MAVEN

Metropolitan Autonomous Vehicle Environments and Neighborhoods

A USDOT ADS Demonstration Grant Proposal

Submitted by

The Seal of the City of Pittsburgh · 1816 · Benigno Numine

Carnegie Mellon University

PPG

SAE International

with additional support from

Argo AI

Ford

Port Authority

Uber

MAVEN

CITY OF PITTSBURGH

"America's Most Livable City"

Office of Mayor William Peduto

March 6, 2019

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

Subject: Commitment for City of Pittsburgh ADS Grant Application

Dear Secretary Chao:

For over thirty years, Pittsburgh has been a leader in autonomous vehicle (AV) technology, development and deployment. The City of Pittsburgh has been a robust testbed that AV testers and developers alike have utilized to advance AV technology safely and equitably.

The city is proud to be both home and partner to a number of the nation's most advanced automated driving system (ADS) testers including Aptiv, Argo AI, Aurora Innovation, Carnegie Mellon University and Uber. More than just job-creators, these companies are co-creators with the City. This close working relationship, unique to Pittsburgh, was evidenced just earlier this month as I was joined by all five of our active ADS testers as I signed an Executive Order issuing guidelines and principles for on-road testing in Pittsburgh – guidelines that the testers not only agreed to follow, but praised as a new high water mark in public-private collaboration in policy development ford this emerging technology. The "Pittsburgh Principles" as they have come to be called balance the need for public safety with the need to test AV technologies in real-world conditions on public roads.

It is often said here that Pittsburgh is small enough to easily get the right people together and large enough that what happens when you do, really matters. Our AV Testing Guidelines are clear evidence of that unique relationship, opportunity, and general trust. We share a commitment with our AV developers to creating a framework for viable voluntary industry standards, particularly for test driver requirements and specifications, that benefit all – public regulators, private testers and of course the general public as a whole. Striking agreement with one or two entities is achievement enough, but it is really only in Pittsburgh, with our dense and close knit ecosystem of AV innovators, researchers, analysts, and material suppliers, that mutual collaboration on such a large scale is much more the norm than the exception.

The City of Pittsburgh has a strong history and commitment to public-private partnership. This has helped lay a solid foundation for equitable economic growth and prosperity for existing residents while also attracting new interest and investment, reversing the decades-long trend of population decline. A city once known for its steel is now known for its strength, leadership, and innovation in education, healthcare, and advanced technologies, with companies such as Caterpillar, Bosch, Amazon, Google,

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Facebook, and Uber's Advanced Technology Group locating centers for excellence here. We have also capitalized on home-grown success stories such as language-learning company Duolingo, which is valued at $700 million. Another local successful startup is the AV safety company Ottomatika, launched by CMU Professor Raj Rajkumar. In 2105, Delphi Automotive acquired Ottomatika and later split into Aptiv, now valued at greater than $20 billion. This strength in innovative advanced technology has helped propel the density of AV companies who utilize Pittsburgh as a testbed. At last count, Pittsburgh is the home base to ten AV companies; with five actively driving their AVs on our streets.

I am proud to have the City of Pittsburgh submit this application in response to the USDOT NOFO 693JJ319NF00001 to demonstrate Metropolitan Automated Vehicle Environments and Neighborhoods (MAVEN). It targets safe and reliable ADS operations in complex urban contexts, and is built on three pillars:

(a) smart infrastructural elements including connectivity, smart coatings, and first-mile/last-mile access;

(b) the development of voluntary safety standards for AV testers; and

(c) raising the awareness and understanding of AV technology amongst the public so they are comfortable with AVs being tested and eventually deployed in their neighborhoods.

Pittsburgh is a large community where neighbors rely on neighbors. We are proud that in addition to the leaders within my own staff, the MAVEN team is joined by exceptional partners including Carnegie Mellon University (considered to be a birthplace of AV technology in 1983), the Port Authority of Allegheny County (PAAC), PPG (a Tier-1 supplier to the automotive industry for decades) and SAE International (the leading standards body for the automotive industry). We are also honored to have as committed partners leading AV developers in Argo AI, Ford and Uber.

