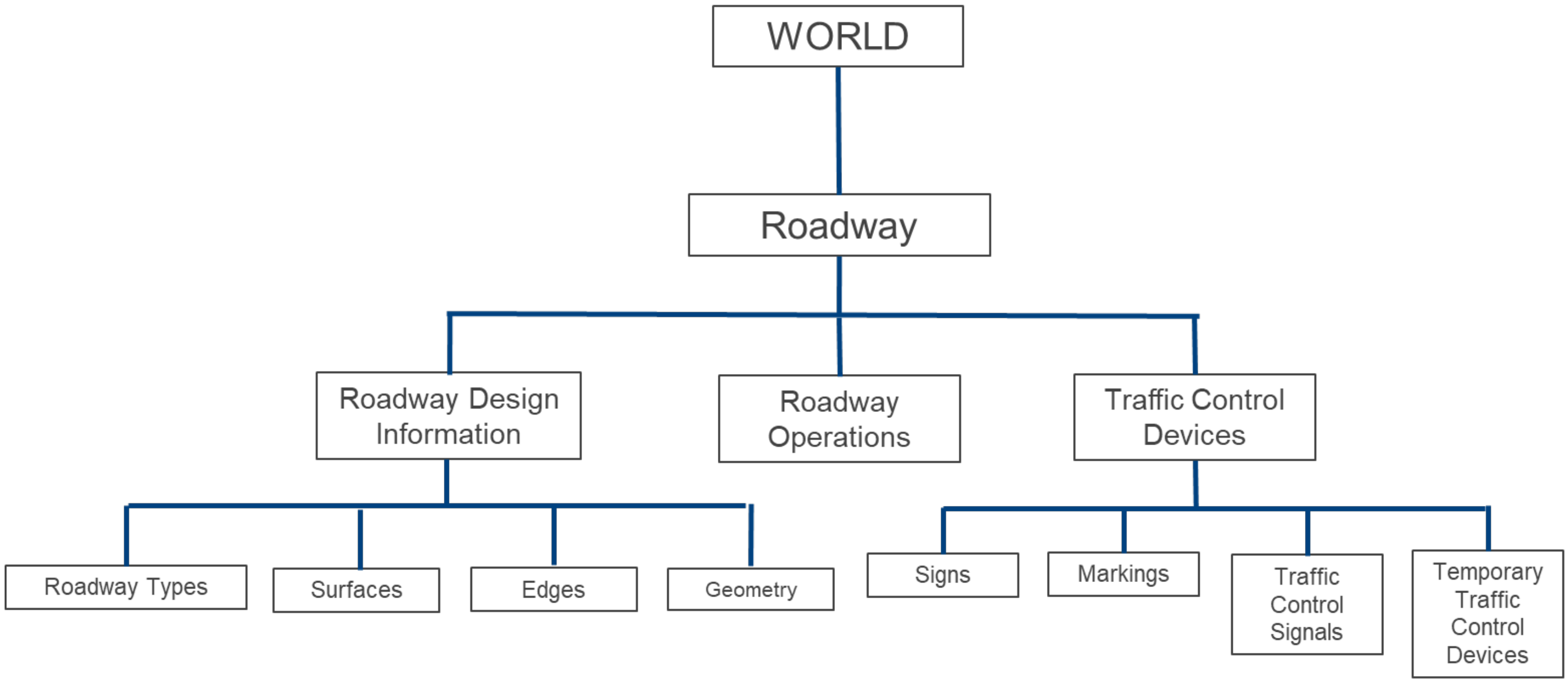


Figure 13. Graphic. A Categorization of Roadway Elements within the World.

Source*: Federal Highway Administration*.

The environment module can be divided into three categories: (1) Atmospherics, (2) Road-weather, and (3) Connectivity. Table 14 provides a brief list of parameters which may be used to describe the environmental elements observed during ADS's deployment in the World.

