# Safe Integration of Automated Vehicles into Work Zones

**Submitted By:**

pennsylvania
DEPARTMENT OF TRANSPORTATION

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**AUTOMATED DRIVING SYSTEM DEMONSTRATION (ADS)**
**GRANT APPLICATION | NOFO693JJ319NF00001**
**SAFE INTEGRATION OF AUTOMATED VEHICLES INTO WORK ZONES**
**| PKG00247169**

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# PART 1

## PROJECT NARRATIVE

## AND

## TECHNICAL APPROACH

The Honorable Elaine L. Chao
Secretary of Transportation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Dear Secretary Chao:

The Pennsylvania Department of Transportation (PennDOT) respectfully submits our "Safe Integration of Automated Vehicles into Work Zones" application for the Automated Driving Systems (ADS) Demonstration Grant - NOFO # 693JJ319NF00001.

As a state that has always been at the forefront of innovation and industry, it should come as no surprise that Pennsylvania is at the very epicenter of the rise in Automated Vehicles (AVs). Pennsylvania's world-class research universities have continually served as a breeding ground for technological advances, with Carnegie Mellon University known as the "birthplace of self-driving vehicles." Since 2011, Pennsylvania has emerged as a leading location for on-road testing of AVs as they steadily advance toward practical use.

PennDOT has supported these advances in automation through the deployment of connected infrastructure and lobbying for uniform standards and practices. PennDOT has acted to sustain Pennsylvania's leadership in AV research, while simultaneously ensuring that the public safety remains the paramount priority.

Through the department's oversight, it has become clear that AVs do not perform well in the work zones and routinely require human intervention. In many cases, testers try to avoid work zones altogether. Unlike other AV challenges, such as variable weather conditions, work zones offer a unique opportunity for industry and the public sector to collaborate to resolve this issue and safely advance ADS technology.

The intent of PennDOT's application is to develop a consistent approach to allow for AVs to safely operate in work zones. Knowing that there is unlikely single solution, the PennDOT proposal focuses on a combination of connectivity, machine visioning, and high definition mapping. To demonstrate the viability of the solution, the project will perform the demonstrations in a variety of work zones configuration with varying scale, complexity, and duration. PennDOT plans to take a systematic approach of working with testers to verify the proposed AV solutions. First, all solutions and approaches will be run through multiple simulations. Then demonstrations will occur on a controlled, closed-course environment in State College. Eventually, upon successful testing, PennDOT will work with the project team to safely integrate the solutions into limited, small-scale demonstrations.

PennDOT has assembled a comprehensive team of subject matter experts including representation from state and local government, metropolitan planning organizations, academic partners, equipment manufacturers, data management specialists, and members of industry. It was important to PennDOT to have this variety of collaboration to ensure we can harness the collective expertise, ingenuity, and knowledge of multiple stakeholders. In addition to the unparalleled expertise, the team will also provide existing equipment/facilities and is willing to share all safety performance data generated throughout the demonstrations. Unique to the PennDOT proposal, all members of the project team have presence in Pennsylvania, with 75% of the members being headquartered in the Commonwealth.

Receiving the ADS Demonstration Grant award would allow Pennsylvania to continue to advance AV efforts and remain a leader in this technology. I thank you for your consideration and should you have any questions, please feel free to contact Mark Kopko, our Special Advisor on Transformational Technology, at (717) 783-1903, or markopko@pa.gov.

Sincerely

Leslie S. Richards, Secretary
Pennsylvania Department of Transportation

# Summary Table

| | |
|---|---|
| Project Name/Title | Safe Integration of Automated Vehicles (AV) in Work Zones |
| Eligible Entity Applying to Receive Federal Funding | Pennsylvania Department of Transportation |
| Point of Contact (Name/Title; Email; Phone Number) | Mark Kopko<br>Special Advisor – Transformational Technology, Office of the Secretary<br>markopko@pa.gov |
| Proposed Location (State(s) and Municipalities) for the Demonstration | Pennsylvania (State College and various other locations to be determined prior to demonstration) |
| Proposed Technologies for the Demonstration (briefly list) | Connectivity between AV and traffic control devices, construction workers, and construction vehicles using a single device with DSRC/CV2X radio;<br><br>Innovative Coating for pavement markings, traffic control devices, construction workers, and construction vehicles;<br><br>High definition work zone mapping using RADAR, LIDAR, and Cameras; |
| Proposed duration of the Demonstration (period of performance) | Four (4) years |
| Federal Funding Amount Requested | **$9,559,817.37** |
| Non-Federal Cost Share Amount Proposed, if applicable | $2,841,575.28 |
| Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable) | $12,401,392.65 |

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# I. EXECUTIVE SUMMARY

***Introduction***

According to a 2017 Wired article [1], "Google and Delphi cite construction as a common reason their human engineers take control of the wheel while testing." AVs do not perform well in the work zones. Through this grant application, the Pennsylvania Department of Transportation (PennDOT), the applicant, and the project team propose to solve the challenge of safe integration of AVs into most work zones by examining if improved connectivity, enhanced visibility, and high definition mapping will enable AVs to safely travel the work zones.

Our team consists of members, who has expertise, experience, capability, capability to conduct the demonstration:

- ***Core team***: PennDOT; Pennsylvania Turnpike Commission (PTC); Pennsylvania State University (PSU); and Carnegie Mellon University (CMU)
- ***Consultant team***: HNTB; Michael Baker International (MBI); Deloitte Consulting LLC (Deloitte); and Drive Engineering Corp (Drive)
- ***Industry partner:*** PPG Industries, Inc (PPG);
- ***Technical advisory***: Project Team; Qualcomm;
- ***Community of Support:*** Cities, Planning Commission; SAE; Ford; Argo; Volvo/Mack; and others.

Our team proposes to demonstrate how the operation of AVs in work zones can be tested, improved and standardized in three phases as shown:

- Phase I – Planning
- Phase II – Deployment
- Phase III – Post-Deployment


During Phase I, we will plan for the deployment of the testing and analysis phase using the project management and systems engineering approaches and develop appropriate planning documentation. In we would have a data management system developed and ready for accepting data.

During Phase II, our team will implement and deploy the plan developed as part of Phase I. Based on PennDOT's experience, our team has identified **17 common work zone scenarios/configurations in different urban, rural, and suburban settings on limited access facilities and urban arterials**, typical to not only Pennsylvania, but other states too. Each work zone scenario, setup will include the lane configuration and traffic control devices as identified in PennDOT's Publication 213 - Temporary Traffic Control Guidelines. In addition, connectivity equipment including DSRC/C-V2X will be added to the appropriate traffic control devices, construction workers and vehicles (collectively called work zone artifacts). Pavement markings and work zone artifacts will be enhanced with special coatings developed by PPG to improve visibility specifically for the AVs.

For each of the 17 work zone scenarios, our team will conduct simulation and closed track testing at the PSU test track in State College, PA. In addition, **our team will conduct live on-road testing for at least three of the work zone scenarios including one (1) demonstration in an urban environment, one (1) on a limited access facility, and one mobile environment. .**

The simulation and testing processes include mapping the work zone in high definition with PSU's enhanced mapping vehicle, making the map accessible to CMU's AV and operating the AVs through the simulation, staged work zones in the closed track and live on-road environment. PSU's vehicle has enhanced capabilities to produce accurate, 3$^{rd}$ party work zone mapping. Throughout the simulation and testing process, mapping data, vehicle data, connectivity ecosystem data, operational data and safety performance data will be collected and stored in a cloud-based Data Management System (DMS) for open access by the United States Department of Transportation (USDOT) and the public (Refer to Part III of this application). In addition to data collection, our team will attempt to standardize the map information so that it can be disseminated in real time to any AV.

**During Phase III**, our team will evaluate the performance of the demonstration project by following the procedures identified in the Project Evaluation Plan, developed during Phase I.

***Project Vision, Mission, Goals, and Objectives***

**Vision** – Enable automated vehicles to safely operate in work zones without human intervention.
**Mission** – Reduce traffic fatalities and increase mobility for all Americans in work zones through automated vehicles.
**Goals** – Achieve safe navigation of automated vehicles on par with non-distracted, human-operated automated vehicles within work zones.
**Objectives** –

1. Evaluate the impact of improved connectivity between the AVs and the work zone artifacts using DSRC/C-V2X.
2. Evaluate the impact of increased visibility (machine vision) of pavement markings and work zone artifacts on AVs through innovative coatings
3. Evaluate the impact of providing high definition mapping of work zone artifacts (i.e. cones, barrels, workers, vehicles)
4. Improve the map information dissemination process from the mapping providers and/or infrastructure owners/operators to the AVs through standardization of digital mapping information for work zones.