A critical test of the viability of self-driving systems is their ability to navigate in complex urban areas. With its narrow roadways, density and diversity of street users, aged infrastructure, tunnels, bridges, steep slopes, variable weather and many irregular intersections within one city, Pittsburgh represents a great many of the complex everyday situations autonomous vehicles will need to navigate in different locations across the country and around the world. While many other communities are questioning the inclusion of AVs on their streets, Pittsburghers are more accepting of sharing the road with AVs. Just this month, the non-profit BikePGH released its latest survey assessing how ordinary Pittsburghers experience of "sharing the roads with robots on a day-to-day basis." They found that people feel safer sharing the road alongside an AV versus human drivers. Likewise, residents are getting used to seeing AVs on Pittsburgh streets.

We are confident that MAVEN will provide another layer of innovation and safety to the Pittsburgh AV testbed, encouraging and enabling new applications of AV mobility and services. We expect to be able to continue to spin out a new generation of AV and related companies, creating opportunity and economic prosperity for all citizens.

I cannot adequately express my excitement for the leadership the US DOT is demonstrating through this NOFO; the great good it will provide to our nation in terms of lessons learned in enhancing evidence-based safety protocols and sensible regulation of testing; and the overall advancement of autonomous driving systems in enhancing roadway safety and the critical preservation of human life on our nation's streets and rights of way. I could not be more pleased with the partnership that has come together among

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private firms, researchers, public advocates, government agencies, and local innovator in response to this opportunity. Without a doubt, Pittsburgh offers a unique opportunity for collaborative learning and exchange around some of the most acute challenges of ADS – the conditions in complex urban environments.

I look forward to your evaluation and feedback. Please do not hesitate to reach out to me or my Director of Mobility and Infrastructure, Karina Ricks, if we can answer any questions or provide any additional information. We are so pleased to have this opportunity to continue to advance ADS technology.

Sincerely,

William Peduto
Mayor of Pittsburgh

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SUMMARY TABLE

Project Name/Title	Metropolitan Automated Vehicle Environments and Neighborhoods (MAVEN)
Point of Contact	Karina Ricks Director, Department of Mobility & Infrastructure City of Pittsburgh *E-mail:* karina.ricks@pittsburghpa.gov *Phone:* (412) 255-2523
Eligible Entity Applying to Receive Federal Funding	City of Pittsburgh 414 Grant Street Pittsburgh, PA 15219
Proposed Location for the Demonstration	City of Pittsburgh Allegheny County Commonwealth of Pennsylvania
Proposed Technologies for the Demonstration	Vehicular V2X Communications with DSRC and CV2X Connected Automation for Level 4 Autonomy Smart Surface Coatings for lane markings, curbs and signage
Proposed Duration of the Demonstration	September 1, 2019 – August 31, 2022
Federal Funding Amount Requested	$ 4,965,680
Non-Federal Cost Share Amount	$ 3,181,163
Total Project Cost	$ 8,146,843

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EXECUTIVE SUMMARY

Vision

A critical test of the viability of automated driving systems (ADS) is their ability to navigate in urban areas, which are inherently complex. Urban contexts pose multiple difficult challenges to automated vehicles (AV). These challenges include, but are not limited to, peak traffic volumes that overwhelm available road capacity;, high pedestrian densities; the presence of bicyclists; parking needs; heterogeneous vehicles including transit buses and trams; the close proximity between automobiles and vulnerable road users; jaywalking including those running to beat the pedestrian light; weak GPS signals in the urban canyon of a downtown; occasional double parking; and taxicabs cutting off vehicles to pick up passengers. In fact, the maturity of an ADS can be readily determined by its capability to navigate through a dense urban context. An overly ADS can cause injury or worse, while a conservative ADS will be unable to make progress causing traffic jams and eliciting vocal disapproval from road users. Ironically, dense urban areas are where car ownership is the lowest, the cost of ownership is the highest, and parking is the most expensive, increasing the need for car-sharing AV technology. This also means, of course, that the urban context is likely the most financially lucrative for AV-based car-sharing.

