Safely Operating ADS in Challenging Dynamic Scenarios: An Optimized Automated Driving Corridor Demonstration

VIRGINIA TECH
TRANSPORTATION INSTITUTE

Project Team

Transurban
Virginia DOT
Public Safety Stakeholders
GCAPS
CAMP Consortium
- Ford
- General Motors
- Daimler
- Hyundai-Kia
- Nissan

Point of Contact:

Dr. Michael Mollenhauer, *Director*

Center for Technology Implementation
Virginia Tech Transportation Institute

mmollenhauer@vtti.vt.edu

Proposed Location

Fairfax County, VA
Washington, DC Area

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March 21, 2019

U.S. Department of Transportation, Federal Highway Administration
ATTN: Sarah Tarpgaard, HCFA-32
1200 New Jersey Avenue, SE
Washington, D.C. 20590

Subject: Response to ADS Demonstration Grants, NOFO #693JJ319NF00001

Dear Sarah Tarpgaard:

The Virginia Tech Transportation Institute (VTTI) is pleased to present this proposal entitled "Safely Operating ADS in Challenging Dynamic Scenarios: An Optimized Automated Driving Corridor Demonstration," to USDOT in response to NOFO #693JJ319NF00001. This project will demonstrate how SAE level 4 Automated Driving Systems (ADS)-equipped vehicles can interact safely in challenging dynamic scenarios such as encounters with public safety providers (organizations including fire, rescue, emergency medical services, police) and other public services (e.g., safety service patrols and work zones). The unpredictable and complex nature of the interactions involved in these scenarios have the potential to be extremely challenging for ADS-equipped vehicles to safely and predictably respond to. Solutions for how these interactions can be safely managed will be a key enabler of the widespread deployment of ADS-equipped vehicles.

VTTI will facilitate a collaboration consisting of stakeholders from the manufacturer, infrastructure owner-operator, and public safety communities to develop and demonstrate effective ADS solutions for these interactions. The team assembled for this project includes:

- VTTI, an internationally recognized transportation research institute with extensive experience in ADS and connected vehicle technology development, testing and evaluation;
- Crash Avoidance Metrics Partners (CAMP), LLC, a consortium of automakers who led an initial project with VTTI to characterize and define interactions between public safety officials and ADS;
- The Virginia Department of Transportation and Transurban, who will represent infrastructure owner-operators and will provide the roadways and corresponding infrastructure for the demonstration; and
- Numerous international, state, and local public safety providers and professional organizations, who will provide indispensable perspectives to help the team develop and validate interaction scenarios and solutions that can be applied across multiple jurisdictions.

With critical input from a range of multiple stakeholders, the VTTI team will define solutions to key interactions between ADS-equipped vehicles and public services, build reference level 4 ADS-equipped vehicles with the necessary technological solutions, and demonstrate the ADS-equipped vehicles safely operating in dynamic scenarios on the I-95 Express Lanes and arterial roadways near Washington, D.C. These roadways will be optimized for ADS operation and real-

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time roadside data transfer through integration with the Virginia Connected Corridors. During the demonstrations, vehicle data will be collected and later processed to create scenario simulations that can be used to support further development of ADS, industry and/or national standards, and educational materials for public service providers. Data collected from vehicles and infrastructure will be distributed to the USDOT, ADS developers, public service providers, and other public users via a data distribution website hosted by VTTI.

Please do not hesitate to contact us with any questions.

Sincerely,

Pascha Gerni
Chief Financial and Administrative Officer
Virginia Tech Transportation Institute

Summary Table

Project Name/Title	Safely Operating ADS in Challenging Dynamic Scenarios: An Optimized Automated Driving Corridor Demonstration
Eligible Entity Applying to Receive Federal Funding	Virginia Tech North End Center 300 Turner Street, Suite 4200 Blacksburg, VA 24061
Point of Contact	Dr. Michael Mollenhauer *Director, Center for Technology Implementation, Virginia Tech Transportation Institute* Mmollenhauer@vtti.vt.edu 970-227-3373
Proposed Location (State(s) and Municipalities) for the Demonstration	Fairfax County, VA (Washington, DC Area)
Proposed Technologies for the Demonstration (briefly list)	Level 4 ADS that respond appropriately to a range of challenging dynamic scenarios on freeways and arterial roadways. Technological concepts and solutions for ADS and public safety providers (police, fire, rescue, EMS, etc.) that facilitate safe interaction. Level 4 ADS and infrastructure solutions that collaborate to respond safely to dynamic roadway and traffic conditions including work zones, signalized intersections, and cooperative ADS interaction concepts. Adaptive ADS user interfaces that support exchange of operational status and intentions with visual and hearing impaired riders.
Proposed Duration of the Demonstration	36 Months
Federal Funding Amount Requested	$9,999,192
Non-Federal Cost Share Amount Proposed	$3,697,299
Total Project Cost (Federal Share + Non-Federal Cost Share)	$13,696,491

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Part 1. Project Narrative and Technical Approach

Executive Summary

The increasing automation of the U.S. vehicle fleet in the coming years has the potential to dramatically enhance safety for motor vehicle occupants and other road users. One significant barrier to fully realizing the benefits of automated driving system (ADS)-equipped vehicles is their ability to navigate the innumerable complex, dynamic scenarios that ADS will inevitably encounter in real-world situations. ADS are rapidly building competence in predictable environments encountered on limited-access operational design domains (ODDs). Examples include General Motors' Super Cruise, Audi's Traffic Jam Assist, and Tesla's Autopilot. However, operating scenarios requiring complicated and less predictable interactions with public services and the associated rapidly changing traffic conditions remain challenging for ADS to navigate safely and predictably. For the purposes of this proposal, the term public services encompasses services provided by infrastructure owner–operators (IOOs), such as work zones, and by public safety providers (police, fire, rescue, and emergency medical services).

As an example, consider a scenario in which a level 4 (L4) ADS-equipped vehicle with no front-seat occupants approaches a freeway crash that is blocking lanes, and a police officer is directing traffic. Today, this interaction would likely be handled through eye contact and hand gestures between the human driver and the law enforcement officer. How does the officer know that the ADS-equipped vehicle will respond appropriately to the hand gestures and whistle? Will the ADS respond as the officer expects? Will the ADS users understand the context of the interaction? This is just one of the myriad scenarios for which ADS developers, IOOs, and the public safety community must collaboratively provide solutions to enable public trust, expand ADS ODDs, and increase market penetration so that the transformative safety benefits of ADS can be fully realized. Furthermore, as these same complex scenarios also present safety risks when navigated by human drivers, ADS have the potential to significantly improve safety by removing opportunities for human error.

Vision

Ubiquitous safe operation of ADS in highly dynamic interactive scenarios

With the overarching vision of a transportation system where ADS-equipped vehicles operate safely and predictably in highly dynamic interactive scenarios, this project will define key dynamic scenarios, develop technological concepts for safe interactions of ADS-equipped vehicles in these scenarios, and demonstrate the solutions in a Northern Virginia corridor optimized for automation while collecting data for ADS development, safety analyses, and rulemaking considerations. Led by the Virginia Tech Transportation Institute (VTTI), the demonstration team includes representatives of manufacturers [through Crash Avoidance Metrics Partners (CAMP), LLC], IOOs [the Virginia Department of Transportation (VDOT) and Transurban], numerous public safety stakeholder representatives from across the nation, and a leader in the provision of data for ADS evaluation and development [The Global Center for Automotive Performance Simulation (GCAPS)].

ADS technology is rapidly evolving, and testing is taking place in multiple locations across the U.S. However, few demonstrations have addressed dynamic interactive scenarios that require collaboration among a range of stakeholders with unique perspectives. The limited work conducted in this area was carried out by isolated ADS developers with little to no interaction with public service providers, who will be critical in integrating ADS into the U.S. transportation system. For example, public safety officers and construction workers will have to operate alongside ADS-equipped vehicles on a daily basis. Even with human-driven vehicles, they face considerable safety risks due to their proximity to traffic, lack of physical protection, and the complex nature of the situations they encounter. Equally important is the involvement of IOOs, who will be tasked with optimizing infrastructure, safety service patrol (SSP) vehicle fleets operated by IOOs to mitigate effects of traffic incidents, and work zone operations to facilitate safe interactions with ADS. By bringing together ADS developers, IOOs, and public safety organizations as key team members, this project addresses a critical market failure in which key players have not yet collaborated to create broadly deployable solutions. Figure 1-1 summarizes our collaborative approach to addressing these important issues through a demonstration of ADS-equipped vehicles.