***Issues and Challenges, Technologies Demonstrated, and Performance Improvements***

***Issues and Challenges –*** Work zones present significant issues and challenges for AVs including: (i) dynamic work zones present unfamiliar conditions, (ii) work zones elements such as barrels, cones, flashers, flaggers, and hand signs present different set of visual cues and conflict with pavement markings, (iii) in urban areas, the presence of pedestrians, bicyclists, transportation challenged populations, and transit vehicles in the work zones increases the complexity of the environment, (iv) night time work zone operations present different bright lighting conditions, and (v) mobile work zones are even more challenging, requiring precise location tagging technology. These challenges will be addressed in our demonstration project.

***Technologies Demonstrated –*** Our proposal seeks to demonstrate the following technologies: (i) Connectivity between AVs and work zone artifacts using connectivity equipment (DSRC and C-V2X radios), (ii) innovative coating for pavement marking and work zone artifacts, (iii) high definition work zone mapping using Radio Detection and Ranging (RADAR), Light Detection and Ranging (LIDAR) and cameras, and (iv) integration of simulation-based analysis of traffic impacts with data obtained from closed-track and live-traffic studies.

***Performance Improvements –*** Our team anticipates the following performance improvements based on the use of proposed technologies and improved processes: (i) connectivity between AV and work zone artifacts will result in improved minimum distance between them, (ii) coating of pavement marking and work zone artifacts will result in improved detection range, detection accuracy and classification accuracy of work zone artifacts, (iii) high definition digital mapping will result in improved map consistency, reduced error in lane marker offset from centerline, reduced error in GPS offset from centerline, improved accuracy of road profile and reduced positioning error, and (iv) development of a standardized mapping format of work zones for the AVs.

***Geographic Area -*** Our closed track testing will be conducted at the Penn State Lawrence Transportation Institute test track in State College, PA and the live on-road testing will be conducted on a limited access facility (freeway) and a conventional highway (urban environment) within Pennsylvania. Exact location of the on-road testing will be determined during the deployment planning stage to align with planned activities.

***Proposed Period of Performance –*** Planning for the demonstration would occur during year 1 following project award, followed by deployment in years 2 and 3, and the post-deployment phase in year 4.

# II. GOALS

***Safety***

Our project proposes to test the safe integration of AVs into work zones by increasing connectivity, increasing visibility, and high definition mapping.

In 2015 there were an estimated 96,626 crashes in work zones, an increase of 7.8 percent from 2014.[2] This makes 2015 the second year in a row that work zone crashes rose after a low of 67,887 in 2013. In 2009, there were 667 work zone fatalities. Crashes in highway work zones have killed at least 4,700 Americans – more than two a day – and injured 200,000 in the last five years alone. There are more than 40,000 injuries in work zones each year. About 85 percent of people killed in work zones are motorists, not workers.

In Pennsylvania, the number of work zone crashes has steadily increased since 2007, as shown in Figure 1. Pennsylvania has also consistently appeared in the top 10 states with the most commercial motor vehicle related work zone crashes.

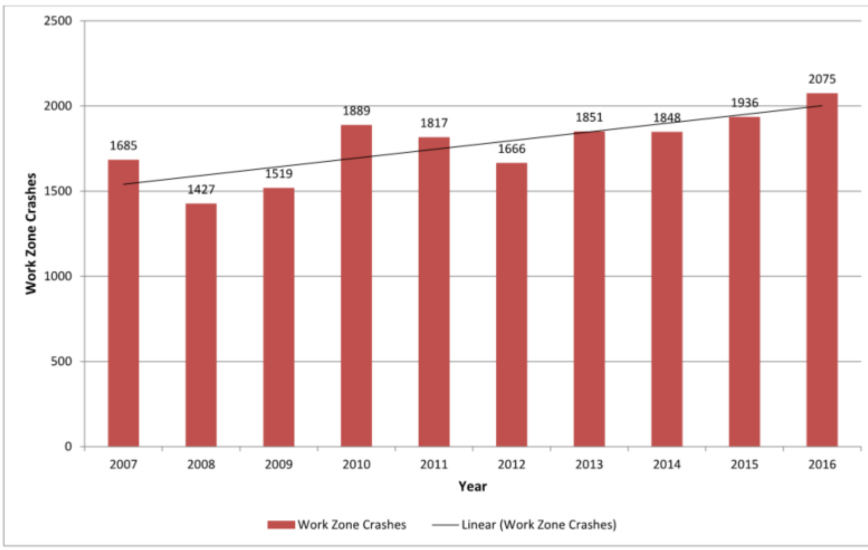


*Figure 1: Number of Work Zone Crashes*

Our project intends to improve safety in and around work zones for AVs by increasing identification and connectivity with work zone artifacts, improving visibility by coating pavement marking and work zone artifacts, and improving mapping of work zones.

### *Data for Safety Analysis and Rulemaking*

Our project proposes to conduct simulation, closed track testing and live on-road testing to evaluate the impact of connectivity, coatings, and better mapping to ensure safe operations of AVs in work zones. Through the simulation and testing process, vehicle data, connectivity ecosystem data, RADAR data, LIDAR data, camera imagery, operational data and safety data will be collected and stored in near real time in a Data Management System (DMS) throughout the deployment phase.

**Our team anticipates data collection of up to 80TB**; the collected data will be made available for USDOT and the public through the DMS managed by PennDOT. It will remain available for at least 5 years to allow researchers and rulemaking groups to analyze it under various operational scenarios and conditions.

### *Collaboration*

Our team consists of State Agencies including PennDOT and PTC committed to providing safer transportation systems, along with universities including CMU and PSU, industry experts including PPG and Qualcomm, and consultants including HNTB, Michael Baker, Drive and

Deloitte. Together, we will create a collaborative environment that harnesses the collective expertise, ingenuity and knowledge of multiple stakeholders.

In addition, our team can rely on the support of many other stakeholders including federal, state and local government, law enforcement, technology companies; higher education, manufacturers, transportation-challenged population, motorists and trucking groups and academic research institutions. Many of these stakeholders are part of a Pennsylvania Autonomous Vehicle Policy Task Force, which was created by PennDOT in 2016. Through this task force, PennDOT and the majority of our team members have been consistently engaged with stakeholders even before the conception of this project.

Our team has received letters of support for this demonstration from 22 of our stakeholders. These letters of support are attached as part of Part 4 of this grant application.

## III. FOCUS AREAS

### *Significant Public Benefits*

Our intent is to save lives. Our project components, including connectivity, coatings and high definition of the work zones will result in significant safety benefits for the traveling public.

Between 2011 and 2016, distracted driving has led to nearly 500 fatal crashes in work zones.[2] AVs have the potential to prevent all these fatal crashes by eliminating distracted driving.

Further, connectivity between the AVs and work zone artifacts (including construction workers), will allow the AVs to “see” them better. Over the past 100 years, researchers have improved roadway safety by making road signs and markers more visible to the human eye and readily understood by the driver. By the same token, PPG’s coatings will make pavement markings and work zone artifacts more visible to the new machine eyes of autonomous sensors.

Finally, providing an accurate map to the AVs in the work zone will help them navigate more safely.

Beyond the primary benefit of safety, reducing crashes in work zones will also decrease congestion and improve mobility and productivity.

### *Addressing Market Failure and Other Compelling Public Needs*

Our project focuses on a much-needed use case, which lacks adequate incentives to participate due to the risk and complexity involved in AV operation in work zones. Safe integration of AVs in work zones serves a compelling public need: **saving lives**.

AV testing in the work zone has remained one of the key gaps in viable research to date, resulting in a glaring weakness of this technology: the inability for AVs to operate in nearly any work zone. Though there are consistent marking and notification protocols for work zones, they are often complicated or confusing due to lane markings that have not been completely removed, old lane markings that left shadows, seams in the pavement that misalign with lane markings and signage that may be inconsistent. Our project will address this market failure condition of safe integration of AVs into work zones.