Today's transportation networks evolved over time, but were designed primarily to be used by humans, who can instinctively accommodate operational ambiguities, uncertainties, imperfections and errors. ADS, however, lack the versatility and flexibility of human intelligence and understanding, and require clarity, certainty, reliability and minimal errors. Our vision is that ADS will benefit significantly from design modifications and infrastructural support explicitly intended for use by automated vehicles. In short, smart infrastructure will accelerate the safe use and adoption of AV technologies.

Our demonstration will be conducted in an arterial urban corridor along Liberty Avenue in the heart of the city of Pittsburgh. Key data collected will be shared to enable future safety analyses and perform different kinds of analytics.

> Our demonstration named **M**etropolitan **A**utomated **V**ehicle **E**nvironments and **N**eighborhoods (MAVEN) plans to
>
> 1. Demonstrate the effectiveness of smart infrastructure in the urban environment for improved ADS safety,
> 2. Develop standards for safety operator training, and
> 3. Raise public awareness about the technologies used by ADS.

Goals of MAVEN

The evolution – and ultimately deployment and adoption – of AV technology relies on three co-equal pillars:

1. Technological advancement of automated driving systems to provide mobility operations that meet the highest standards of safety and reliability,

MAVEN

2. The development of appropriate testing standards and regulations that protect the public safety and enhance mobility access that drives economic vitality, and
3. Public trust in the technology that underpins ADS deployment and broad adoption.

The proposed MAVEN demonstration advances all three fronts. It asks the questions, "How can we enhance the transportation infrastructure to make ADS safer and more robust? What is the role of smart infrastructure technologies such as V2X (DSRC and CV2X), high-definition cameras at intersections and smart materials in contributing to create safe regions for AVs to operate within?" The demonstration hypothesizes that the evolution of ADS technology can be accelerated through smart infrastructure support and appropriate geo-fencing. Features that will be supported include vehicular (V2X) communications (including Vehicle-to-Infrastructure, Vehicle-to-Vehicle and Vehicle-to-Cloud communications), high-definition cameras at intersections, first-mile and last-mile support, and smart surface coatings. Team members will perform live physical demonstrations on public urban roads in and near downtown Pittsburgh. Performance outcome changes in response to these deployments will be reported, and sensor data will be shared.

Leveraging the close working relationship that exists in Pittsburgh among multiple AV testers, researchers and public agencies, we are uniquely positioned to ask members of our own ecosystem, "How can AV testers create voluntary standards for test operations?" Thanks to a solid foundation established with our five local AV testers during the development of an Executive Order for Autonomous Vehicle Testing released earlier this month, we have a collaborative environment in which to test ADS technology to frame viable voluntary industry standards for testing particularly with regard to test driver requirements and specifications. Such a standard is essential when testing in a dense urban environment and generally informative to regulators. This proposed effort will gather evidence through data reporting as to the efficacy of such standards in protecting public safety. It will also inform the standardization of testing protocols.

MAVEN Team Members

- City of Pittsburgh
- Carnegie Mellon University
- PPG
- Society for Automotive Engineers (SAE International)

Key MAVEN Partners

- Argo AI
- Ford
- Port Authority of Allegheny County
- Uber

Finally, in many respects Pittsburgh is not only pioneering ADS technology, but also pioneering the public's relationship with and understanding of the technology. With a population that has had more experience with and exposure to autonomous vehicles than most, we are uniquely well positioned to ask, "What are effective strategies to de-mystify ADS technology to the public, with the intention of creating awareness of, educating about the testing rigor, and building confidence in AV safety systems?" and be able to get sophisticated and informed feedback. We know public confidence and trust are critical in enabling broader and more diversified on-road testing of the technology. Due to the wide chasm that exists between simulation environments and real-world conditions, on-road testing is essential to developing and maturing the technology to a point where deployment becomes feasible. The public, understandably, will not trust what they do not understand or cannot see. We in Pittsburgh have a general public that has basic foundational knowledge and a relatively high degree of tolerance and trust, and yet retain healthy skepticism. We can build on an already established foundation of understanding to assess what gaps remain that must be addressed to build public trust and acceptance of testing necessary to enable expanded on-road testing in more areas and more contexts. Gathering information about how to improve public understanding and confidence will pay dividends in introducing testing in other areas of the country.