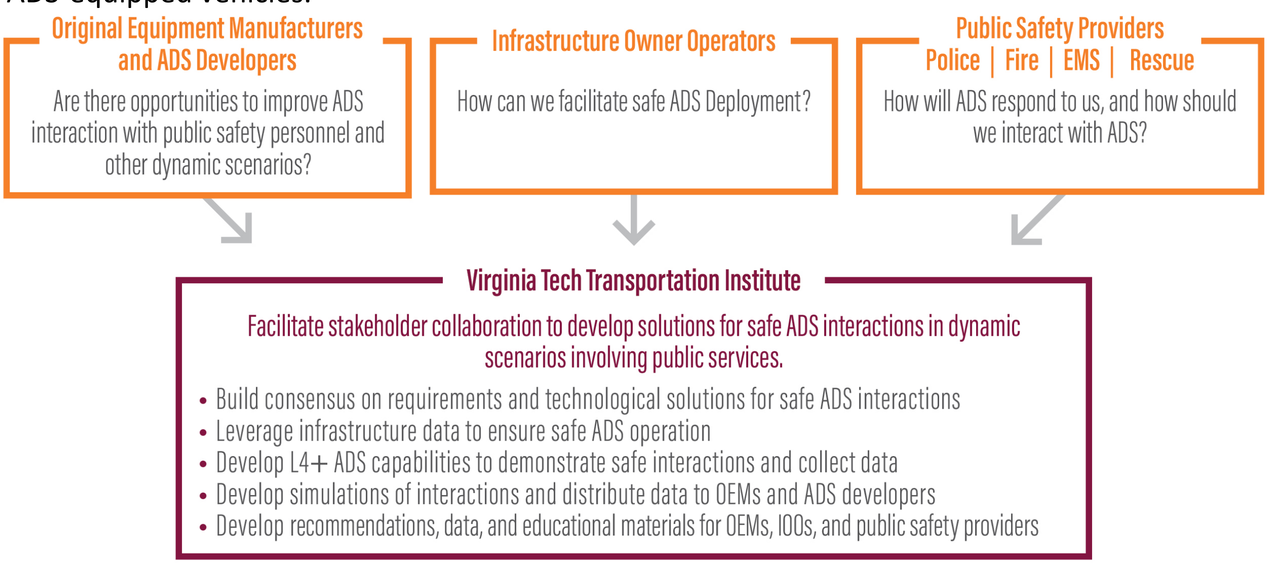

Figure 1-1. Concept for the collaborative demonstration of safe ADS interactions in challenging dynamic scenarios.

The demonstration approach and team composition are a direct result of our extensive discussions with ADS developers, IOOs, and public safety providers, which revealed that some of the most essential challenges to the safe operation of high-level ADS pertain to real-world scenarios in which L4+ ADS must:

- Respond appropriately and safely to a range of dynamic conditions, including lane closures and merges associated with work zones on freeways and arterials; and
- Interact directly (i.e., through physical contact) and indirectly (i.e., communicate without physical contact) with public services personnel.

While the above scenarios are often discussed as edge cases, in reality, they represent thousands of interactions per day and thus must be addressed to achieve a safe and efficient transportation system. ADS technology offers the potential to improve safety in many of these critical situations. In addition to technology-based solutions and standardized interaction protocols, these scenarios will also require adaptive ADS user interfaces that support exchanges of operational status and intentions with a wide range of users, including transportation-challenged populations.

The successful demonstration of ADS safely navigating the challenging dynamic scenarios introduced above will be accomplished through the following objectives, which also achieve the USDOT goals for this demonstration program (Safety, Collaboration, and Data for Safety Analysis and Rulemaking, as discussed in the next section).

Develop solutions for challenging dynamic scenarios through a combination of technology-based solutions, standardization of ADS response, and real-time infrastructure data support. With extensive input from OEMs, IOOs, and public safety stakeholders, the team will identify targeted dynamic scenarios, define the interactions between the actors and ADS, and develop technological solutions to address each scenario. The team will equip vehicles with a prototype open-reference ADS package that also includes the ability to exchange data through connected vehicle systems. This capability will allow the ADS to cooperate with the roadside when needed for the ADS-equipped vehicle to maneuver in the selected scenarios. The scenarios will be extensively validated and refined, with consideration of various interaction strategies and practicality of technological solutions, while maximizing performance and knowledge acquisition. Data will be collected throughout scenario development to facilitate ADS and infrastructure application development.

Demonstrate how L4+ ADS can safely interact with challenging dynamic scenarios while operating on corridors optimized for automation. The VTTI team will build L4+ ADS-equipped vehicles and demonstrate how a cooperative exchange of information between infrastructure and ADS can better equip ADS to manage dynamic scenarios on arterial and express lane roads in Northern Virginia. The demonstrations will include a combination of controlled and naturally occurring scenarios coordinated in collaboration with IOOs, public safety organizations, and OEMs. To maximize impact and educational potential, the demonstration events will be captured on video and disseminated through industry and media groups.

Collect demonstration data and create practical datasets and simulations of dynamic scenarios for use by USDOT, ADS developers, IOOs, and public safety organizations. ADS developers need data to create and test effective solutions to complex scenarios, and government agencies need data to assess the safety of ADS and evolve the regulatory framework. The team will collect comprehensive data during testing and demonstrations, including:

- Raw data from various perception sensors (e.g., inertial measurement units, LiDAR, radar, and global positioning system [GPS]);
- Infrastructure data, including messages exchanged between ADS and infrastructure and messages exchanged directly between scenario actors in some scenarios; and
- Survey and focus group responses reflecting the unique perspectives of targeted stakeholder demonstration participants (e.g., transportation-challenged populations and first responders).

Collected data will be processed into discrete data epochs for a set of collaboratively selected complex scenarios demonstrated in real-world settings. These data will be shared openly to allow ADS developers to investigate the scenarios through the “digital eyes” of their ADS. The data will also permit our team to investigate ADS readiness at the perception layer. In addition, key data elements will be abstracted into a powerful 3D simulation environment, enabling countless additional scenario investigations though ADS modeling using industry-standard toolsets. VTTI is currently providing similar simulation data packages for ADS development based on naturalistic driving data. However, no comparable datasets exist for the challenging scenarios to be addressed in this project. A simulation environment focused on complex dynamic scenarios will be extremely valuable to industry as well as to USDOT for safety analyses and potential training and outreach programs.

Finally, we will analyze the data with respect to the effectiveness of ADS implementations across the scenarios tested to assist with USDOT readiness assessments. This will include evaluations of:

- The ability of ADS to successfully navigate complex dynamic scenarios as intended;
- Stakeholder feedback to validate strategies and identify opportunities for improvement across each scenario; and
- Readiness assessments by representative groups from across the nation that will interact with ADS in the future (e.g., police, fire, OEMs, maintenance crews, and transportation-challenged populations).

The above objectives will be carried out over the course of a three-year period of performance, following the schedule shown in Figure 1-2.

Figure 1-2. Period of performance and implementation schedule.

Rather than simply demonstrating market-ready technologies, we are targeting the most complicated and difficult challenges within the ADS industry. It is critical to show the nation that ADS can overcome these challenges. We have the team, expertise, and facilities to collaboratively demonstrate complex ADS interactions while capturing the data needed to help USDOT evaluate safety readiness *and* enable continuous ADS improvement and virtual testing for difficult scenarios. Beyond that, the demonstrated solutions along with the datasets and outreach materials produced by this project will be extremely valuable to a wide variety of public service providers. Throughout the project, we will engage public service providers across jurisdictions and domain types (rural, urban, volunteer, etc.), with additional public service stakeholders to be added to our team after award. Their representation will ensure that public service providers come away with a better understanding of how ADS will respond to them and how their fragmented, multi-jurisdictional community can proactively prepare for ADS deployment. In turn, ADS developers will be more likely to apply the developed solutions because they will have been vetted within the public services community. Ultimately, this project will produce the basis for standard protocols covering complex interactions with ADS, allowing ADS to improve safety beyond what is possible with human drivers.

Goals

Our proposed demonstration is fully aligned with the goals presented within the ADS Demonstration Grants NOFO, as concisely described in the subsections below. The detailed goals of our proposal are further discussed in the Approach section.

Safety

Safety and innovation are two of the USDOT's top strategic goals.[1] As one of the key emerging innovations in transportation, ADS-equipped vehicles have the potential to improve safety by reducing opportunities for human error[2] while increasing operational efficiencies, leading to substantial societal benefits. Despite the recent significant technological progress, a number of dynamic operational scenarios remain unsolved in terms of how they will be safely negotiated by ADS, thereby limiting our ability to integrate ADS-equipped vehicles into the U.S. transportation system. These unsolved scenarios are characterized by interactions with infrastructure or other actors (cars, workers, etc.) that tend toward the unexpected and/or atypical, including interactions with public services. Many of the features necessary for reliable perception and response in these scenarios may be obstructed, incorrect, or difficult for ADS to identify and interpret. This presents a safety concern for both the users of ADS-equipped vehicles and public service providers.