***Economic Vitality***

Our project will support economic vitality at the national and regional level, including advancing domestic industry and promoting domestic development of intellectual property.

All the team members proposed for this project are U.S.-based companies. PennDOT, PTC, CMU, PSU, PPG, Michael Baker and Drive all have their headquarters in Pennsylvania. HNTB and Deloitte have several offices in Pennsylvania. Our team members employ several hundred thousands of employees in PA and around the Country.

Connectivity equipment, traffic control devices and the coatings proposed for our project are also areas for potential economic growth. The success of AVs in the U.S. will bring economic vitality to the local supply chain that supports it. Our project proposes to procure all connectivity equipment, traffic control devices and coating materials according to Buy America Act requirements.

Also, Pennsylvania is investing millions of dollars in the improvement of existing roads, building new roads and moving freight through the state. As such, countless work zones will be required over the next several years. Work zone incidents – especially those involving freight traffic – have the potential to negatively impact the economy in addition to loss of life and property damage. Smooth operation of AVs in work zones is in the best interest of not just increased mobility but also the economic vitality of the region.

Our project will support economic vitality through helping establish the standards that can be used by developers of ADS technology.

***Complexity of Technology***

Identifying and maneuvering through work zones is one of the most complex autonomous vehicle scenarios and will require systems operating at NHTSA-defined Level 4 automation or higher. This level of automation comprises complex systems with sensors detecting the environment in real time and adjusting to it.

The connectivity component of work zone implementation requires vehicles to constantly detect work zone vehicles, mobile work zone roadside equipment and most importantly, work zone crews.

For the DMS component, the AV needs to receive updated mapping information of the work zone area prior to arrival at the work zone.

In terms of visibility, PPG's technologies range from easy-to-use coatings for temporarily masking standard road lines to more complex coatings that provide hidden symbols to ADS that don't interfere with what the human eye sees.

Successful implementation requires a total synchronization of all the technological components involved.

*Diversity of Projects*

Our project serves a variety of communities including urban, suburban and rural environments. Our closed test track facility is in a rural environment. We are planning on testing in live, on-road work zones in urban and suburban environments.

In addition, showing successful integration of AV into work zone, the technology and the process identified in this demonstration can be scalable for variety of transportation markets including freight, personal mobility and public transportation.

*Transportation Challenged Populations.*

Successful demonstration of AVs in work zones will encourage widespread adaptability of AVs by the public, which will increase the mobility of the transportation challenged population based on other programs focused on these population. By our project removing a barrier to broad implementation, our project indirectly improves the mobility of these populations.

In addition, our project proposes connectivity and machine-readable coatings for work zone artifacts. Third party developers may leverage the connectivity and coatings within the work zone to develop an app for personal information devices to notify the transportation-challenged population of the presence of work zones, work zone artifacts and AVs within the work zone. In addition, the app can warn the transportation-challenged population when an AV is moving in a manner that appears to create an unsafe condition.

*Prototypes*

All the planned components for our project are, at a minimum, in a limited prototype state suitable to support safe deployment and meet all applicable safety standards.

For the vehicle component, our project proposes to use PSU's mapping vehicle and CMU's AV. They are both already in operational use and meet all applicable safety standards.

For the connectivity component, our project proposes a neutral position between Dedicated Short-Range Communication (DSRC and Cellular V2X (C-V2X) for communications between vehicles, and between vehicles and the infrastructure. The project will employ both technologies, supporting development of standards for both communication media.

For the coating component, all technologies proposed by PPG are a minimum TRL of 4, meaning they have been demonstrated to operate at a lab scale. Some lab work may be necessary to customize the coating to work in the specific end use. For example, PPG has tested Lidar enhanced coatings on cars to prove the effect, but PPG may need to do some lab work to customize the formula so that it can be applied to a flexible, plastic traffic barrel. All approaches will be able to be incorporated in a field demonstration according to the PennDOT timeline.

Cloud-based data management systems are already widely available on the market.

# IV. REQUIREMENTS

Our project complies with all demonstration requirements as described below.

***R&D of Automation and ADS Technology***

Research and development of the automation and ADS technology includes the work directed toward the innovation, introduction, and improvement of products and processes as it relates to AV operations in work zones.

Our project will demonstrate the behavior of L4 or greater automation (as defined by the Society of Automotive Engineers) in work zones and evaluate the improvements to AV operations in work zones through improved connectivity, introduction of innovative coatings on pavement markings and work zone artifacts and improved mapping.

In addition, our project will attempt to standardize the map information used by the AVs, thereby improving the process of map information exchange between map providers and AV operators. Currently, AV manufacturers either create their own mapping or rely on their own mapping providers. If multiple AVs from different manufacturers need to run on the same road, they all need to map the same road individually. Through standardization of map information, our team's expectation is that the road can be mapped once and used by all AVs, irrespective of the manufacturer. The standardization of work zone mapping will also enable updating map data in real-time as AVs approach a work zone.

Our project includes traffic and operational analysis, informed by simulation to guide field studies, which in turn provide data to further challenge and refine simulations. Operational evaluation, management, and policy formation are thus facilitated by fusing map, vehicle, and traffic measurements into simulations of work-zone behavior to enable comprehensive testing.

***Physical Demonstration***

In addition to the simulation, our project will include physical demonstration of AV operations in a closed track facility for 17 different work zone configurations and in live on-road environment for 3 different work zone configurations. The live on-road testing will be conducted on one long-term work zone setup on a freeway, one short-term work zone setup in an urban environment and one mobile work zone setup in a rural environment. The exact location of the live on-road testing will be identified as part of the deployment plan.

***Gathering and Sharing of All Relevant and Required Data with USDOT***

Most AV testers balk at sharing their vehicle and ecosystem data due to its proprietary nature. Our team members, CMU and PSU, both research institutions who will be deploying and operating the ADS technology, are willing to collect and share the vehicle data, ecosystem data (RADAR, LIDAR, camera images from both the mapping vehicle and AV), connectivity data, operations data and safety related data in near real time from both PSU's mapping vehicle and CMU's AV.

Through the Pennsylvania Automated Vehicle Testing Guidance, CMU is required to report any crashes during the AV operations. CMU will provide: general location of the crash, approximate date and time of the crash and severity of the crash. In addition, as a crash investigation progresses, CMU will keep PennDOT and PTC abreast of new information relating to the cause of the crash as it becomes available. By policy, PennDOT currently shares this information.

The collected data will be stored in a secure DMS and be openly accessible to USDOT and the public for a minimum of five years after the award period of performance expires. Our team will remove sensitive CBI and PII before providing public access to project data, consistent with the public access requirement in Section F, Paragraph 2.I. of the NOFO. A draft Data Management Plan containing these details is included in Part III of this application.

***Allow Users with Varied Abilities***

CMU AV includes a touch screen user interfaces that can allow users with varied abilities to input a new destination or communicate route information. CMU vehicle also has access to information generated by the ADS through computer system connected directly to the AV.

***Scalability of Demonstration***

Our project will demonstrate the impact of technology (connectivity, coating and high definition mapping) on improving AV operations within work zones. Our project also establishes a process for conducting simulation, closed track testing and live on-road testing for additional work zone scenarios not considered for this project. In addition, our project also establishes a process for standardizing map information.

The identified demonstration technology and the process can be scaled to be applicable across the nation for any type of work zone.

***Outreach Task -*** Our team proposes to maintain a public project webpage; conduct technical outreach to the community through webinars, workshops, conferences and trade shows; coordinate with media; develop industry publications; and accommodate site visit requests to share demonstration status, results and lessons learned with other jurisdictions and the public in furtherance of technical exchange and knowledge transfer. Refer to Task II.12 of the technical approach section for additional information on our outreach efforts.

# V. TECHNICAL APPROACH

Due to the technical and complex nature of the demonstration project, a combination of project management and systems engineering approach is required to deliver the project. The project management aspect of the project will deal with describing all activities, including technical activities, to be integrated and controlled during the life of the project. Our team will use "A Guide to Project Management Body of Knowledge (PMBOK® Guide) – Sixth Edition" as a fundamental resource for effective project management as applicable on a scale commensurate with the project scope. The Systems Engineering (SE) aspect of the project will define the processes and methodologies used on the project and the relationship of SE activities to other project activities. Our project will use "Guide to the Systems Engineering Body of Knowledge (SEBoK)" as a fundamental resource for SE management as applicable on a scale commensurate with the project scope.