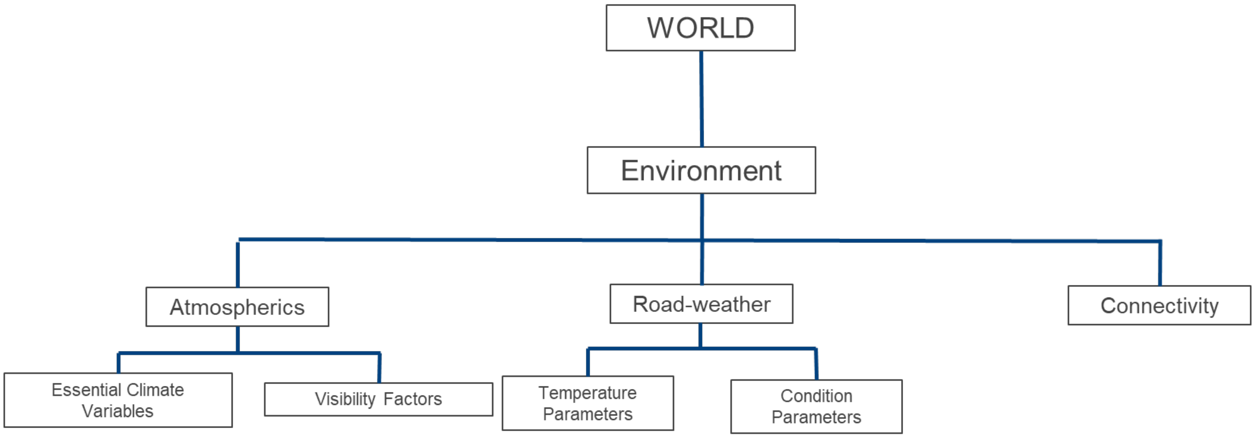


Figure 14. Graphic. A Categorization of Environment Elements within the World.

Source: *Federal Highway Administration.*

Table 14. Parameters within the World – Environment Category.

Category	Sub-category	Parameters
Atmospherics	Essential Climate Variables	Air temperature, humidity, wind speed, wind direction
	Visibility Factors	Distance, illumination factors
Road-weather	Temperature	Pavement temperature, pavement freeze point and moisture, subsurface temperature and moisture, water level sensor
	Condition	Black ice, flooded roads, snow, standing waters, dry
Connectivity	V2X, GPS, or Cellular	Signal strength, GPS accuracy, time delay, 3D map accuracy

The objects which the ADS Vehicle encounters in the World can be broadly categorized into 1) Roadway Users and 2) Other objects. Roadway Users form the bulk of the objects observed by the ADSs while driving on roadways. The "Other Objects" category is used to functionally identify all non-roadway users observed by the ADS Vehicle while operating on a roadway. Table 15 provides a brief list of parameters which may be used to describe objects observed by the ADSs operating in the World.