In addition, responders and workers operating within these scenarios are often put at risk due to the combination of their proximity to traffic, lack of physical protection, and the complex nature of the environments and situations they work in. In 2017, 81 public safety officers and 710 road workers were killed on the job due to motor vehicle crashes; it is critical that ADS do not exacerbate the risks faced by these workers.[3,4]

Underscoring the importance of creating solutions to public safety interactions, CAMP recently demonstrated industry leadership by self-funding the Automation and Public Safety Common Solutions (APSCS) project[5] to better define these interactions, including an analysis of the task breakdowns and the nature of interactions between public safety officials and drivers. Our project builds upon the CAMP-APSCS project by extending it to include scenarios involving other public services such as work zones and SSP. While individual IOOs may define the exact roles of their SSP differently, typical SSP functions (e.g., securing crash scenes) overlap with those of

[1] USDOT Strategic Plan for FY 2018-2022 https://www.transportation.gov/dot-strategic-plan
[2] Automate Vehicles 3.0 https://www.transportation.gov/av/3
[3] 2017 Line of Duty Death (LODD) Report, International Public Safety Association. https://www.joinipsa.org/Publications
[4] https://www.workzonesafety.org/crash-information/work-zone-fatal-crashes-fatalities/#national
[5] Terry, T., Trimble, T. E., Blanco, M., Fitzgerald, K. E., Fitchett, V. L., and Chaka, M. (Unpublished). Support Services to Conduct Structured Small Group Interviews and User Needs Analysis: Final Report. Farmington Hills, MI: Crash Avoidance Metrics Partners LLC.

public safety providers. Therefore SSPs will be considered an extension of public safety for the purposes of this proposal.

Collaboration

Through our regular interactions with OEM, IOO, and public safety partners, VTTI has identified several common themes espoused by each of these communities. OEMs are interested in developing ADS-equipped vehicles that can safely interact with public service providers to overcome this unsolved problem before it becomes a barrier to safe ADS integration. Public service providers are aware that increasingly capable ADS are being deployed, and they need to know (1) how to interact with the ADS and (2) how they should expect ADS-equipped vehicles to respond in critical situations along the roadway. The public safety community does not always feel that their inputs and concerns are adequately addressed and would like to contribute more significantly to solutions and to the development of standard processes and interfaces. The IOO community is interested in identifying how they can prepare their infrastructure and operational systems to support the deployment of ADS to enable cooperative operations. In fact, some IOOs are directly supporting the needs of ADS to both attract ADS to their facilities and realize the projected safety and mobility benefits of broader ADS deployment in the near future.

Collaboration is a foundation of this project, which brings together some of the largest national voices within the OEM, IOO, and public safety communities to collaboratively develop solutions. Further, through our open-reference ADS platform and associated sharing of data, we intend to broadly motivate collaboration beyond this demonstration.

Data for Safety Analysis and Rulemaking

Our demonstration will collect and deliver data tailored to the anticipated needs of USDOT and other stakeholders to support safety analysis, industry standards and possible rulemaking. In addition, ADS developers need rich data to build and test safe solutions to scenarios involving public service providers. It is difficult to capture sufficient data on such interactions. To address this broad industry need, we will collect high-resolution raw datasets as we test and demonstrate the interactive scenarios and package the output to maximize their utility for future development and analysis.

As part of this effort, the Global Center for Automotive Performance Simulation (GCAPS) will create innovative 3D simulations of the ADS-equipped vehicles operating in dynamic scenarios during the demonstrations (Figure 1-3 and Figure 1-4). Over the past two years, VTTI and GCAPS have partnered to conduct similar work in support of VTTI's Automated Mobility Partnership (AMP) Program, which promotes the development of tools, techniques, and data resources to support the rapid advancement of ADS deployment. Leveraging VTTI's 70 million miles of naturalistic data, VTTI and GCAPS are actively delivering a library of real-world scenarios for use by AMP members, which include 13 industry leading OEMs and suppliers.

Figure 1-3. Example of a simulated police stop scenario (left) created by GCAPS based on an actual police stop captured in forward video within VTTI's naturalistic driving data (right).

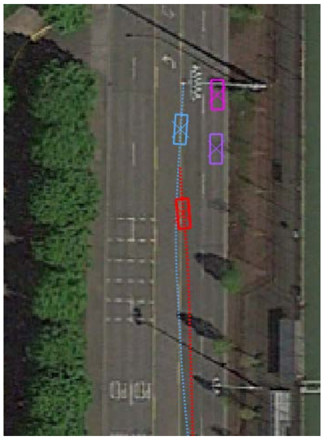

Figure 1-4. Bird's-eye view of the police stop scenario shown in Figure 1-3.

The scenarios provide virtual reconstructions of interactions that enable ADS and algorithm development. The simulations include the static and dynamic actors' global paths, vehicle dynamics characteristics, and relevant environmental features (e.g., road geometry, surface and curb type, lane lines, signs, buildings, and trees). AMP members have found these simulations extremely valuable, and we will apply the same processes and techniques used in the AMP project to generate simulations of the dynamic scenarios conducted during this effort and distribute the data to the public via a web-based data portal.

Our demonstration project will provide the following datasets.

1) On-board DAS datasets: High-resolution video, sensor, and ADS control system data will be collected from ADS-equipped vehicles as they encounter dynamic scenarios during the demonstrations. These data will be collected by a high-performance Data Acquisition System (DAS) installed on each vehicle.

2) Scenario demonstration dataset: Individual scenarios will be extracted from the full data stream, and annotations will be added describing the characteristics and context for each.

3) Scenarios simulation dataset: For selected key scenarios, DAS data will be processed to produce detailed 3D simulations from the raw data in commonly used formats. The 3D simulations will provide a basis for the development of standards and educational materials for public service providers and training organizations.

4) Infrastructure dataset: Connected vehicle messages exchanged between ADS and infrastructure applications will be captured from the data management system and archived to a database. The archive will be exported to downloadable data packages that can be used to help reconstruct scenario interactions at a system level. In addition to Basic Safety Messages (BSMs) and messages received from ADS and other actors staged in the demonstrations, these data will include real time ODD information and other information required by ADS, such as roadside safety messages (RSM) (which include work zone geometry, lane closures and associated speed limits, etc.), signal phase and timing (SPaT), road geometry/MAP, and traveler information messages (TIM).

5) Subjective assessment dataset: Subjective data will be collected from participants during the demonstrations through questionnaires and focus groups. Assessments will focus on participant's perceptions of trust, comfort, and readiness of the ADS functions, public safety interaction, and cooperative operation as observed through direct experience in the demonstrations. User interface assessments from the hearing- and visually impaired participants will also be provided. Analysis will capture readiness from the lens of each key stakeholder group, providing a valuable dataset for USDOT readiness assessment.

All datasets will be made available to USDOT and the public through a data dissemination portal.

Focus Areas

The alignment of our demonstration with each focus area presented in the USDOT NOFO is briefly described below.

Significant Public Benefit(s)

In 2017, motor vehicle crashes caused 37,133 fatalities in the U.S.[6] along with eight billion lost hours of productivity, four billion lost gallons of fuel, and an annual congestion cost of $200 billion to the U.S. economy.[7] ADS-equipped vehicles have the potential to fundamentally transform transportation by reducing crashes, congestion, pollution, and cost while improving traffic efficiency, economic opportunities, and access to mobility for transportation-challenged citizens. A recent study estimated that ADS could free up as much as 50 minutes each day[8] per person previously dedicated to driving.

The above benefits are expected to increase significantly as ADS achieve higher levels of capability and require less human involvement to assure safe operation. ADS must demonstrate safe operation across the full range of driving conditions including the challenging dynamic situations addressed by this project. We postulate that collaborative solutions for interactions between ADS-equipped vehicles, public service providers, and road operators can ensure safety if deployed across multiple jurisdictions throughout the country. This project will demonstrate how ADS can safely and predictably respond to dynamic traffic scenarios, helping overcome one of the key barriers preventing the incorporation of high-level ADS in the U.S. transportation system. Project outcomes will ensure that the people who serve us, protect us, and maintain our roads will have the information to do their jobs safely and can benefit equally from future ADS deployment.

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[6] DOT HS 812 603, Traffic Safety Facts 2017

[7] Texas A&M Transportation Institute & INRIX. (August, 2015). 2015 Urban mobility scorecard.

[8] http/www.mckinsey.com/industries/automotive-and-assembly/our-insights/ten-ways-autonomous-driving-could-redefine-the-automotive-world

Addressing Market Failure and Other Compelling Public Needs

Most stakeholders involved in ADS development will acknowledge that the safe, predictable interaction of ADS-equipped vehicles with public service providers remains a largely unsolved problem. The market has not fully addressed this issue for a variety of reasons. The public safety community is fragmented across jurisdictions and functions; thus, a single national standards organization representing their collective perspective does not exist. OEMs and ADS developers appear to have a mixed approach to solving dynamic scenarios. Some ADS developers are focused on developing individual proprietary solutions,[9] while others have begun a pre-competitive collaborative approach to understand the nature of interactions with public safety[3] as a basis for creating common solutions.

Further, the mechanisms by which occupants of ADS-equipped vehicles should interact in dynamic situations are not fully developed. While we will examine aspects of user interfaces that should be standardized during the demonstrations, we anticipate that ADS developers will further study this space to develop brand-differentiated user experiences. However, we do not expect the market to fully address the needs of physically challenged populations, such as those suffering from hearing and vision impairments. Thus, our demonstration considers interfaces that directly support the needs of these users.

In the absence of ADS, public safety scenarios are quite complex and dynamic, often resulting in inconsistent responses from human drivers. Thus, the integration of ADS-equipped vehicles may represent an opportunity to remove human error and increase the reliability of vehicle response. A collaboration between OEMs, public safety providers, and IOOs is necessary to develop practical, technology-based ADS solutions and standardized protocols that meet the expectations of all community members. This project provides an opportunity to raise awareness of this unresolved issue and provides a way to show how OEMs, public safety providers, and IOOs can come together to create and demonstrate solutions that reflect the needs, perspectives, and expectations of all parties.