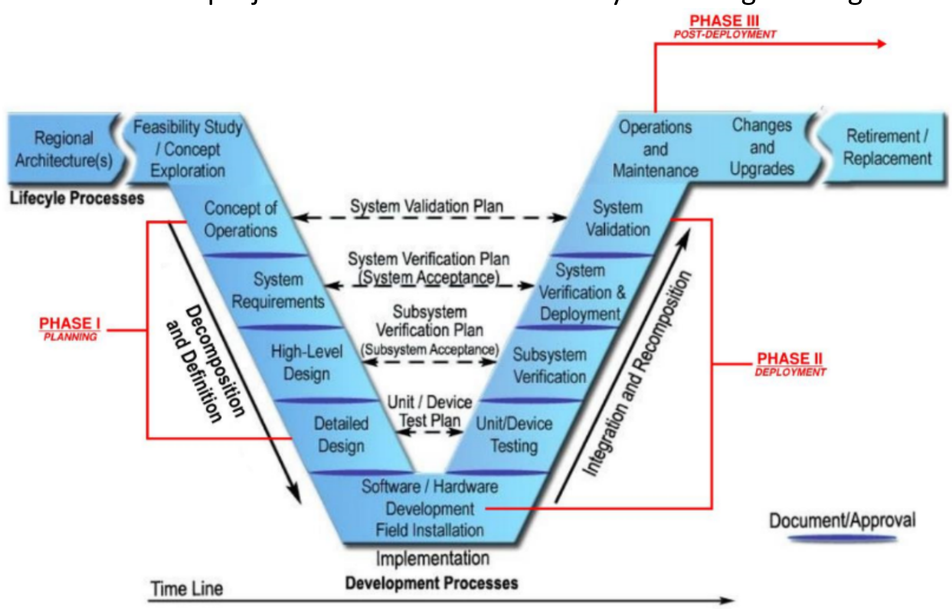


*Figure 2: Systems Engineering "V" Diagram*

As detailed above, our team proposes a three-phase approach for the demonstration of AVs in work zones – planning, deployment and post-Deployment. Figure 2 shows the Systems Engineering "V" diagram, recommended by USDOT for technical projects along with our proposed project phases. Phase I (Planning) will include the planning phase from concept of operations through detailed design. Phase II (Deployment) will include the actual deployment and testing phase. Phase III (Post-Deployment) will include the evaluation phase.

Several project management and SE related deliverables are anticipated as part of the project. For each of these deliverables, a draft version will be developed with input from the core team and technical advisors, then submitted to USDOT for their review and comments. Once comments are received, they will be addressed, and a final version of the deliverable will be submitted to USDOT.

For all the SE related documents, our team will follow the FHWA recommended document template. ([https://www.fhwa.dot.gov/cadiv/segb/views/deliverable/index.cfm](https://www.fhwa.dot.gov/cadiv/segb/views/deliverable/index.cfm))

## *PHASE I – PLANNING*

The planning phase will include a total of 12 tasks as discussed below.

### *TASK 1.1 – Project Management*

For approach and deliverables, refer to Project Management Approach section of Part 2 of this grant application. The referenced section also includes our approach and deliverables for Safety Management Plan.

***Task 1.2: Risk Management/Mitigation Plan –*** Refer to Risk Identification, Mitigation, and Management Approach section of Part 1 of this grant application.

***Deliverables*** – Electronic copies of draft and final version of the Risk Management/Mitigation Plan (RMP).

### *TASK 1.3 – Systems Engineering Management Plan*

Because of the complex interplay of all of the components within the ADS project, strict adherence to the SE process is required to minimize risk and to ensure that user needs are met, and performance goals realized. For this project, the **system engineering process will be constrained to the data management system, the mapping system and field components. System engineering for both the automated vehicle and the mapping vehicle systems is outside the scope of this project as they already exist**.

The Systems Engineering Management Plan (SEMP) will detail the SE processes to be followed for this project. Our team, led by HNTB with support from other team members, will develop the SEMP. At a minimum, the SEMP will describe: technical challenges of the project addressed by the SE process; processes needed for requirements analysis; design processes and design analysis; necessary supporting technical plans; stakeholder involvement; required technical staff and development teams; and interfaces between the teams.

Our team will develop the SEMP in two steps. In the first step, the framework for the document will be prepared with enough detail to identify all the needed tasks and any important constraints on the performance of a task. In the second step, the various sections of the SEMP framework will be completed by the team that will perform each task. For instance, the requirements team will provide details on the analysis and the tools used to manage requirements.

***Deliverables –*** Electronic copies of draft and final version of the SEMP.

### *TASK 1.4 – Concept of Operations*

Our team, led by PennDOT with support from other team members, will develop the Concept of Operations (ConOps). Due to the demonstration nature of the project, a simple ConOps will be developed, which will identify the following:

- Stakeholders and roles and their needs
- Alternative operational approaches

- Operational scenarios including normal, maintenance and failure
- Operational, support, and external environments
- Use cases and test scenario
- System constraints

***Deliverables –*** Electronic copies of draft and final version of the ConOps.

***TASK 1.5 – Systems Requirements and Testing Plan***

Our team, led by HNTB with support from other members, will develop a System Requirements Specification (SyRS) document based on the ConOps and meeting the requirements of PennDOT and USDOT for technology projects.

Our team will develop initial requirements based on stakeholder needs and inputs received as part of ConOps and other project meetings. We will analyze, refine, decompose, finalize and then validate them through stakeholder walkthroughs with the core team and technical advisors and tracing requirements to an associated need. We will provide a Requirements Traceability and Verification Matrix (RTVM), **tracing requirements back to needs** defined in the ConOps. Once the requirements have been accepted and a baseline established, changes to the requirements will be controlled using a change management process, which will be defined as part of SEMP.

Our team, led by Drive with support from other team members, will also develop a test plan for verifying the requirements at each step.

***Deliverables –*** Electronic copies of draft and final version of the System Requirement Specifications; Electronic copies of draft and final version of Test Plan.

***TASK 1.6 – System Architecture and Standards Plan***

Our team, led by HNTB with support from other team members, will develop the System Architecture and Standards Plan (SASP).

Our team will use the USDOT's Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) architecture framework (https://local.iteris.com/arc-it/), which includes a set of interconnected components that are organized into four views that focus on four different architecture perspective: Physical; Enterprise; Functional; and Communications. Our team will use the SET-IT tool, developed by USDOT, to develop these architecture views and identify applicable ITS Standards.

In addition to the SASP, a high-level system design specification will be developed by HNTB with support from other team members. The system design will translate the requirements into a hardware and software design that can be built. The system design will describe the design of the system and the internal and external interfaces in sufficient detail that its component parts can be procured and built. It is anticipated that the system and equipment will be available as a

Commercial Off the Shelf (COTS) system and hence only one minimal documentation will be developed.

The system architecture and system design for the data management system will be developed as part of the Data Management Plan.

***Deliverables*** **–** Electronic copies of draft and final version of the SASP; Electronic copies of draft and final version of High-Level System Design Specification.

***TASK 1.7 - Deployment Plan***

Our team, led by CMU who will be responsible for the AV simulation and driving the AVs in work zones in closed track and live on-road environment, will develop a Deployment Plan **applicable for simulation, closed track testing, and live on-road testing**. The deployment plan will include, at a minimum, the following for each of the test scenarios: deployment summary, deployment risks, deployment location map, applicable PennDOT work zone setup standards, deployment schedule/person responsible, deployment requirements (equipment and hardware/software), deployment communication plan, and an integration plan, if applicable.

Our deployment approach for this project is identified under Phase II. This deployment approach will be refined as we go through the project planning process from Concept of Operations through design phase. The deployment approach for the Data Management Plan will be identified in the Data Management Plan.

***Deliverables*** **–** Electronic copies of draft and final Deployment Plan.

***TASK 1.8 – Operations and Maintenance Plan***

Our team, led by Michael Baker with support from other team members, will develop an Operations and Maintenance (O&M) Plan. The O&M Plan will identify, at a minimum: the aspects of the system needing operations and maintenance; identify the manuals and procedures that are to be used in operations and maintenance; identify the personnel responsible for operations & maintenance; and include detailed configuration management procedures of the deployment components. The O&M procedures will be verified and updated during the test deployment of the systems.