With these three pillars as the focus of the proposed research and learning, the goals of the MAVEN effort are to:

1. Accelerate AV technology development as a significant safety enhancement and risk-reducer for traveling through complex urban environments with a diversity of street users,
2. Evaluate the efficacy and return of investments in infrastructure or equipment/system installations in improving AV safety and operations in a complex environment,
3. Enhance safety outcomes through standardized testing protocols, and
4. Increase understanding of the general public such that they can better engage in and be comfortable with public policy around AV testing on public streets.

Why Pittsburgh?

With its narrow roadways, density and diversity of street users, aged infrastructure, tunnels, bridges, steep slopes, variable weather and many irregular intersections within one city, Pittsburgh represents several of the complex everyday situations automated vehicles will need to navigate in different locations across the country and around the world. Having been a testbed for safe development and testing of autonomous vehicle technologies for many years, Pittsburgh has grown and attracted a dense and thriving ecosystem of AV innovators, researchers, analysts, and material suppliers. With Carnegie Mellon University, considered to be a birthplace of ADS technology dating back to 1983, the City has a well-established and respected research partner that continues to evolve and advance the technology and industry. Partnership, trust and collaboration are the hallmark of our City and the industries that choose to call the city home. This common ground is an invaluable commodity and essential ingredient to successful testing and governance. This history and foundational value system are also what contribute to a generally-tolerant public who embrace their city as a living laboratory for innovation and advancement. Pittsburgh has the discipline to bring together different perspective to solve problems and build a better future.

Key Partners, Stakeholders, Team members, and Other Participants

The MAVEN team comprises thought leaders from the public sector, technology pioneers from the academic sector, AV standard-bearers from the standards community, and innovative companies in the corporate sector that have worked with carmakers and state and municipal DoTs for many decades.

Issues and Challenges to be Addressed

The proposed MAVEN effort will directly address the following issues:

- Taming the complexity of the urban environment for automated vehicles,
- Dealing with in-vehicle sensor limitations by adding sensing modalities in the infrastructure through V2X, and using smart materials in the environment to make AV-sensing longer-range and reliable,
- Providing V2V support among a heterogeneous fleet of city-owned vehicles,
- Enabling first-mile and last-mile access for picking up and dropping off passengers using automated vehicles,
- Understanding of the interactions between the smart infrastructure and vehicle automation,
- Addressing the need for safety standards for testing on public roads, and
- Instilling trust and confidence in the public about ADS technologies and processes.

Technologies that will be Demonstrated

The technologies that will be demonstrated by MAVEN will be:

- Automated driving on urban roads with in-vehicle sensors including cameras, radars and lidars;
- Connected automation with V2X communications complementing in-vehicle sensors and including V2I (for SPAT messages from traffic signals), V2V (for BSM messages to/from other vehicles);
- Connected fleets with V2X communications enabled on a fleet of 170 City-owned and operated vehicles that traverse the MAVEN demonstration corridor (with many based in or very close to the corridor including refuse vehicles, law enforcement vehicles, fire trucks, and public-works trucks);
- Smart surface coatings that significantly enhance the reflectance and absorbance of road signage, lane markings, and curb markings for lidar and radar sensors (without causing any impairments to human visibility); and
- Smart surface coatings that can embed "hidden" symbology on road signs that are not visible to humans, but can be read by lidars used in AVs.

Anticipated and Quantifiable Performance Improvements

Technology Being Demonstrated	Anticipated and Quantifiable Performance Improvements
Surface Coatings from PPG	Improvements in reflectance and absorbance of lane markings, curb markings and signs.
	Improvements in detection range for lane markings, curb markings, and signage.
	Improvements in detection range for lane markings, curb markings and signage.