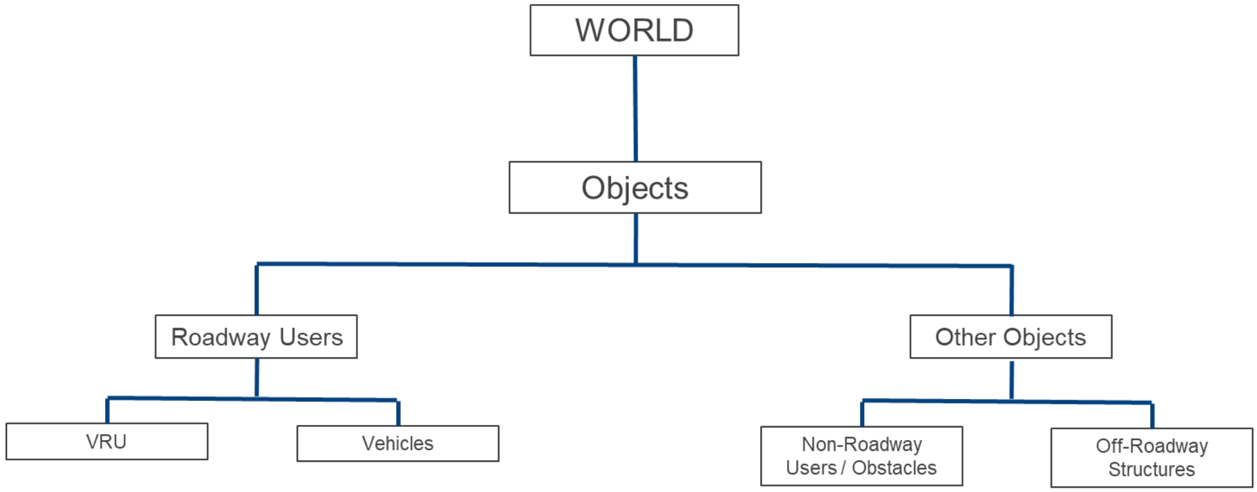


Figure 15. Graphic. A Categorization of Objects within the World.

Source: *Federal Highway Administration.*

Table 15. Parameters within the World – Objects Category.

Category	Sub-category	Parameters
Roadway Users	Vulnerable Road Users (VRUs)	Object type – pedestrian, bicyclist, motorcyclist, etc.
	Vehicles	Object type – passenger vehicles, commercial vehicle, etc.
Other Objects	Non-Roadway Users/Obstacles	Object type – debris, construction equipment, animals, etc.
	Off-Roadway Structures	Object type – buildings, post-boxes, guardrails, etc.

Compatibility with Other Language and Taxonomies

- Demonstrate harmonious co-existence with SAE J3016[25], UL4600[26], SAE Automated Vehicle Safety Consortium (AVSC) operational design domain (ODD) Framework[27], NHTSA Testable Cases[28].
- What other documents may stakeholders use to facilitate communication and collaboration?

[25] SAE Int. (2021). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. Society of Automotive Engineers International, J3016_202104. Available at https://www.sae.org/standards/content/j3016_202104/, accessed September 2021.

[26] Underwriters Laboratories. ANSI/UL 4600 is the Safety Standard for the Evaluation of Autonomous Products. UL4600 addresses safety principles and processes for evaluating fully autonomous products requiring no human driver supervision. https://ul.org/UL4600

[27] SAE AVSC ODD Framework: AVSC00002202004. https://avsc.sae-itc.org/principles-02-5471WV-44074RU.html?respondentID=25427355#

[28] NHTSA DOT HS 812 623 (2018). https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf

Appendix B. Summary of ADS/World Data Sources

ADS and roadway testing requires a range of data for system evaluation and performance. The stakeholders may have a clear idea and be able to differentiate between essential and trivial data, such as the amount of data collected from the ADS-World is huge and a considerable portion of the data is redundant. These data can be filtered depending on factors such as intention of the test, storage restrictions, already available and established data, and evaluation matrix.

The two main sources for obtaining data are:

- ADS Vehicle.
- World elements (Roadway, Environment, Objects).

These two sources provide different data, which can be merged to evaluate the joint ADS/Roadway system performance.

ADS Vehicle Data

Stakeholders may collect three forms of data from the ADS Vehicle per the requirements enforced by their test programs. Figure 16 illustrates possible data access points from an ADS Vehicle.