The AVs and mapping vehicles are currently owned and maintained by our team members CMU and PSU respectively. These partners will continue to operate and maintain their vehicles. The new systems and equipment that will be procured as part of this project include the DMS, connectivity (V2X) related equipment, and traffic control devices. The O&M plan will be developed for these systems and equipment.

***Deliverables*** **–** Electronic copies of draft and final version of the O&M Plan and a written evaluation of the O&M Plan after deployment is complete.

***TASK 1.9 – Data Privacy and Data Management Plan***

Within 60 days after effective date of award, our team, led by Deloitte and supported by other team members, will develop a Data Management Plan (DMP), which will also address data privacy and data sharing. The DMP will include: a) a description on how data will be managed during and after the project, including non-public data provided to the USDOT for analysis and data to be shared with the public in accordance with paragraph 7.4.2 of the U.S. DOT Public Access Plan. b) delivery of data and associated documentation as outlined in the DMP.

Our team has developed a Draft Data Management Plan for project and included it in Part 3 of this application. The Draft Data Management Plan identifies our approach to data management, which will be refined throughout the project.

***Deliverables* –** Electronic copies of DMP updated as needed on a quarterly basis.

**TASK 1.10– Project Evaluation Plan**

Within 90 days after effective date of award, our team, led by PSU and supported by other team members, will develop a draft Project Evaluation Plan. Our team will adopt and customize the USDOT-recognized 10-step approach for performance measurement in developing the Project Evaluation as shown in Figure 3.

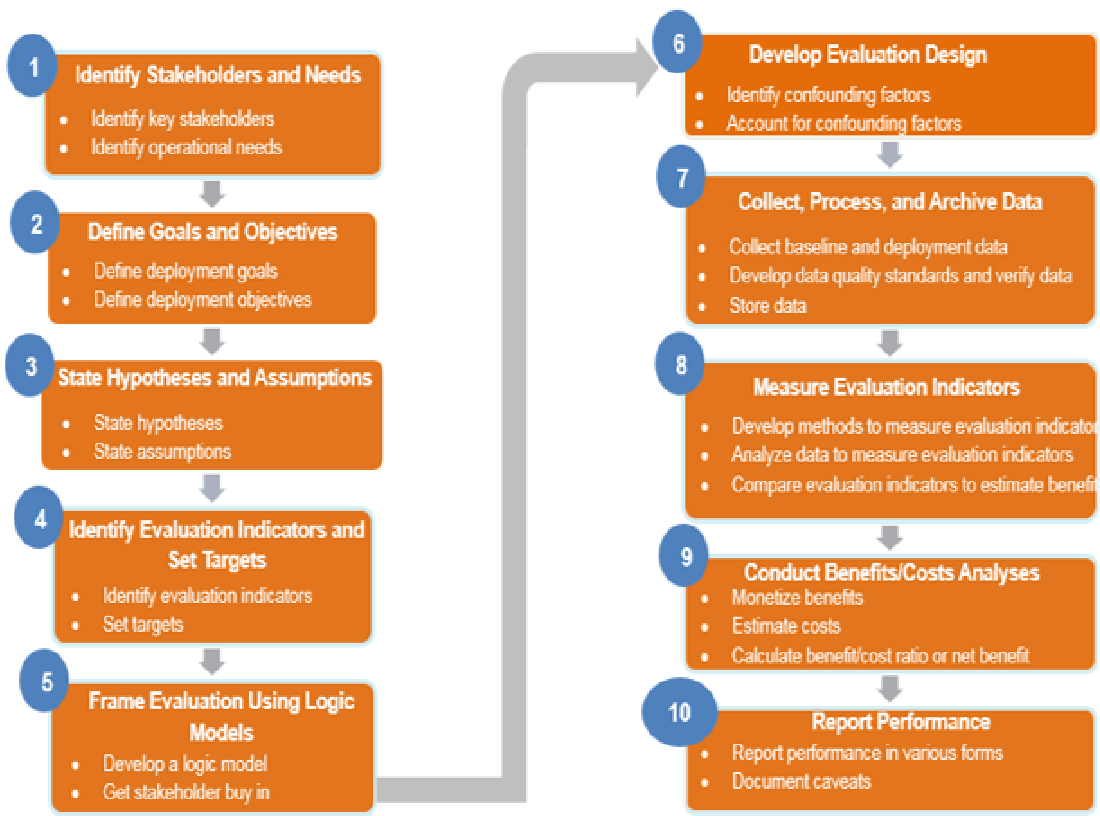


*Figure 3: Project Evaluation Approach*

*(Source: Methodology to Evaluate the Benefits of Cooperative System Applications Report)*

The evaluation plan will include, at a minimum: a) Statement of **Project Objectives** b) List of **Evaluation Criteria** (e.g. quantitative performance metrics and/or qualitative assessments) tailored to the Project Objectives and c) Description of **data-collection procedures** tailored to these criteria, which could include, for example, before/after data, surveys, interviews, system-monitoring data, or other data needed to report on achievement of project objectives. d) **Outline of Evaluation Report** (1-page, draft list of topics to be addressed). e) Description of **data system** where evaluation data will be stored, and how USDOT analysts and public will be provided access to the system.

Due to the demonstration nature of the project, our team will not set targets for the metrics. In addition, we will not conduct a cost/benefit analysis for the project.

Our team will also support an independent evaluation by a third party, if applicable.

***Deliverables* –** Electronic copies of draft and final Project Evaluation Plan; Electronic copies of draft and final Independent Evaluation Support, if applicable.

**TASK 1.11 – Human Use Approval**

This project will involve human drivers to be present within the AV both during the closed track testing and live on-road testing. Our team acknowledges the requirement to comply with 49 CFR Part 11 and 45 CFR Part 46 governing the establishment of an Institutional Review Board (IRB) and the protection of human subjects in connection with all proposed research activities.

Both PSU and CMU have conducted several research studies with human subjects in the past and have an established IRB process for review and approval of use of human research subjects.

Our team member, DRIVE, will coordinate with PSU IRB [3] (for closed track testing) and CMU IRB[4] (for live on-road testing) to prepare and submit an IRB application for approval through their respective IRB approval systems.

***Deliverable* –** PSU and CMU IRB applications

**TASK 1.12 – Coordination, Communication, and Outreach**

Through this task, our team will assist USDOT with increasing the visibility of the ADS demonstration and its benefits on a national basis through coordination, communication, and outreach. Our team member, Drive, will lead this effort with support from other team members. Our team will develop a comprehensive outreach plan that leverages our team's expertise in the AV field. The outreach plan will include the types of stakeholders and audience for the outreach and develop strategies for each type of stakeholder and audience. We anticipate the following outreach efforts as part of this project:

***Public Outreach* –** Since public outreach will involve a national-level audience, we will develop a project-specific webpage within PennDOT's website. This will allow the public access to facts, information and points of contact for the project. We will also upload all the formal technical deliverable documents to this webpage for the public consumption.

***Technical Outreach* –** Our team will leverage our Technical Advisory team for technical outreach task. Our team will participate in up to three webinars, workshops, conferences, or trade shows per each project phase to share our project objectives, progress, successes, lessons learned and to promote the inclusion of other partners. This will include supporting USDOT booths and participation on selected panels.

***Media Coordination –*** Our team will leverage our extensive national and local media contacts and partners to coordinate with, and participate in, media events organized by our team and/or USDOT. We anticipate a minimum of three media events at each project phase. One media event per year will be held in conjunction with the ITS America Annual Meeting.

***Industry Publications –*** Our team will pitch a minimum of three stories to industry publications at both the Planning and Deployment phases and one at the Post-Deployment phase. Potential topics include the Concept of Operations, Deployment Plan, Deployment success stories and lessons learned and a project evaluation summary.

***Accommodation of site visits –*** Our team will accommodate requests from USDOT or others for up to six site visits to the closed track testing facility and/or live on-road testing.

***Critical communications –*** Our outreach plan will also include a crisis communication plan, which will contain the necessary requirements to respond to any negative or unforeseen event that coincides with deployment. Critical aspects of the plan include consideration of the message that will be communicated to all those affected, internally and externally. We anticipate up to three critical communications during the deployment phase of the project.