	Improvements in sign classification accuracy.
V2I Support (DSRC and CV2X)	Improvements in traffic signal status detection accuracy under different lighting, traffic and weather conditions for AVs.
V2V Support (DSRC and CV2X)	Improvements in minimum distance between a CAV and other V2V-equipped vehicles.
	Reductions in manual interventions at traffic signals and multi-way stop intersections.
Public Outreach	
Feedback from the public through SAE surveys	Improved exposure to and understanding of AV technologies and experience.

Table 1. Anticipated and Quantifiable Performance Improvements from MAVEN.

Geographic Area or Jurisdiction of Demonstration

The MAVEN demonstration will be carried out within the heart of the City of Pittsburgh along the arterial corridor of Liberty Avenue shown in Figure 2. Specifically,

1. This MAVEN corridor will be traversed by CMU's self-driving Cadillac SRX, a Level 4 Connected and Automated Vehicle (CAV) to collect data and measure safety improvement metrics.
2. V2I support using both DSRC and CV2X radios will be added to 18 traffic signals along Liberty Avenue, with 8 more planned in the future.
3. V2V support also using both DSRC and CV2X radios will be added to 170 fleet vehicles operated by the City of Pittsburgh (refuse vehicles, fire trucks, EMS, ambulances and public-works vehicles that traverse the demonstration corridor.
4. PPG's reflective coatings that are responsive to lidars will be used to paint all curbs, lane markings and signs along this corridor for easier detection.

Period of Performance

September 1, 2019 to August 31, 2022.

This corridor was chosen since the traffic signals along the Liberty Avenue corridor will be upgraded in late 2019 and 2020, and its many segments exhibit a broad range of urban traits.

The proposed demonstration will be carried out in three activity clusters, one corresponding to each of the 3 pillars underlying MAVEN (as discussed on Page 10): The tasks to be performed in these clusters and the respective roles of MAVEN team-members and partners are shown in Table 2. The MAVEN implementation schedule is shown in Figure 1.

Evaluation of the Demonstration

The MAVEN ADS demonstration will be carried out along Liberty Avenue in the core of the City of Pittsburgh as shown in Figure 2. This corridor comprises various segments that are typically found in many urban contexts including a dense downtown core, an urban canyon with tall buildings on both sides, an industrial segment, residential segments, small businesses with storefronts along the street, hospitals, hotels, an urban business district and different ethnic neighborhoods along the way. The avenue also has large and complex (5-way) intersections, sharp turns and curves, overpasses, bridge traffic, bike lanes, lane merges, and unprotected left turns at traffic lights. The City of Pittsburgh is scheduled to upgrade the traffic signals from one end of Liberty Ave (at Commonwealth Place) to 31st Street.

The MAVEN demonstration will

- add Vehicle-to-Infrastructure (V2I) capabilities with DSRC and CV2X radios to the upgraded signals along the MAVEN demonstration corridor,
- add V2V and Vehicle-to-Vehicle (V2V) capabilities with DSRC and CV2X radios to a heterogeneous fleet of city-owned vehicles that traverse the demonstration corridor,
- use PPG surface coatings to paint curbs, lane markings and signs along the corridor, and
- collect data from the corridor at different times of day, lighting conditions and weather conditions for sharing with the USDOT.

Evaluations using the metrics of Table 1 will be carried out to assess (a) enhancements in range and detection accuracy of signs, lane markings and curbs with the PPG surface coatings, and (b) improvements in distances to objects and manual interventions with CMU's Connected and Automated Vehicle (CAV).