Economic Vitality

In alignment with Executive Order 13788, Buy American and Hire American, this project will support economic vitality through procurements made while preparing the demonstration. In addition, this project is expected to contribute to economic vitality on both the national and regional level. The project will facilitate deployment of ADS-equipped vehicles by (1) demonstrating solutions for ADS-equipped vehicles overcome challenging dynamic scenarios, and (2) providing associated data for readiness and rulemaking.

Broadly speaking, ADS-equipped vehicles have the potential to eliminate the vast majority of motor vehicle crashes since 94% of crashes are attributable to human error.[10] Thus, the

[9] https://www.gearbrain.com/waymo-driverless-car-hand-signals-2629692132.html
[10] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

implementation of ADS could vastly reduce the economic costs associated with vehicle crashes ($242 billion in 2010, including $57.6 billion in lost workplace productivity).[11] ADS also stand to improve economic vitality by reducing lost productivity associated with traffic congestion (estimated at $87 billion in 2018).[12] In addition, high market penetration of ADS-equipped vehicles is expected to generate significant economic ripple effects throughout multiple industries, including vehicle hardware and software. For example, software costs are expected to increase from 10% of current car values to 40% in a connected ADS environment.[13] By helping to lay the groundwork for safe ADS deployment, this project will position the U.S. as a leader in transportation, providing a competitive edge for U.S. industries in numerous related fields.

At the regional level, this project will help solidify the Commonwealth of Virginia as a leader in ADS testing and demonstration by optimizing Transurban's Express Lanes in Northern Virginia for ADS operation. The optimized corridor and successful demonstration will attract additional ADS testing projects to Northern Virginia in addition to helping solve important traffic and safety issues in this region, which was ranked as the second most congested in the U.S. last year and experiences significant productivity losses as a result of congestion.[14]

Complexity of Technology

We have intentionally focused this project on some of the most complex scenarios ADS will encounter. This complexity is precisely why industry has not broadly demonstrated the ability to successfully address ADS responses to the unpredictable dynamic scenarios presented herein. Overcoming this challenge requires breaking down the rather complicated barriers to collaboration among various stakeholders, as we have successfully achieved within this offer.

This project will demonstrate that a collaboration between OEMs, IOOs, and public safety organizations will enable highly capable reference prototype L4+ ADS-equipped vehicles to safely and consistently navigate complex dynamic scenarios. The project will leverage state-of-the-art facilities including freeways and arterial roadways (detailed in Part 2), where the prototype vehicles and traffic operations centers (TOCs) will share real-time data through connected vehicle systems, permitting cooperative operation with the roadside infrastructure when needed. While the underlying technologies needed to achieve this demonstration are extremely complex, they are within the ability of the team to integrate, validate, and demonstrate, as shown throughout this response.

Diversity of Projects

Our demonstration will provide inclusive benefits to all types of communities, roadway environments, and transportation markets. With a focus on the public service interactions which are required everywhere, this project will accelerate the safety, mobility, and economic benefits

[11] Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised)(Report No. DOT HS 812 013). Washington, DC: NHTSA.

[12] http://inrix.com/press-releases/scorecard-2018-us/

[13] Jonas, A., S. C. Byrd, R. Shankar, and M. Ono. (2014) Nikola's Revenge: TSLA's New Path of 39 Disruption. Morgan Stanley & Co., LLC.

[14] http://inrix.com/press-releases/scorecard-2018-us/

of a broad rollout of ADS-equipped vehicles throughout the U.S., independent of personal diversity, geographic location, economic status, or transportation market. The diverse stakeholders involved in this project will ensure the representation of all constituents throughout the planning and demonstration phases of this project.

In regard to transportation markets, while this project focuses on L4+ ADS-equipped light vehicles, the underlying lessons will apply to all classes of vehicles across a variety of transportation markets. For example, the capabilities developed and shared throughout this project will also benefit freight, taxi, and public transport.

Transportation-challenged Populations

Today, over 49 million Americans are over age 65, and 53 million people have some form of disability.[15] L4+ ADS may provide new mobility options to millions of transportation-challenged Americans, enhancing prospects for employment and independent living. However, it may be difficult for ADS-equipped vehicles to interact with these riders, particularly in unusual situations where a user's accurate situational awareness and mental model of the ADS are critical to user safety, comfort, and trust. Thus, before the benefits of ADS can be realized, ADS developers must incorporate accommodations for disabled users, including providing the user with contextual information about the intentions of the ADS.

Our demonstration will specifically consider hearing and visually impaired ADS users by developing inclusive user interfaces. These interfaces will leverage the integrated capabilities of vehicle sensors, connected vehicle infrastructure, and standardized scenario responses to provide the user with situational context and information on how ADS-equipped vehicles will react. Such interfaces will help ensure the user's comfort and trust in complex driving scenarios.

Prototypes

Prototype technologies are pervasive throughout this project. These prototypes are suitable to support safe demonstrations but are not ready for broader deployment. For demonstration, we will add a reference L4+ ADS package to production vehicles. This approach provides an excellent tool for OEM collaboration without exposing their intellectual property or impinging on antitrust laws. However, the demonstration ADS will not have undergone the full battery of regulatory, safety, and durability processes necessary for a marketable vehicle, which is infeasible within the resources available.

Critical to this demonstration, the ADS and associated infrastructure systems are built by our team specifically to support rapid prototyping. Unlike systems developed with production intent, which face administrative and development hurdles that slow the process, our platforms enable quick, iterative learning within our collaborative agile development (focusing on developing technical solutions rather than excessive documentation). All ADS and infrastructure systems are within the team's ability to directly program, modify, and improve. This substantially reduces project risk by ensuring that we can integrate systems without requiring outside assistance.

[15] https://www.nhtsa.gov/technology-innovation/automated-vehicles

As detailed in subsequent sections, all prototypes will be constructed with a safety-first mentality. For example, all factory safety systems will be retained, and a safety backup driver will always be present within the vehicle. Fortunately, with verifiable support from the state, our team has permission to operate our prototype ADS-equipped vehicles on open roadways using a self-certification approach.

Requirements

The demonstration proposed herein meets each of the requirements outlined in the NOFO as concisely outlined below and demonstrated throughout this submission.

Requirement a. R&D of automation (L3 or greater)

Our demonstration focuses on the **research and development of ADS-equipped vehicles with L3+** automation technologies per SAE definitions. Specifically, with OEM collaboration, VTTI will develop two or more L4+ ADS-equipped prototype vehicles, as discussed in the Approach section (Task 3).

Requirement b. Physical Demonstration

We will demonstrate L4+ ADS-equipped vehicles on public roadways in Northern Virginia. The demonstrations will take place on the I-95 Express Lanes, which are safely controlled by Transurban and may be closed to the public as needed, and arterials controlled by VDOT. The demonstrations are described in the Approach section (Task 5), and the demonstration environment/facilities are described in the Capabilities sections included in Part 2.

Requirement c. Data Requirement

During this project, we will capture and share a variety of rich datasets, including on-board DAS data, a dynamic scenario library with annotations describing data characteristics, an archive of infrastructure data captured from the real-time ODD information tool and cooperative ADS applications, an archive of connected vehicle data from other vehicles and actors participating in the demonstrations, and a collection of subjective assessments and focus group feedback from stakeholder participants captured during the demonstrations. These data will be gathered and shared with the USDOT and public throughout the project, in near real time, and will be accessible for a minimum of five years after the award period of performance expires. Details of the datasets and how they will be captured and shared can be found below in the Approach section (Task 6) and the Draft Data Management Plan (Part 3).

Requirement d. User Interfaces

Our project will demonstrate accessible user interfaces that will allow users of ADS-equipped vehicles with varied abilities to receive information generated by the ADS regarding relevant interactions with public services. During the demonstrations, the L4+ ADS-equipped vehicles will respond to a variety of scenarios involving public services and cooperative operation where users will want to understand the context of the interactions, input a desired response/route when appropriate, and be informed of the ADS's intended/executed response(s). The nature of these dynamic and likely unexpected scenarios makes the clear communication of such information even more critical for users. We will also integrate external user interface components to support public service providers engaging in the scenarios with ADS-equipped vehicles.

Requirement e. Scalability / Outreach

Our demonstration will demonstrate complex but not uncommon scenarios involving: 1) representative ADS functions to be incorporated into OEM products internationally, 2) nationally representative IOOs, and 3) nationally representative public safety officials. The resulting products will include a technical information package and data that can be directly disseminated by stakeholders and their collaborators to help build a transportation system prepared for scaling ADS to deployment. It is our intent to broadly disseminate this information beyond our stakeholder group to ensure the entire nation, including the general public, is informed on the readiness of ADS deployment with regard to dynamic scenarios.

Approach

The following sections describe our plan to satisfy the project requirements through a robust technical approach. First, we summarize our overall technical approach to implementing and evaluating the demonstration and detail the work to be completed in each task, including our approach to providing data and participating in the evaluation of the safety outcomes (Task 6). Second, we provide our strategies for: 1) addressing legal, regulatory, environmental, and/or other obstacles; 2) risk identification, monitoring, and resolution; and, 3) managing our significant non-federal (cost-share) resources.