***Outreach Materials on Request –*** Our team will support the USDOT with addition outreach materials upon request. Materials may include news releases, high-resolution images, promotion video in high-resolution digital format with two updates, brochures and other print materials, web-site content, banners and graphics, display graphics, and visualizations as needed during the project. We anticipate up to three outreach material requests per project phase.

All outreach efforts will be coordinated with USDOT and materials will be submitted to USDOT for review and approval prior to dissemination.

***Deliverables –*** electronic copies of draft and final outreach plan; a project webpage; up to nine technical outreach events; up to nine media events; up to seven industry publications; accommodation of up to six site visits; up to three critical communication events; up to nine outreach materials on request.

### *PHASE II – DEPLOYMENT*

This section identifies a preliminary deployment approach for our project. This initial approach will be refined in the Deployment Plan, which will be developed as part of the project.

During the deployment phase of this project, the AV will be deployed and tested within different work zones scenarios in various environment including simulation, closed track testing, and on-road live testing environment as shown in Figure 4. In addition, a DMS will be deployed for uploading and sharing the data from the deployment and testing.

PennDOT has developed Publication 213 with Pennsylvania Typical Application drawings (PATA) for work zones to provide detailed guidelines for most common work zone situations. These are minimum desirable applications for normal situations, and additional protection may be needed when special complexities or potential hazards prevail.

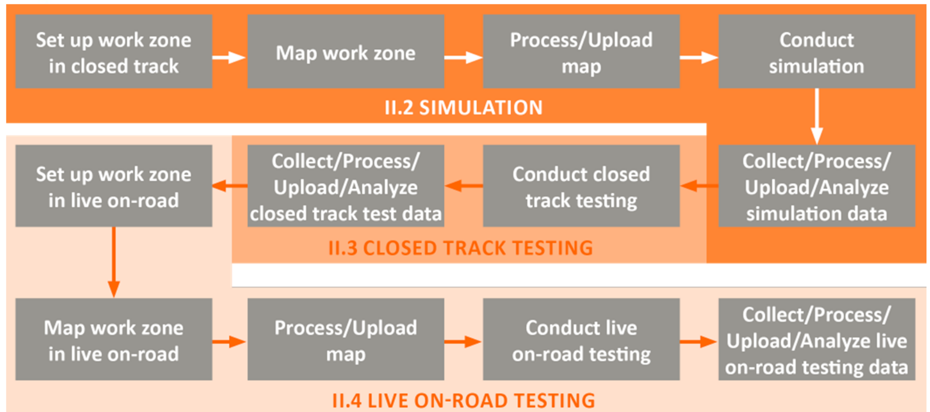


*Figure 4: AV in Work Zone Process*

Our team's goal is to deploy and test the AVs in the most commonly occurring work zones. A total of 17 work zone scenarios are shown in Figure 5. Within each scenario, there will be multiple subsets including:

- AV operations with connectivity and without enhanced coating application
- AV vehicle operations with connectivity and coating during day time
- AV vehicle operations with connectivity and coating during night time
- AV vehicle operations without connectivity but with coating during day time
- AV vehicle operations without connectivity but with coating during night time.

| No. | Scenario Description | | PennDOT Pub | Simulation | Closed Course Testing | Live On-Road Testing |
|---|---|---|---|---|---|---|
| | Number of Lanes | Scenario | | | | |
| **Use Case 1** | **Conventional Highways - Short-Term** | | | | | |
| Scenario 1.1 | Any | Work Space on or Beyond Shoulder (Minor Roadway Encroachment) | PATA 102 | X | X | |
| Scenario 1.2 | Any | Road Closure with Detour | PATA 116 | X | X | |
| Scenario 1.3 | 3 | Work Space in the Single-Lane Approach | PATA 118 | X | X | |
| Scenario 1.4 | 3 | Single Lane Closure; Traffic Shifted into Two-Way Left Turn Lane | PATA 121 | X | X | |
| Scenario 1.5 | 3 or More | Work Space in the Two-Way Left Turn Lane | PATA 122 | X | X | |
| Scenario 1.6 | 3 or More | Work Space in the Left or Right Lane of a Two-Lane Approach | PATA 124 | X | X | |
| **Use Case 2** | **Conventional Highways - Long-Term** | | | | | |
| Scenario 2.1 | Any | Detour of a Numbered Traffic Route | PATA 215 | X | X | X |
| Scenario 2.2 | 2 | Self-Regulating Stop Sign-Controlled Lane Closure | PATA 205 | X | X | |
| Scenario 2.3 | 2 | Temporary Roadway | PATA 206 | X | X | |
| Scenario 2.4 | Temporary Signals | Complex Condition; Trailer-Mounted Signals | PATA 706 | X | X | |
| **Use Case 3** | **Conventional Highways - Mobile** | | | | | |
| Scenario 3.1 | 2 or More | Moving Lane Closure | PATA 303 | X | X | |
| **Use Case 4** | **Freeways and Expressways - Short-Term** | | | | | |
| Scenario 4.1 | 2 or More | Work Space in the Left or Right Lane of a Two-Lane Approach | PATA 402 | X | X | X |
| Scenario 4.2 | Divided | Lane Closure Near a Freeway or Expressway Exit Ramp | PATA 404 | X | X | |
| Scenario 4.3 | Divided | Lane Closure Near a Freeway or Expressway Entrance Ramp | PATA 405 | X | X | |
| **Use Case 5** | **Freeways and Expressways - Mobile** | | | | | |
| Scenario 5.1 | 2 or More | Work Space in the Left or Right Lane | PATA 602 | X | X | X |
| Scenario 5.2 | Divider or One-Way | Work Space in Any Lane of a Three Or More-Lane Approach | PATA 603 | X | X | |
| **Use Case 6** | **Others** | | | | | |
| Scenario 6.1 | 2 or More | Freeways and Expressways - Long-Term Shouder Lane Use | Not Applicable | X | X | |

*Figure 5: Work Zone Setup for demonstration*

The connectivity may be provided by DSRC and/or CV2X and the coating composition may also be varied as subset scenario.

These test scenarios, along with all subsets, will be refined and finalized during the Concept of Operations phase.

**Task 2.1 – Data Management System**

Refer to Part 3, Draft Data Management Plan for the implementation approach to data management system. DMS will be developed as part of Phase I. In Phase II, DMS will be used for data storage and retrieval.

***Deliverables –*** Cloud Based Data Management System

**Task 2.2 – Simulation**

The Simulation task will include the following:

***Set up work zone in closed track –*** The testing process for any given scenario starts with the simulation of the AV operations in the work zone. Work zone simulation will be done by mapping the work zone setup at the closed track facility by PSU. The work zone setup will include setting up the traffic control devices and lane configuration as identified in each PATA drawing per the PennDOT Publication 213 for the given scenario.

In addition, Road Side Units (RSU), which provides connectivity with the traffic control devices, construction workers, and construction vehicles will be installed and tested. Our approach will utilize a neutral position between DSRC and C-V2X and will employ both technologies. Qualcomm is one of part of our technical advisory committee and is committed to providing us with technical assistance in the connectivity ecosystem.

An alternative work zone setup will include the pavement markings and work zone artifacts coated with the PPG's coating material, which will allow the AVs to "see" these artifacts better.

It is anticipated that the work zones will be less than half mile in length.

***Map work zone –*** Once work zone is setup, PSU will use their mapping vehicle to map the work zone. The PSU team is proposing to deploy its mapping vehicle system, a unique university-owned and operated data collection system able to collect the geolocation information for lane designations, lane stripe information, camera images to assess visibility, RADAR information, and LIDAR information similar to what would be measured by an AV. The PSU team will map the work zones both with and without the coatings provided by the PPG.

***Process/Upload map –*** From these collected data, the team can process the lane definitions to assist with AV guidance; however, the ADS itself would be responsible for classification of collision hazards, guidance policy decisions, etc., as the intent of this project is to assess ADS performance and infrastructure interaction, not to design ADS.

Once processed, the PSU team will upload the map information and other camera images, RADAR information, and LIDAR information to the DMS.

The project team will develop a "standard" format for the map information. Our team will outreach to up to three (3) AV manufacturers and/or map developers to develop open data specification standards for harmonized work zone map information, which will be modeled on the General Transit Feed Specification (GTFS). It is anticipated that open data specification standards for work zone mapping will encourage an incremental adoption of data elements from the broader specification documented in the work zone Activity Data Dictionary developed through FHWA's Work Zone Data Exchange Initiative, which addresses the role of this data in use cases spanning the entire project delivery life-cycle.