Schedule for Implementation

Technical Tasks			Core Team					Industry Partners		
Task	**Sub-Task**	**Task Description**	**City of Pgh**	**CMU**	**PAAC**	**PPG**	**SAE**	**Argo**	**Ford**	**Uber**
Planning and Preparations	Task 1.1	Project Management	R	S	S	S	S			
	Task 1.2	Risk Management/Mitigation	R	S	S	S	S			
	Task 1.3	Systems Engineering and Management	S	R	S	S				
	Task 1.4	Concept of Operations	R	R	S	S		C	C	C
	Task 1.5	System Requirements and Testing	R	R	S	S		C	C	C
	Task 1.6	Operations & Maintenance	R	S	S	S				
Smart Infrastructure	Task 2.1	V2I Infrastructure	R	R						
	Task 2.2	V2V Infrastructure	S	R	S					
	Task 2.3	Surface Coatings	S	R						
	Task 2.4	First-Mile and Last-Mile Access	R	R						
	Task 2.5	Connected and Automated Driving	S	R	S	S				
Voluntary Testing Standards	Task 3.1	Safety Operator Standards	S	R			S	C	C	C
	Task 3.2	Testing Practices	S	R			S	C	C	C
Raising of Public Awareness	Task 4.1	Public engagement and education	S	S	S	S	R			
	Task 4.2	Information Dissemination	S	S	S	S	R	C	C	C
Evaluation	Task 5.1	Evaluation of ADS	S	R	S					
	Task 5.2	Evaluation of Public Awareness	S	S	S		R			
Post-Analysis	Task 6.1	Post-Deployment Analysis	S	R	S	S	S	C	C	C
	Task 6.2	Writing of Final Report	R	R		S	S			

R	Responsible	C	Consult
S	Support		

Table 2. MAVEN Demonstration Roles by Team Members and Partners

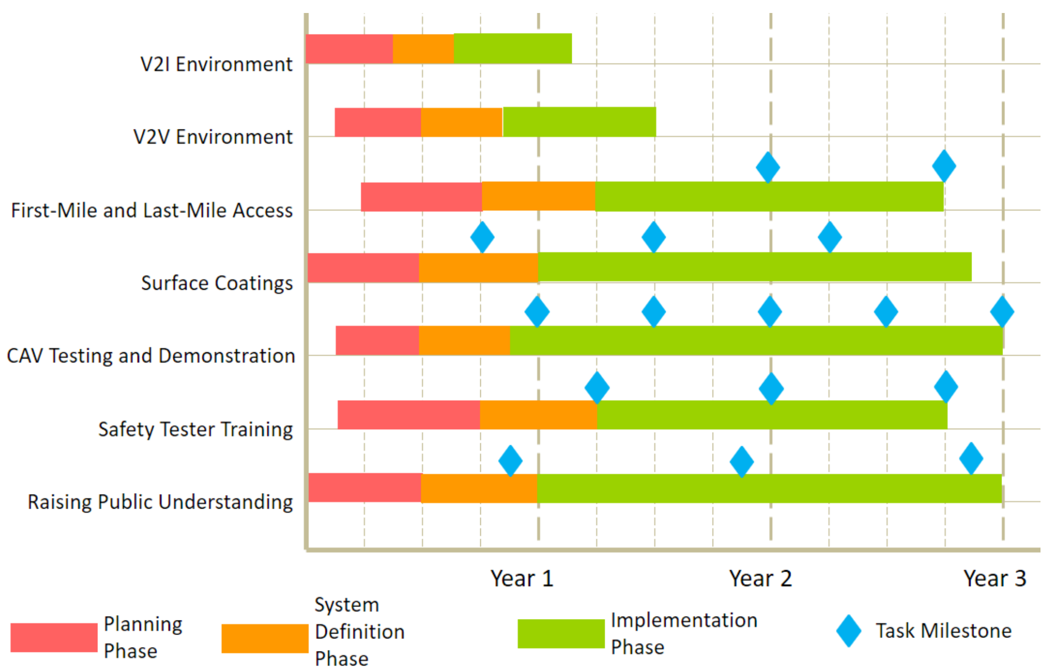

Figure 1. MAVEN Demonstration Schedule.

Figure 2. The MAVEN Demonstration Corridor in Pittsburgh along its artierial Liberty Aveneue.

GOALS

The MAVEN demonstration is tailored to meet the programmatic goals of the USDOT as follows.