Technical Approach to Implementing and Evaluating the Demonstration

Our technical approach to implementing and evaluating the ADS-equipped vehicle demonstrations is divided into six tasks. In **Task 1**, we focus on optimizing the infrastructure capabilities for demonstrating safe ADS operation in dynamic scenarios. In **Task 2**, we select the scenarios, generate ADS-equipped vehicle interaction requirements, and finalize the candidate technological concepts using a structured process with significant stakeholder involvement. The results of Task 2 will inform the design of the L4+ ADS-equipped reference platform vehicles to be built and tested in **Task 3**. The reference platforms will provide the necessary capabilities to collaboratively demonstrate safe ADS operation in challenging scenarios involving public services. In **Task 4**, the team will develop the TOC cooperative operation applications necessary to provide real time ODD information and suggested operating parameters (speed, headway, lane selection, etc.) to support safe ADS operation in the selected scenarios. Within **Task 5**, we conduct high-profile demonstrations in Northern Virginia. Each demonstration will span several days with participants representing specific groups of key ADS stakeholders necessary for successful deployment. Demonstrations will showcase the L4+ ADS-equipped reference vehicles operating safely through a combination of scripted and naturally occurring dynamic scenarios while collecting a wide variety of high-definition data. Finally, in **Task 6**, the data collected during the demonstrations are processed into datasets along with powerful simulations and published through a web portal for safety analyses, ADS development, and standards development along with use as a media source for public services training materials.

Task 1: Develop Solutions for Corridor Optimization

Many IOOs are evaluating infrastructure needs for future ADS-equipped vehicles and considering how to prepare their roadways for ADS deployment. Some IOOs are actively seeking ways to facilitate deployment on their roadways to accelerate the projected safety and mobility benefits that may follow. However, at present, few well-defined infrastructure requirements are available to support IOOs in their preparations. Connectivity provides an opportunity to enhance safety and mobility through the exchange of vehicle-to-infrastructure (V2I) information that can help ADS assess current and future operating conditions. For example, data that support ADS evaluations of the ODD may provide significant value. SAE Standard J3016 defines ODD as "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics." As these conditions are dynamic, an ADS should monitor the current ODD so it can modify or control availability of ADS functions. This assessment may include identifying transitions between certain ODD states based on current operating conditions (roadway type, traffic levels, weather, presence of public services, etc.).

To support timely and accurate ODD determination by ADS, VTTI will collaborate with Transurban to define a Real-time Operational Design Domain Information Service (RODDIS) application that combines data from multiple independent sources to indicate current conditions for fixed roadway segments (Figure 1-5). As the operator of the I-95 Express Lanes, Transurban manages a highly capable TOC that includes traffic sensors every 1/3 mile, full video monitoring, weather sensors, and SSP staff that continuously monitor the roadway. The RODDIS app will leverage Transurban's infrastructure and public services to provide the required operating conditions for ODD evaluation to ADS in real time via connected vehicle messages. We expect RODDIS to accept a combination of local sensor inputs while enabling TOC staff to supplement the status with manual input. In conjunction with OEM stakeholders, we will define a prototype V2I message set and protocol that makes the information available for both current and upcoming roadway segments. The ADS-equipped vehicles will use the messages to make real-time ODD assessments and modify or disable ADS function as necessary.

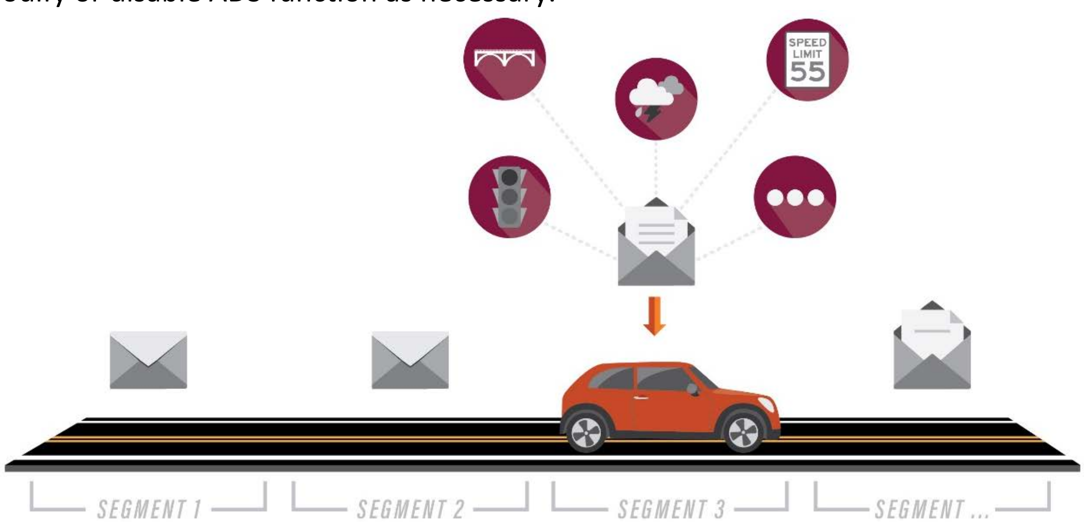

Figure 1-5. Concept for the RODDIS application, which will collect and send real-time ODD information to ADS-equipped vehicles for fixed segments along a corridor.

Also in this task, the team will evaluate communications needs and deploy solutions along the demonstration corridor as necessary to support V2I features. We will leverage components of the Virginia Connected Corridors (VCC), which already support many of the project needs (see Part 2 for more information). Likewise, any other infrastructure-related enhancements (real-time kinematic GPS corrections technology, maintenance of roadway markings, or signage upgrades) necessary to support the demonstrations will be addressed during this task.

Task 2: Dynamic Scenario Definition and Development of Technological Solutions

The demonstrations will focus on dynamic scenarios that require interactions with other actors on the roadway. During the selection process of the demonstration scenarios, we will take into account the previous work led by CAMP and performed with VTTI.[3] Key public safety interactions that warrant consideration include incident response, securing an incident scene, traffic direction and control, traffic stops, and encountering an abandoned or unattended vehicle (maroon boxes in Figure 1-6). Additional dynamic scenarios will also be considered to address various work zone scenarios (orange box in Figure 1-6) and incorporate further input from stakeholders, resulting in an initial list of candidate demonstration scenarios.

Figure 1-6. Key scenarios involving public services to be considered in the demonstration (adapted from CAMP-APSCS project[3]).

The list of candidate scenarios will then be reviewed to determine the interaction requirements and associated ADS requirements, defined below.

Interaction requirements will consist of any direct, indirect, or informational interaction necessary within a given scenario. Per the CAMP-APSCS project,[3] a direct interaction is defined as any interaction that requires a public services actor to physically contact an ADS-equipped vehicle. An indirect interaction is when a public services actor interacts with a vehicle without physical contact such as via emergency lights, sirens, or gesturing. An informational interaction occurs when a public services actor needs to acquire information from a vehicle such as the number of occupants, license plate, or owner identification. The type of interaction will be characterized for each candidate scenario prior to determining the ADS requirements for achieving those interactions.

The **ADS requirements** to be determined include the expected actions of the ADS-equipped vehicle based on its anticipated interaction in a public service scenario. Required actions may include merging, slowing, stopping, signaling, or yielding. For example, an ADS-equipped vehicle may be expected to merge out of its current lane if approaching a lane closure caused by a work zone or traffic incident. The technological solutions may differ in these cases since a work zone lane closure can be proactively conveyed, whereas a sudden lane closure due to a traffic incident will be unanticipated. The combination of ADS and interaction requirements will guide the selection of technology solutions.

As shown below (Figure 1-7) for each candidate scenario, the research team will outline the step-by-step procedures for public service interactions in the form of a task analysis. The task analysis will result in an exhaustive list of possible interactions and associated requirements, which will then be reviewed by our stakeholders. Interaction policies and procedures may differ by jurisdiction or other circumstances; thus, multiple interaction methods will be considered when appropriate. Determining the proper interaction requirements and ADS responses will require a constant feedback loop between all team members and stakeholders.

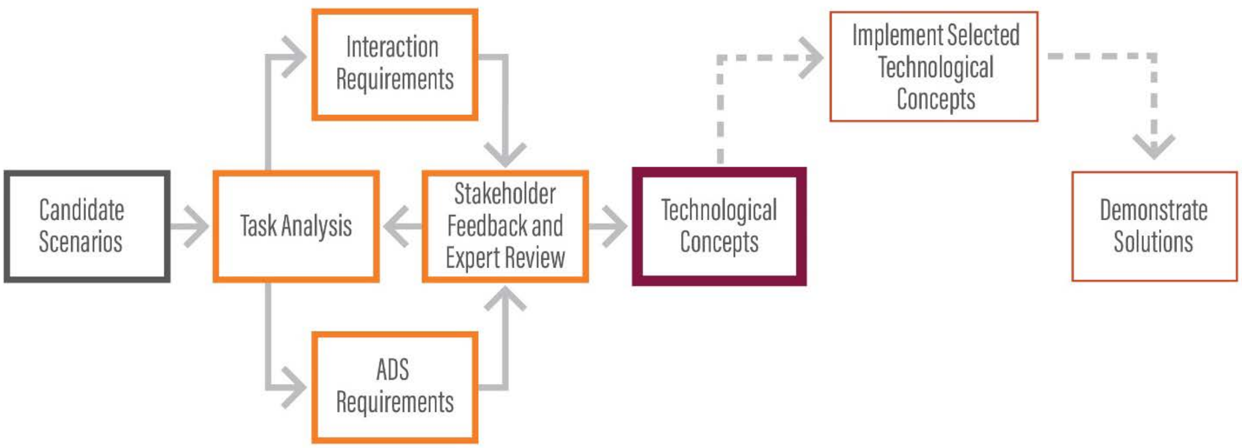

Figure 1-7. Scenario selection and vetting process to be applied in Task 2.