Developing an industry standard for the map information is outside the scope of this project. However, the open data specification developed as part of this project will act as a stepping stone and enable a standards development agency or USDOT to help industry and non-federal governments reach agreement on common data formats that lower the cost of data exchange. This project aims to produce a repeatable approach to accelerate harmonization of map data sources across the country, and a sustainable model for stakeholders to expand and maintain such open specifications over the long-term.

***Conduct Simulation* –** CMU will use an already developed simulation software tool, which enables the simulation of connected and AVs in a virtual world. Simulation tool will use the map information provided by the PSU to configure the work zones setup along with the connectivity and coating in the virtual world. Then, CMU will instantiate work zone workers and traffic in the area to study the AV behavior in the work zone. The PSU simulation efforts will focus on traffic flow and corresponding safety impacts to surrounding vehicles.

***Collect/Process/Upload/Evaluate* –** CMU will observe, collect, process, and analyze the behavior of the AV in the simulation world. Collected data in the simulation environment would include the virtual camera and LIDAR data, safety data, operations data, and connectivity data (BSM Part I and Part II data) from the vehicles.

The collected data will be processed and uploaded in near real time to the DMS using the process and format defined in the draft DMP.

BSM data will be stored in the format identified by the Connected Vehicle Pooled Fund Study project – 5.9 GHz Dedicated Short-Range Communication Vehicle-Based Road and Weather Condition Application: Phase I. PennDOT is a member of the Connected Vehicle Pooled Fund Study and has access to the final report and format. Alternatively, BSM data may be stored in either XML or JSOB format, both of which are relatively easily parsable.

The data will also be evaluated to control the AV behavior. Following the evaluation, software tool will be used to calibrate the AV to adjust its behavior to ensure safe and correct behaviors are obtained under multiple different combinations of traffic settings.

Test results from the simulation and evaluation will be documented in the Test Results document by Drive.

***Deliverables –*** Simulation data for each scenario uploaded into the DMS; Test Result Document.

**Task 2.3 – Closed Track Testing**

Following the simulation task, a closed track testing at PSU's Lawrence Transportation Institute in State College, PA, will be conducted for all scenarios.

***Conduct Closed Track Testing -*** The work zone setup used for mapping in the simulation phase will be reused for closed track testing unless the setup has been modified or removed for any reason. Prior to the starting of the closed track testing, PSU will ensure that the field work zone setup matches the test scenario PATA. In addition, the connectivity between the AV and the work zone artifacts will tested.

CMU's AV will be pre-loaded with the map from the DMS prior to testing. Additionally, the AV will update the map using V2X in real time as shown in Figure 6. Once map is uploaded, the AV will navigate the work zone collecting the camera images, LIDAR data, and connectivity data (BSM I & II).

***Collect/Process/Upload/Evaluate –*** The collected data will be processed and ingested into DMS in near real-time using the process and format defined in the DMP (Part 3 of this application).

The data will also be evaluated to monitor and control the AV behavior. Following the evaluation, AV will be calibrated to adjust its behavior to ensure safe and correct behaviors are obtained under multiple runs. Test results from the testing and evaluation will be documented in the Test Results document by Drive.

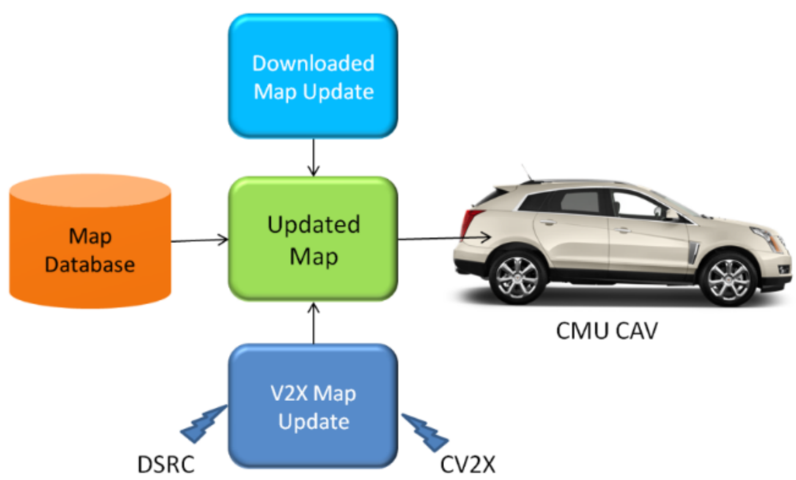


*Figure 6: Map Update Process*

***Deliverables –*** Closed track testing data for each scenario uploaded into the DMS; Test Result Document.

**Task 2.4 – Live On-Road Testing**

Due to inherent risk associated with live on-road testing, at least three of the 17 scenarios will be tested in this environment. The core team will select one scenario in each of the long-term, short-term, and mobile use cases for live on-road testing and identify an existing or proposed active work zone in which to conduct live on-road testing with live traffic. To minimize risk, the core team will select active work zones with minimal traffic to conduct this testing.

***Set up work zone in Live On-Road Traffic Testing –*** Since the live on-road testing will be conducted in an active work zone, work zone setup specifically for this testing is not required. Prior to testing, PennDOT will coordinate with the work zone construction team to ensure all involved parties are aware of the on-road testing. Also, connectivity equipment and coatings will be installed and tested in the work zone.

***Map work zone –*** Similar to the simulation phase, PSU will map the live on-road work zone following the same process followed during the simulation and closed track testing phases.

***Process/Upload map*** – Once complete, PSU will process and upload the map to the DMS. The map would be able to be downloaded to the vehicle prior to the start of the testing or updated "on the fly" using a V2X map update.

***Conduct Live On-Road Testing –*** Once the map is downloaded, the AV will navigate the work zone collecting the camera images, LIDAR data, and connectivity data (BSM I & II).

***Collect/Process/Upload/Evaluate –*** CMU will collect, process and upload the data in near real time, then evaluate it in a manner similar to the closed track testing phase. Following the evaluation, the AV will be calibrated to adjust its behavior to ensure safe and correct behaviors are obtained under multiple runs. Test results from the testing and evaluation will be documented in the Test Results by Drive.

***Deliverables –*** Live On-Road Testing data for each scenario uploaded into the database management system; Test Result Document.

## *PHASE III – POST-DEPLOYMENT*

Following the completion of deployment and testing, the project will be evaluated based on the Project Evaluation Plan, and a final evaluation report will be developed to document the research finding and the lessons learned from both the planning and deployment phases of the project.

### Task 3.1 – Final Evaluation Report

90 days prior to the end of the project, PSU will develop and submit a final evaluation report with support from the project team to USDOT for review and comment. This report will be a summary of and inclusive of the findings report developed after each testing scenario. The project evaluation report will include, at a minimum, (1) how the project has met or not met the original expectations projected in the PMP; (2) evaluation results of the project according to the Project Evaluation Plan; (3) summary of any complications experienced with the ADS demonstration, specifically outside the ADS including pedestrians, infrastructure, and/or other vehicles; and (4) how to use the demonstration results to help the public interact and better understand the operations of ADS.

Throughout the project, our team will constantly track the original expectations for the project through the PMP and document how those expectations are being met, along with other lessons learned. These will be shared with the USDOT during the regular quarterly briefings.

At the completion of each testing scenario, our team will prepare an interim report that documents how those expectations were met, any evaluation results, any complications identified or experienced and any other lessons learned that will help the pubic better interact with and understand the operations of the AV.

The interim reports will be summarized in the Final Evaluation Report.

***Deliverable*** - Electronic copy of draft and final version of Final Evaluation Report.

***LEGAL, REGULATORY, ENVIRONMENTAL APPROACH***

In June 2016, PennDOT assembled the "Autonomous Vehicle Policy Task Force" made up of a diverse and comprehensive set of stakeholders, including representatives from federal, state and local government, law enforcement, technology companies, higher education, manufacturers, motorists and trucking groups, and academic research institutions to prepare draft legislative policy recommendations for the testing of AVs in Pennsylvania. This task force has also convened two PA AV summits, bringing together industry partners to encourage public discussion on critical issues facing the community such as regional infrastructure planning and workforce development. This task force is active and has been instrumental in removing several legal and regulatory obstacles to promote AV in PA.