Safety

The USDOT has spent a considerable amount of time and effort in promoting V2X communications to improve road safety. Studies have indicated that, V2X communications can either prevent or mitigate up to 80% of automotive crashes. A key element of the MAVEN demonstration is the use of V2V communications among a heterogeneous fleet of V2X-equipped devices with both DSRC and CV2X On-Board Units (OBUs), and V2I support that enables AVs to know the status of a traffic signal reliably at much longer distances and under all kinds of lighting, weather and occlusion conditions. The new surface coatings from PPG, when used for lane markings, curb markings and signage, explicitly enable easier detection and classification of these road artifacts by AV sensors. As a result, AVs can react sooner and be safer. Our task on voluntary testing standards has the aim of ensuring safe testing techniques that not only safeguard the public and vulnerable road users but also enable ADS testing under real-world conditions. Our thrust on public education will inform the public about both the capabilities and limitations of ADS technology, so that they can act appropriately in the proximity of AVs.

Data for Safety Analysis and Rulemaking

We believe that the outcomes of the MAVEN demonstration can serve a strong foundation for safety analysis in general and rulemaking in particular. Tall vehicles in front and parked vehicles on the side can occlude an AV's camera sensors from determining the status of a traffic signal correctly, as can the sun's position low on the horizon directly behind the traffic signal. In junctions with some acute angles at which roads intersect, the traffic light positions can themselves be confusing, and older traffic signal lights may not be bright enough for highly accurate detection on sunny days. With V2I support on the traffic signals, AVs can determine traffic light status accurately. This is a classic example of traffic signals being designed for human consumption, with V2I support being explicit for AV consumption. Similarly, surface coatings for lane markings, curb markings and signs enhance detection by AV sensors, and thereby enable the driving environment to make AVs safer. The safety improvements that result can then be a strong basis for a rulemaking process (or provide evidence to the contrary). V2V communications between city-owned fleet vehicles will also yield new data for performing safety analyses. Since CV2X is not commercially available yet, MAVEN will also generate data to perform some objective comparisons between DSRC and CV2X. Lastly, our public education task targets the de-mystification of AVs in the public consciousness, and can help industry and/or the USDOT to launch education and awareness campaigns with its national reach and rulemaking authority.

Collaboration

The MAVEN team-members and its partners bring together a city known for its leadership in AVs, a prominent set of AV developers and testers, a public transit agency, Tier-1 automotive suppliers, the world's leading automotive and AV standardization body and a global carmaker. Such cross-disciplinary collaboration is essential to make AV technology safer for use on public roads. This explicit and focused collaboration is also effectively complemented by the fact that the MAVEN demonstration will produce data that can be used by both testers and developers for many years to develop and test new techniques that make ADS safer over time.

FOCUS AREAS

Significant Public Benefits

AVs can (and must) leverage the USDOT's investments in V2X both for their own benefits (by making their sensing tasks much easier to accomplish) and for the safety of the public. Over the past 100 years, better surface coatings have improved highway and road safety by making road signs and markers more visible to the human eye and readily understood by the driver. PPG's coatings to be evaluated in the MAVEN demonstration can improve ADS safety by making signs, infrastructure, and even other vehicles more visible to the new "machine eyes" of AVs and make them be readily recognizable. Making surroundings quickly and easily visible and understood to both human and automated drivers cater directly to the public need for safety, and contributing positively to the core safety mission of the USDOT.

Addressing Market Failure and Other Compelling Public Needs

Most AV developers today strongly believe that regulatory or rulemaking processes will take too long and/or be too expensive to complete, to be adopted and to be implemented on a nation-wide basis. Hence, most resources are invested today in making all the intelligence be local within an AV, thereby making it "self-sufficient". This trend represents market or regulatory failure of the worst kind. Connected automation can and will make AVs safer whether they are deployed nationally or only in dense pockets at the beginning. The ongoing technology rivalry between DSRC and CV2X also needs to be resolved sooner rather than later, in order to enable one technology to take hold and bloom.