Once consensus has been reached regarding the interaction and ADS requirements for the candidate scenarios, CAMP and VTTI will generate **technological concepts** which will be the primary output of this task. The concepts will vary depending on the interaction requirements for each scenario. An example technological concept may use onboard sensors to detect the physical presence of a public safety official directing traffic or to detect the directionality and proximity of an approaching emergency vehicle. In another concept, a public service vehicle may relay information via connected vehicle technologies to instruct other ADS to follow a non-intuitive pathway around an incident. When conducting traffic stops, connected vehicle or connected infrastructure concept may assist law enforcement in selecting safe locations for vehicle stops (e.g., not on the crest of a hill or in the apex of a curve).

The technological concepts for each scenario will be reviewed by stakeholders, and a subset will be selected for implementation and demonstration. Ultimately, the selections will be based on the scenario prevalence and importance, as determined by public safety experts and literature review; the ability to be demonstrated within project constraints (road types, operating environment, etc.), and the feasibility of developing the solution with available resources. Any scenarios deemed infeasible will be documented as areas for future research and potential challenges to deployment as appropriate.

Stakeholders will provide regular feedback on candidate scenarios during the development, selection, and implementation processes. Public service provider feedback in the early design stages of Task 2 will ensure the final product is supported by public service communities and can be rapidly transitioned from test and demonstration to deployment. Regular stakeholder meetings will provide constant opportunities for collaborative technological development and assurance that systems developed have a path to a scaled to deployment.

Task 3: Build Reference Demonstration Vehicles

As detailed in the Capabilities section of Part 2, VTTI has a longstanding research and development program centered on the development and testing of ADS-equipped vehicles. The Automated Vehicle Research Platform (AVRP) is an executive vehicle control system designed by VTTI for the rapid prototyping of specific ADS functions. In the AVRP, high-definition onboard sensors fused with appropriate vehicle-to-everything (V2X) information, threat assessment, path planning, and actuation provide the basis for full authority over longitudinal and lateral vehicle maneuvers. The AVRP also provides a human–machine interface (HMI) that integrates with the native HMI of the equipped vehicle. The AVRP permits running code from the Robotic Operating System (ROS) in parallel to the real-time system and thus should be compatible with the Cooperative Automotive Research Mobility Applications[16] (CARMA) platform. VTTI will assess opportunities to implement portions of the CARMA software stack where appropriate and within project resource constraints. The AVRP provides a reference automated driving capability up to highway speeds that will react to traffic and various roadway obstacles and events as programmed for a given scenario.

In Task 3, the AVRP will be refined to address the specific needs of this program based on the scenarios defined within Task 2 along with additional guidance from the project stakeholders, with a particular focus on inputs and design reviews from vehicle manufacturers represented in the CAMP consortium. The AVRP-equipped vehicles will be capable of demonstrating various dynamic interactions with public services along with dynamic speed harmonization (DSH) and RODDIS applications. As discussed within Part 2, VTTI previously demonstrated the AVRP on Transurban roadways in 2016, showing both our technical capability and ability to leverage established partnerships within this specific ADS domain.

We also recognize the need to gather data to enable the refinement of ADS and support USDOT evaluations of safety and readiness. The primary types of data to be collected in this project place some requirements on the ADS-equipped reference vehicles, as discussed below. The exact vehicle models will be selected in collaboration based on the requirements established in Task 2.

The first data type comprises assessments and recommendations provided by selected stakeholder demonstration participants, including first responders, IOOs, policy makers, system developers, and the physically impaired. Based on experiences in projects such as the Safety Pilot Driver Acceptance Clinics,[17] we know that individuals need to directly experience technology to provide meaningful feedback. To ensure a realistic experience, we propose vehicle modifications

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[16] https://highways.dot.gov/research/research-programs/operations/CARMA

[17] Ahmed-Zaid, F., Krishnan, H., Vladimerou, V., et al. 2012. Vehicle-to-Vehicle Safety System and Vehicle Build for Safety Pilot (V2V-SP) Final Report, Volume 1: Driver Acceptance Clinics.

that reduce the obtrusiveness of the safety driver (i.e., an experimenter present in the vehicle that can take control if necessary to maintain safety) and create the experience of full ADS capability for front-seat occupants. In a technique pioneered and currently in use by VTTI, the primary mechanical driving systems are moved to the rear, and the front-seat controls are replaced with by-wire equivalents. This architecture (additional details in Part 2) allows the safety driver to sit in the rear of the vehicle, permitting safe testing across the levels of automation while providing a true-to-feel experience for participants. We believe an accurate experience of L4 automation is paramount to acquiring quality data regarding ADS readiness from participants.

The second key data type will be captured by a full suite of vehicle sensors. While the exact sensor suite will be collaboratively selected, it will be comparable to ADS perception systems in prototype form across the industry. Described further in Task 6, these reference data will provide the foundation for creating a proven and powerful environment that allows system developers to test and evaluate ADS-equipped vehicles using software- and hardware-in-the-loop methods. Finalized data sources will be selected in collaboration with our stakeholder advisors, but are anticipated to include onboard LiDAR, radar, cameras, ultrasonic, inertial measurement units (IMUs), and GPS. These data will be captured by VTTI's robust FlexDAS—a refined and well-tested high-performance DAS. This DAS has been used in various studies and captures data from a network of sensing systems, each receiving any necessary input parameters while providing data for logging. This system has a full user interface enabling precise control over the data captured without distracting the attention of the safety drivers.

To capture data specifically about the needs of transportation challenged populations, VTTI will develop user interfaces targeting the unique needs of these populations during the scenarios and interactions defined in Task 2. During Task 2, we will collaborate with stakeholders to define interactions between ADS-equipped vehicles and public services, including the additional interactions required to support the needs of the vision- and hearing-impaired. These interfaces will enable two-way communication via visual and auditory interfaces that permit individuals with impairments to safely navigate the required interactions. VTTI has a longstanding history of developing user interfaces based on sound human factors principles. VTTI also has expert personnel available to design and develop effective prototypes, which will provide the basis for evaluation by transportation-challenged participants within our demonstration.

The AVRP will be designed and developed by VTTI's engineering division, the Center for Technology Development. This Center's group of hardware and software engineers work within the ADS field every day and are more than qualified to integrate the technology and capabilities needed for this vehicle build. During development, vehicle and ADS performance will be safely validated on the Virginia Smart Roads (see Part 2) on the campus of VTTI. We will build at least two ADS-equipped vehicles with the potential for more based on future component pricing and available project resources. Once readiness for field demonstration is fully verified, we will execute a carefully developed validation plan at the Northern Virginia demonstration location.

Task 4: Build Traffic Operations Center (TOC) Applications

In Task 4, we will build and test TOC applications to demonstrate how ADS-equipped vehicles can use information provided by the infrastructure to help them safely operate in dynamic scenarios. The TOC applications will include the RODDIS application described in Task 1 and a DSH application with a focus on enhanced functions supporting safe ADS-equipped vehicle operation in cooperative dynamic traffic scenarios.

The RODDIS application will provide real-time updates of roadway, environmental, traffic, and incident information from the TOC to the ADS to help determine ODD status and adjust the availability and/or parameterization of ADS functions accordingly (Figure 1-5). Transurban is currently investing in an innovative DSH traffic control strategy to improve roadway mobility. The solution will include a microsimulation-based approach to detecting downstream bottlenecks, predicting immediately near-term traffic conditions, developing speed harmonization control strategies, and generating and delivering vehicle-specific speed advisory messages directly to drivers via a smartphone application, voice command, or lights.

The team will develop the microsimulation model for I-95 roadway segments, collect historical traffic data for model calibration, integrate the microsimulation model with the new or existing DSH algorithms, and customize the interfaces via infrastructure for deployment. To demonstrate how this system could also be used with L4+ ADS to improve safety and mobility, VTTI will add logic that provides suggested operating parameters (target speed, headway, and accelerations) directly to the ADS, which will respond appropriately based on the scenario definitions.