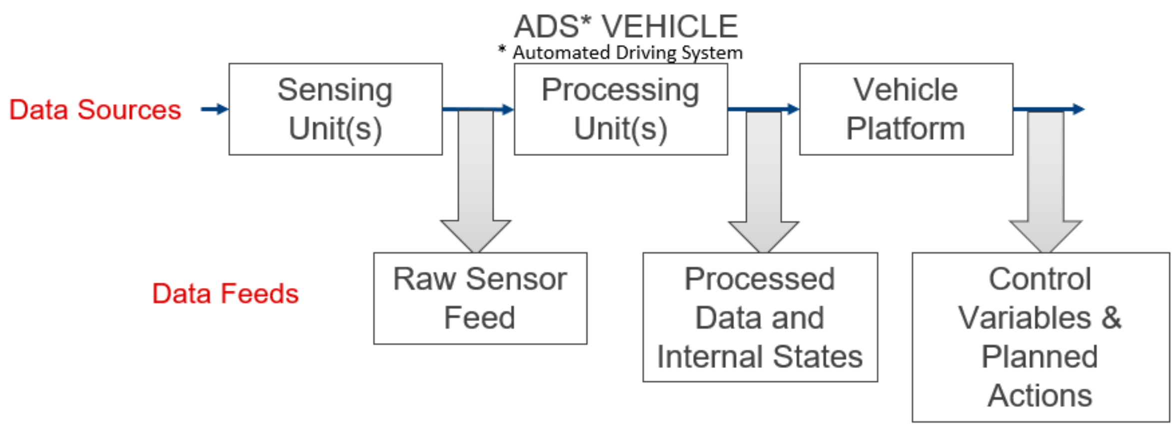


Figure 16. Graphic. Data Access Points from the ADS Vehicle.

Source: *Federal Highway Administration.*

The paragraphs below outline salient features of the variety of data which may be collected from the ADS Vehicle.

- Raw Data: these data are obtained directly from the sensors with no or minor processing. They can be used for a variety of purposes, such as performance evaluations (fundamental or algorithmic). In absence of internal data streams, the raw data can be used as an alternative for simulation of any other algorithms related to the study. Though this form of data can be extremely useful, storing these data directly has its drawbacks. For instance, raw data require enormous storage. Additionally, most of the data can be redundant or duplicate due to multiple sensors used, and it would be a waste of storage resources to accumulate unnecessary data. To overcome this, the data can be filtered.
- Processed Data: This type of data is obtained by filtering the acquired raw data from multiple sensors of ADSs or other internal states of ADSs and synchronizing them to remove redundant data. These data also reveal the actual causes of certain behaviors of ADSs, and stakeholders can get a better perspective of actual functionality of ADSs by studying these data. However, in most cases the ADS manufacturer may restrict access to the processed data feed. Stakeholders who wish to study this data feed may need to be granted permission to do so by the ADS manufacturer.
- Control Variables and Planned Actions: This type of data is usually a command for ADSs to directly act upon, such as brakes, steering, gear changes, etc. These channels can be crucial for determining performance of actuators or to troubleshoot behavior from an ADS Vehicle. Another use of this type of data can be to compare the output with offline simulation data. Sometimes the ADS internal data are not sufficient to fully determine their capability, so additional sensors can be added to independently and impartially verify the vehicle's performance.

World – Roadway Data

Stakeholders may choose to collect data from Roadway elements to improve ADS navigation performance in joint ADS/roadway testing and evaluation. Additionally, these data sources may be collected during testing for independently validating the performance of ADSs. Hence, data from Roadway elements is a vital part of joint ADS/Roadway testing and evaluation.

Appendix A outlines a modular description of World – Roadway Elements. These include a description of parameters involved in the Roadway Design, Operations, and Traffic Control Devices categories. These parameters are not repeated in this section for the sake of brevity. However, Table 16 introduces some sources of data for these elements.

Table 16. Data Sources for World-Roadway Elements.

Category	Sub-category	Source of Data
Roadway Design Information	Roadway Types	DOT road inventory data, road inventory, HD maps, maps
	Roadway Surfaces	DOT road inventory data, aerial imagery, DOT infrastructure management technical services, in-pavement sensors, proprietary methods using in-vehicle sensors.
	Roadway Edges	DOT road inventory data
	Roadway Geometry	DOT road inventory data, HD maps
Roadway Operations	Dynamic Message Signs	Traffic management system, DOT operations, TMP rules
	Variable Speed Limits	Traffic management system
	Managed Lanes	DOT operations for active traffic management
	Real-time data	Traffic management system, DOT operations – sources like CCTV feeds, law enforcement, computer-aided-dispatch, service patrols or crowdsourced.
	Work Zone Data	WZDx elements, BSM data from roadside equipment
Traffic Control Devices	Signing	MUTCD information on sign-code, required action and condition type of installed signing. State DOT traffic sign inventory / graphic/video log, State DOT maintenance systems
	Marking	Pavement marking management systems used by DOTs
	Traffic Signals	Traffic management centers/systems, traffic signal controller, traffic detector using in-roadway sensor