***Legal Approach –***

The following two laws are relevant to AV testing in PA:

1. Under existing PA law, unmanned and/or remote testing of AV on trafficways is prohibited. For this project, a licensed driver will be seated in the driver's seat during both the closed track testing and live on-road testing.
2. Pennsylvania General Assembly passed Act 117 on October 24, 2018 (HB 1958). It allows for PennDOT and PTC to implement a platoon of highly autonomous work zone vehicles (Truck Mounted Attenuators - TMA's) in active work zones. For this project, this Act will enable incorporating automated TMA's in work zones, which will be part of the testing scenario.

   The Act also allows PennDOT and PTC to authorize the locations in Pennsylvania on a periodic basis to implement the deployment of a highly automated work zone vehicle when used in an active work zone.

**Our team doesn't anticipate any legal obstacles caused by Federal, State or local requirements in demonstrating the AV in work zones** in either closed track and on-road testing scenarios identified for the project.

**Regulatory Approach –**

The following regulations will impact the AV operations in work zones:

1. In July 2018, PennDOT issued AV Testing Guidance. The guidance requires a HAV tester to receive authorization from PennDOT prior to testing on Pennsylvania trafficways. CMU, who will test the AVs vehicle in work zones both in the closed track and on-road environment, has already been authorized to conduct testing in Pennsylvania trafficways. Our team will utilize the guidance as required to ensure safety in each phase of testing.
2. USDOT's "Preparing for the Future of Transportation: Automated Vehicles 3.0", provides guiding principles and strategy to address existing barriers to safety innovation and progress. Our project will build upon these foundational guiding principles and strategies.
3. Our team is planning on using an existing AV from CMU, which is currently operational. Therefore, Federal Motor Vehicle Safety Standards (FMVSS), Federal Motor Carrier Safety Regulations (FMCSR), or any other regulations are not applicable for this project.
4. Our team will use the existing AV, mapping vehicle, and other work zone related equipment. Our team anticipates procuring connectivity related equipment (DSRC, C-V2X), and a DMS following Buy America Act. An exception under the Buy American Act or an exception to the terms of the NOFO Clause at Section F, Paragraph 2.J. entitled BUY AMERICAN AND DOMESTIC VEHICLE PREFERENCES is not anticipated for new procurement.

**Our team doesn't anticipate any regulatory obstacles caused by Federal, State or local requirements in demonstrating the AV in work zones** in either closed track and on-road testing scenarios identified for the project.

**Environmental Approach –**

Pennsylvania is keenly aware of the impacts that projects can have on the environment. **Our team does not anticipate any environmental or other obstacles caused by Federal, State or Local requirements in demonstrating the AV in work zones** in either closed track and on-road testing scenarios identified for the project.

## COMMITMENT TO PROVIDE DATA AND PARTICIPATE IN THE EVALUATION OF THE SAFETY OUTCOMES

PennDOT and its partners including CMU, PSU, and PPG believe that sound policies and informed decisions require the free flow of information. To that end, our team commits to making data from the demonstration freely available to USDOT and the public throughout the project to identify risks, opportunities, and insights relevant for USDOT safety and rulemaking priorities needed to remove governmental barriers to the safe integration of ADS technologies. Refer to the Draft Data Management Plan in Part 3 of this application, which identifies a preliminary list of data that will be available as part of this project.

To support this, our team commits to the following principles of open data: Data will be licensed openly for free, allowing anyone to use and share; Data will be easily accessible and downloadable, thoroughly described, machine readable, and maintained during the duration of the project; Both raw and processed data will be provided so that others are able to leverage the demonstration data and results in innovative ways.

To provide the open data, our team will: Publish data via an open data portal, and ensure our data are documented, archived, and machine readable; Publish data under a creative commons or equivalent license;

Our team's data commitment applies to the identified data with the following exceptions: When our team is legally obligated to not disclose data; When the disclosure may threaten the personal privacy of individuals, only anonymized or redacted data will be provided; When the archived data has not yet been reviewed, the decision to share the data will be left to the discretion of the partner responsible for generating the data; When the data includes proprietary information, and/or the data is not relevant to the ADS demonstration, it will not be shared. For example, our partner, PPG, will not share data regarding the composition of the coatings necessary to deliver the increased detection or specific approaches to ensure coatings adhere strongly to a traffic cone, as these data are proprietary and not relevant to assessing the success of the demonstration.

Our team also commits to participate in the evaluation of the safety outcomes of proposed activities as part of an independent evaluation, if applicable.

### *RISK IDENTIFICATION, MITIGATION, AND MANAGEMENT APPROACH*

The Project Risk Management Plan (RMP), which will be developed as part of the project, will identify the processes of conducting risk management planning including risk identification, quantitative and qualitative risk analysis, response planning, and monitoring and controlling risks. An initial set of possible risks will be identified and discussed at the kick-off meeting. This will offer an early opportunity to discuss collaborative ways to mitigate such risks.

**Risk Identification** - Risk identification determines which risks might affect the project and documents their characteristics. Risks will be identified continuously throughout the project by the project team through checklist analysis of risk categories and expert judgement at core team and quarterly meetings with technical advisors. Once identified, risks will be quantitatively and qualitative analyzed to determine the risk exposures. Risk exposure, which is the product of probability of risk occurrence and risk impact rating, will be calculated and a risk occurrence timeline will be identified. The risk, its probability of occurrence, risk impact rating, risk exposure, and the timeline will be documented in the risk register. For this demonstration project, technology and schedule will pose major risks due to the demonstration of AV in work zones and the complexity of the project involving multiple partners and multiple test scenarios.

**Risk Response Planning** - A risk response action plan for each of risks including risk description with risk assessment, description of action to reduce the risk, owner of the risk action, risk trigger, and committed completion date will be developed. Risk response plan will be aimed at eliminating the risk, lowering the probability of risk occurrence, and/or lowering the impact of the risk. For this project, technology risk will be mitigated by seeking inputs from technical advisors throughout the project. Schedule risk will be managed by maintaining the schedule at a common location, which could be accessed by all the project partners at any time, identifying the critical path schedule items, assigning a risk owner, and tracking them at each of the biweekly core team meetings and quarterly meetings with technical advisors.

**Risk Monitoring and Control** - Risk monitoring and control is an iterative process, which includes identifying new risks and planning for them; tracking existing risks; reclassifying risks as applicable and updating the risk register.

***Risks will be discussed as part of each of the biweekly core team meetings and quarterly meetings with technical advisors.***

*COST SHARE APPROACH*

PennDOT and its partners realize the importance of enabling AVs. As such, PennDOT and several of the project partners are contributing non-federal resources (cost-share) for the demonstration and evaluation as identified below:

- **PennDOT –** PennDOT's personnel will be part of the core team and they will lead and support several tasks. PennDOT will also procure automated truck mounted attenuator vehicles, which will be used during the closed track testing and live on-road testing.
- **CMU –** CMU will provide two CMU College of Engineering Dean's Fellowships, faculty time, allow partial use of AV, allow use of simulation tools, and provide AV software development platform.
- **PSU –** PSU will provide access to their roadway mapping vehicle including all the associated sensors for mapping various work zones scenario both during closed track testing and live on-road testing. PSU will also provide access to the closed track facility in University Park, PA.
- **PTC –** PTC's personnel will be part of the core team and provide technical advisory services throughout the life of the contract.
- **PPG –** PPG will provide support to the workshops and conferences throughout the life of the contract and will supply visibility-enhancing coatings specially designed for AV, to be used in V2V, V2I, and V2X demonstrations.
- **Qualcomm –** Qualcomm personnel will provide technical advisory support during quarterly workshops/conferences throughout the life of the contract at no-cost to this project.

Each partner providing cost-share will own, operate, maintain, and manage their personnel and resources throughout the project duration. The project manager will develop, maintain and share a detailed, resource-loaded schedule with the partners and coordinate with each of the partners to ensure the required personnel and resources are available at right time to complete the assigned work.

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[1] https://www.wired.com/2017/02/self-driving-cars-cant-even-construction-zones/
[2] NHTSA, Fatality Analysis Report System (FARS), (2011 – 2016)
[3] https://www.research.psu.edu/irb
[4] https://www.cmu.edu/research-compliance/human-subjects-research/