We will further extend the DSH application to account for work zone lane closures and dynamic traffic scenario information to provide additional parameters (suggested lane selection, merge points, etc.) that assist the ADS in responding safely to dynamic roadway scenarios. The team will coordinate with participating OEMs to develop a data communication protocol to support the exchange of operating parameter commands from the enhanced DSH microsimulation model. Messages exchanged will leverage work performed under CAMP and VTTI's Advanced Messaging Concept Development (AMCD[18]) and forthcoming Event Data Configurable Messaging (EDCM) projects to define a flexible message structure for two-way data exchanges between vehicles and infrastructure. The full DSH application and data flows are depicted in Figure 1-8.

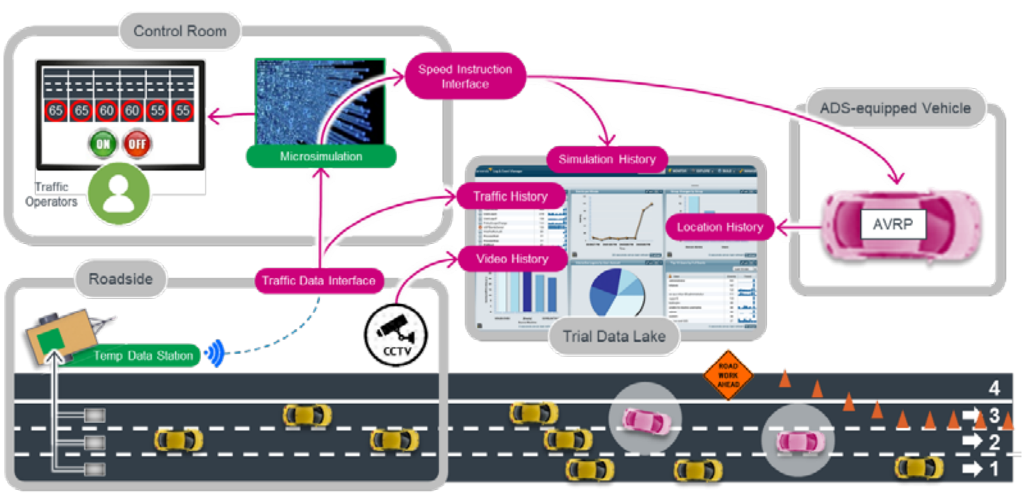

Figure 1-8. Dynamic speed harmonization (DSH) concept.

[18] Stowe, L., Abubakr, M., Adla, R., Ali, M., Casadei, S., Goudy, R., Deering, R. (2017). Advanced Messaging Concept Development (AMCD) Project Vehicle-to-Infrastructure Program; Final Report (FHWA-JPO-18-620). Retrieved from United States Department of Transportation: https://rosap.ntl.bts.gov/view/dot/37214

As the IOO for the majority of the planned demonstration area and operator of the TOC, Transurban will lead the development of the RODDIS and DSH applications. VTTI will provide support to integrate these applications with existing systems on the demonstration corridor for data management, monitoring, and communication services. VTTI will lead the integration of these applications to provide the additional enhanced information that will benefit ADS.

We will first build and test these applications on the Virginia Smart Roads facility (see Part 2), which is fully integrated into the data management and communication systems of the actual demonstration corridor. VTTI will deploy prototype versions of the real-time RODDIS and DSH applications in the Smart Roads control room (Figure 1-9) and test the responses of the demonstration ADS-equipped vehicle to suggested operating parameters.

Figure 1-9. VTTI's Smart Roads control room (left) and Transurban's TOC (right).

Through the demonstration of these cooperative ADS functions, we intend to show how ADS can be more safely integrated into modern transportation systems through interaction with the infrastructure. Our goal is not to deploy adequate volumes of ADS to impact mobility along the entire corridor which is beyond the scope of this project. But rather, we intend to demonstrate how ADS can react safety to infrastructure information and suggested operating parameters.

Task 5: Design and Conduct Demonstrations

In Task 5, we will design and choreograph three high-profile, multi-day demonstration events. Each event will include similar content but be tailored to one of three primary stakeholder groups: OEMs, IOOs, and public safety providers. The events will be held in Northern Virginia at a combination of venues appropriate to the scenarios being tested. Venues will likely include the I-95 Express Lanes, connecting arterial roadways, Transurban's TOC, and a large outdoor parking lot facility (such as VDOT's Northern Region Operations facility in Fairfax, VA). During demonstrations, participants will rotate through a series of stations that include on-road ride-alongs, a demonstration of the TOC applications in operation, and some staged events in a closed parking facility since not all aspects of dynamic scenarios may require on-road operation.

Given the broad interest in ADS, the team anticipates attendance exceeding the available capacity for participants to ride in ADS-equipped vehicles. We will reserve ride-along invitations for key primary stakeholders to help underscore the collaborative purpose of our demonstration. To be inclusive of a broader audience, we also envision using a large VDOT parking facility in Northern Virginia with several tents and demonstration areas where stakeholders can showcase their capabilities and program participation. A main viewing area with large screens and higher attendee capacity will show live video streams from the ADS-equipped vehicles along with video feeds from multiple perspectives within the dynamic scenarios as they unfold. Expert narration will be provided to explain the relevance of the scenarios, how the solutions support the safe integration of ADS into the transportation system, and where challenges remain.

For the on-road demonstrations, VTTI will select routes that provide ample opportunity to demonstrate the selected scenarios while providing the maximum level of safety for participants and the general public. We expect to include arterial roadways to support intersection-based scenarios as well as freeways to exercise higher-speed dynamic traffic scenarios. With VDOT and Transurban as partners, we have the ability to control access, when needed, to both the arterial and express lanes allowing demonstration in live traffic or on a closed course. The demonstrations are expected to include a combination of staged events and naturally occurring dynamic conditions. To ensure safety and avoid interfering with official public safety provider responses, we expect to stage most of the public safety scenarios with assistance from our public safety partners from a variety of jurisdictions. ADS responses to work zones and DSH scenarios will be demonstrated on the roadway in live traffic. Support for these scenarios will be provided primarily by Transurban and VDOT public service resources.

A series of focus group sessions will be conducted to assemble attendees and stakeholders who participated in the event. Feedback and subjective responses will be gathered to provide a collective assessment of readiness from the lens of each representative group and guide additional efforts needed prior to broad deployment.

Task 6: Data Collection, Processing, and Dissemination

In Task 6, we will collect and process the data products and prepare them for broad distribution through a robust web-based data portal. Specific data products are outlined in the *Goals* section above; here, we will focus on how the data will be produced. Maintaining and hosting the data distribution portal are discussed and budgeted separately under Task 6a.

Data will be derived from multiple complimentary sources, including on-board DAS for vehicle and sensor data, the VCC data management system for infrastructure-related data, and subjective questionnaires and focus group results that capture stakeholder perception of demonstration experiences.

VTTI will install a high-performance DAS on each demonstration vehicle during the vehicle build process in Task 3. The DAS will interface with the on-board sensors, VTTI's AVRP system, and multiple high-resolution video cameras to consolidate and synchronize the data to a common time reference. The DASs will save the data to solid-state storage media that can be removed to support an efficient data harvesting process at the end of each demonstration day. Data from the removable storage media will then be extracted and transferred to a VTTI data server and subjected to quality control to verify the data meet established VTTI data quality standards.

These bulk raw data will then be segmented to create data packages for three specific datasets: the **on-board DAS, scenario demonstration, and scenario simulation datasets**. VTTI's data reduction team (discussed in Part 2) will review the video to add annotations describing characteristics of the content (e.g., the types of scenarios included, technological solutions applied, and success or failure of the ADS interaction). GCAPS will use the raw data to develop simulations (i.e., virtual reconstructions of interactions during the demonstrated scenarios) by estimating the spatial time histories of the dynamic actors and locating static actors within the 3D environment. Any sources of personally identifying information will be removed from the data stream during data preparation.

In addition, data from the connected vehicle environment and TOC applications will be captured and stored via the VCC data management system to create the **infrastructure dataset**. These data will include messages exchanged between the ADS and TOC applications (RODDIS information, DSH data, suggested ADS operating parameters, work zone data, SPaT and MAP messages from arterials, etc.) and information about the location and activity of other actors participating in the demonstrations (BSMs from public safety assets, scenario staging vehicles, and work zones). In prior projects, VTTI applied similar data collection strategies using the VCC data management system to evaluate various connected vehicle messaging strategies (AMCD [19]) and communication performance (SPaT and MAP latency). In both cases, infrastructure messages were captured on the VCC servers in parallel with on-board unit data collected from connected vehicles, and both were synced in post-processing to provide a basis for system performance analysis. Data collected through the VCC Cloud will be exported to downloadable data files in near-real time (within days of the demonstration events). Infrastructure data will be exported to flat data files with metadata that will be distributed through the data portal.

Feedback about the demonstration, including participant trust and comfort along with stakeholder perception of readiness, will be captured with IRB-approved surveys and focus groups to create the **subjective assessment dataset**. Participant data will provide meaningful readiness assessments from the perspective of each stakeholder group. Subjective assessment data will be compiled into data files with metadata for distribution through the data portal.

Data will be captured during both the final testing phases and the actual demonstrations to increase the volume of data captured. Task 6 will be conducted in parallel with final testing and subsequent execution of the demonstrations to assure timely delivery of all data collected and processed as a result of this program.