World – Environment Data

Environment plays a vital role in ADS-equipped vehicle's driving performance. There are a wide range of data sources which monitor the parameters which may influence ADS performance. There are basically three major elements that may be considered for collecting data including Atmospherics, Road-weather, and Connectivity.

Appendix A outlines a modular description of World – Environment elements. These include a description of parameters involved in the Atmospheric, Road-weather, and Connectivity categories. These parameters are not repeated in this section for the sake of brevity. Table 17 introduces sources of data for these key elements.

Table 17. Data Sources for World-Environment Elements.

Category	Sub-category	Source of Data
Atmospherics	Essential Climate Variables	Environmental Sensor Stations (ESSs), weather stations, external data sources
	Visibility Factors	ESS, weather stations, applicable external data sources, local sensors, solar maps
Road-weather	Temperature	ESS, local sensors, Multi-Domain Sensing System (MDSS), crowd-sourced information
	Condition	
Connectivity	Signal Strength	Wireless providers cellular coverage maps
	GNSS Accuracy	Inference from HD maps data based on objects in environment, specialized GNSS accuracy surveys conducted with proprietary standardized equipment
	Time Delay	Latency assessments in cellular, V2X or GNSS modes of communication

World – Objects Data

The ADS observes the objects in the environment with perception sensors; these data are then processed and stored to anticipate the motion and behavior of objects around it. The ADS Vehicle has its own characteristic sets of the collected object agnostic data and special characteristic data to distinguish and characterize the object. ADSs also rely on natural data for objects found in global space around it. The type of data collected is constant and universal irrespective of the method used to collect it.

Appendix A outlines a modular description of World – Object elements. These include a description of parameters involved in the Roadway User and Other Object categories. These parameters are not repeated in this section for the sake of brevity. However, a small summary of the key facets is provided in paragraphs that follow. Table 18 introduces sources of data for these key elements.

Salient features of key elements in the World – Objects category:

- Vulnerable road users (VRUs): includes different users such as pedestrian, bicyclist, and/or motorcyclist. Depending upon the state and scene information, the vulnerability of these users varies. It is critical to correctly identify and distinguish these objects.
- Vehicle: includes passenger vehicles, commercial vehicles, and recreational vehicles. Important to identify the vehicle's shape/size, unique information, position, orientation, velocity, and acceleration are to be characterized correctly.
- Non-roadway users: includes other objects not using the roadway but may cause hindrance. Depending on static or dynamic nature of the object, it has the potential to cause disturbance in flow of navigations (e.g., debris, construction equipment, animals, carts).
- Off-road structure: includes objects such as buildings, post-boxes, roadside furniture (guardrails, crash barriers, etc.). These may also be identified and characterized for better performance.

Table 18. Data Sources for World-Object Elements.

Category	Sub-category	Source of Data
Roadway Users	Vulnerable Road Users	Reliance on ADS observations, validation by external sensors when possible
	Vehicles	Reliance on observations made by ADS, validation by external sensors such as CCTV cameras on roadways
Other Objects	Non-Roadway Users/Obstacles	Reliance on observations made by ADS, validated by roadway sensors (such as CCTV cameras) or input from other agency officials as needed
	Off-Roadway Structures	Reliance on ADS observations, validation by external sensors when possible, HD maps, LiDAR data, city planning inventory

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December 2021
FHWA-HOP-21-012

U.S. Department of Transportation
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