Task 6a: Data Storage and Hosting

To facilitate distribution of data to USDOT and public consumers, VTTI will leverage its AMP data portal platform (Figure 1-10) to deploy a new web-based public data distribution hub for housing data collected during this program. As in the existing AMP data portal, the portal for this project will allow data consumers to self-register and browse for data and scenarios of interest based on a wide variety of annotation and metadata filter criteria. Individual scenarios may be played back through a scenario viewer tool that displays DAS-related measures synchronized with video sources. The data packages (including sensor data exports, video, and simulations) for each scenario may be downloaded by the end user. Dataset descriptions and data dictionaries will also be made available to download from the portal.

The infrastructure and subjective assessment datasets will be posted to the portal as exported flat files and may be downloaded via links on a data products page along with data dictionaries

[19] Stowe, L., Abubakr, M., Adla, R., Ali, M., Casadei, S., Goudy, R., Deering, R. (2017). Advanced Messaging Concept Development (AMCD) Project Vehicle-to-Infrastructure Program; Final Report (FHWA-JPO-18-620). Retrieved from United States Department of Transportation: https://rosap.ntl.bts.gov/view/dot/37214

that will describe all measures and data collection methods. Once the data packages are processed, as outlined earlier, they will be posted to the project portal, which will be hosted from Amazon Web Services (AWS). The data portal and all data products will be hosted by VTTI on AWS for a period of five years after the conclusion of the project, as detailed in Part 3.

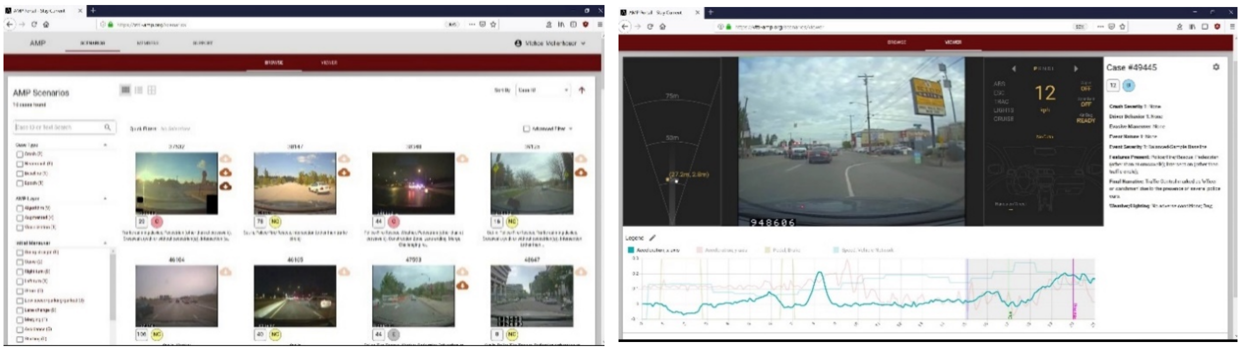

Figure 1-10. Demonstration data will be distributed through a VTTI data portal similar to the existing AMP data portal (left). The right-side image shows the corresponding event viewer.

Approach to Addressing Legal, Regulatory, Environmental, and Other Obstacles

VTTI has been performing vehicle testing and demonstrations on closed courses, such as the Virginia Smart Roads, and public roads for the last 25 years. VTTI is confident in its ability to conduct the demonstrations in the Commonwealth of Virginia. In preparation for the demonstrations, the project team will work with federal, state, and local government agencies to keep them informed of plans for safety management. The Commonwealth regulatory framework for testing of ADS-equipped vehicles is straightforward. The laws and regulations related to human-operated vehicles apply to ADS-equipped vehicle operations. A human safety driver is required to be behind the controls and responsible for the vehicle's operation during the testing periods. We will include a safety driver for all testing periods along with several other safeguards (e.g., emergency stop button and additional vehicle monitoring). The safety driver will ensure all general laws are followed. Insurance, licensing, and registration will be maintained for demonstration vehicles. Within these provisions, the ADS-equipped vehicle demonstrations can be conducted on the roadways identified for this project:

1) The I-95 Express Lane facilities in the greater Washington, D.C. area, which are operated by Transurban through a public–private partnership;
2) Arterials that approach and provide access to the I-95 Express Lanes; and
3) A parking lot facility in Northern Virginia that can support a media event and collection of tents/booths with partner displays.

VTTI, Transurban, VDOT, and the Virginia DMV have past experience collaborating to conduct successful demonstrations of ADS technology on these same roadways. In 2016, they collaborated to conduct a demonstration of how a vehicle equipped with a L3+ ADS prototype could safely interact with work zones, police vehicles, and various traffic scenarios along a 15-mile stretch of I-395 and Transurban's Express Lanes facility. These examples demonstrate VTTI's prior ability to safely navigate and address any local and/or state regulatory obstacles to demonstrate ADS-equipped vehicle technology.

VTTI is familiar with and understands the regulations associated with NHTSA's Federal Motor Vehicle Safety Standards (FMVSS). The modifications to equip the vehicles with the ADS technology will not affect the vehicle's FMVSS (49 CFR Part 571) compliance. Vehicle systems that are covered by FMVSS (e.g., lighting, brakes, restraint systems, controls and displays, rear visibility systems, etc.) will retain the production level systems. Therefore, the demonstrations outlined in this proposal will not require a petition for exemption under 49 U.S.C. § 30113 and 49 C.F.R. Part 555.

NHTSA's Automated Vehicles 3.0, Preparing for the Future of Transportation (AV 3.0)[20] also features guidance for developers testing vehicles with ADS SAE L3-5 features. The project team will consider all applicable elements identified in AV 3.0 as well as A Vision for Safety 2.0[21] that may be relevant for the demonstrations. Finally, and most importantly, VTTI will continue to prioritize safety and leverage its expertise and standard internal safety processes for vehicle testing and demonstrations.

No exceptions to the Buy American Act or the terms of the NOFO Clause at Section F, Paragraph 2.J. entitled BUY AMERICAN AND DOMESTIC VEHICLE PREFERENCES are anticipated.

Risk Management

The project team's risk management plan follows the general management plan described in Part 2 and will ensure that potential risks do not negatively affect the completion of the demonstrations or the budget and timeline. The Task Leads (see Figure 2-2 in Part 2) will monitor potential risks related to the tasks that they oversee. Emerging risks will be reported by the project team to the Task Leads during regularly scheduled progress meetings. The leads will then report potential risks to the Program Manger and decide upon the most appropriate mitigation strategy with input from the Steering Committee, who will provide oversight and address risks related to issues within any partner organization. Several potential risks identified a priori, and corresponding mitigation strategies, are shown in Table 1. In Table 1, the risk rating refers to the impact on the project (4 = major impact, 1 = negligible impact); probability rating reflects the likelihood of the risk occurring (4 = high risk; 1 = negligible risk), and mitigation rating reflects the ability to mitigate a particular risk (4 = no ability; 1 = excellent ability). Table 1 is provided to help illustrate risk management processes but is not complete for the entire project due to space limitations in this response. The table will be expanded and refined throughout the project, and the updated risk management plan and risk log will be provided to FHWA as part of quarterly progress reports (see Table 2 in Part 2).

[20]https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf
[21] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

Table 1-1. Summary of example risks and corresponding mitigation strategies

Risk	Risk Rating	Prob. Rating	Mitigation Rating and Strategy
Lack of public safety demo participation	3	1	2 – Multiple potential public safety providers have been invited, and alternative groups could be used.
Technology malfunction/damage	2	2	1 – Proven technology will be used, and replacement parts will be available.
Delays/changes in funding	4	1	2 – VTTI will work closely with FHWA to agree on the specifics of the project and resolve funding issues.
Lost demo sessions due to weather	1	2	1 – In cases of adverse weather, indoor facilities will be used when possible.
Loss of key project personnel	3	1	2 – Multiple individuals will be briefed on the project so that they can quickly step in if needed.
Injury during testing	4	1	1 – Extensive training; VTTI has emergency protocols in place.

Contribution and Management of Non-Federal Resources

The project team is committed to contributing and managing non-Federal resources as cost share to supplement the proposed Federal resources. Team members have all contributed to the $3,697,299 total cost share, and as such, each has a vested interested in the success of this ADS demonstration program. Additionally, public services stakeholders will provide resources throughout the dynamic scenario development (Task 2) and demonstration (Task 5) components of this project. These contributions are not captured in the cost share total. The non-Federal resources contributed by project team members are summarized in Table 2. For an inclusive list of cost share contributions, please reference Part 6 of this response.

Table 1-2. High-level summary of non-Federal resources provided by team members

Cost Share Provider	Resources Provided as Cost Share
VTTI	Virginia Smart Roads for vehicle and application development and testing
	Data sharing and storage
Transurban	TOC applications providing DSH and real-time ODD information functionality
	I-95 Express Lanes and associated resources (TOC, SSP, Virginia State Police) for testing and demonstrations
VDOT / VTTI	VCC infrastructure and applications (e.g., Work Zone Builder application and Smart Vest, VCC Cloud, DSH extensions, and communications infrastructure)
CAMP	Perform lead role in the development of public service ADS interaction concepts; provide support for message and data definitions and engineering support for L4+ vehicle builds and demonstrations.