Similarly, for surface coatings, PPG, for example, would not be able to assess the benefits or drawbacks of its coating without close coordination with the type of cross-functional team assembled for the proposed MAVEN demonstration. PPG personnel are experts in coatings and materials that can manipulate wavelengths of light, but need the assistance of others to incorporate those materials in road networks to improve safety. The MAVEN demonstration will collect useful and valuable data to address these issues. The data and the results will be shared with the USDOT as required by the program.

Economic Vitality

The global market for ADS is estimated to be a few *trillion* dollars per year in the 2040s. The US, where the technology was born and nurtured through the momentous 2007 DARPA Urban Challenge, must continue to be a world leader to keep, sustain and extend its economic vitality. However, for this to occur, the public must be confident and trust that the technology is safe. Infrastructure improvements, such as V2X technologies and new surface coatings, will help AVs become safer; safety standards will infuse confidence in the public; and public education will keep them informed and build trust. A significant segment of the public is concerned about the increasingly disturbing use of smartphones by drivers, but ADS developers and regulatory agencies have the burden of proof to show to the public, who rightfully want and deserve to know, that AV technology will be safe to use.

PPG is a US-based company with headquarters in Pittsburgh close to where the MAVEN demonstration will be conducted (Figure 2). Operating since 1883, PPG employs ~47,000 people worldwide and ~18,500 in in the US, operating 45 U.S. manufacturing locations in 19 states. Coatings for autonomous driving represent an area for economic growth. The success of ADS in the U.S. will bring economic vitality to the local supply chain that supports it.

Complexity of Technology

V2X technology has been demonstrated years back by USDOT projects such as the Crash Avoidance Metrics Partnership (CAMP), the Safety Pilot Deployment, and the subsequent Connected Vehicle Pilot. AV technology has been evolving quite rapidly in recent years. A constructive convergence of the two technologies awaits, and has been shown to be feasible in real-world driving conditions by CMU's self-driving Cadillac SRX as far back as 2013. Physical road artifacts like lane markers and signs however are passive, and innovations are necessary. As vehicle automation moves beyond Level 3 and higher, the ability for sensors to quickly and accurately interpret their surroundings becomes more critical. Lidar- and radar-friendly surface coatings range from options as simple as line-marking coatings to more complex coatings that provide hidden symbols to AVs that do not interfere with what the human eye sees.

Diversity of Projects

The ADS technologies being demonstrated in the MAVEN effort are readily transferable to other locations, multiple populations and mobility types.

Transportation-Challenged Populations

There are more than 1.5 million legally blind people and more than 5 million physically disabled persons in the US alone. These persons likely have to depend on others for their mobility needs. Meanwhile, many hundreds of thousands of the elderly have lost their driver licenses due to decline in their cognitive skills. ADS technology that is known to be safe, reliable and robust will enable these transportation-challenged populations to regain mobility options and have a much better quality of life. The MAVEN demonstration hopes to highlight the fact that AVs, in time, will become available for use in urban areas where more than 80% of the US population lives.

Prototypes

The PPG surface coating technologies are a minimum Technology Readiness Level (TRL) of 4, and have been demonstrated to operate at a lab scale. Some lab work may be necessary to customize the coating to work for the specific end-use intended by MAVEN. For example, Lidar-enhanced coatings have been used on cars to demonstrate the positive benefits, but some lab work may be needed to customize the formula so that it can be applied for marking lanes and curbs. However, all candidates can be incorporated in a MAVEN field demonstration as per the proposed schedule.

REQUIREMENTS

The MAVEN demonstration is explicitly designed to meet the ADS grant requirements:

- Our demonstration targets the dense urban context, which is simultaneously among the most challenging from a technology perspective, and the most lucrative from a market standpoint. The Level 4 demonstration must be able to handle dense vehicular traffic, high pedestrian volumes, the presence of bicyclists, urban canyons, non-straight-line road segments, existing traffic signals, legally- and illegally parked vehicles, and different lighting conditions. Two safety operators will be present to ensure safe operations during testing.
- The demonstration will be carried out using CMU's self-driving Cadillac SRX along the corridor shown in Figure 2. This ADS has been shown to be capable of operating at Level 3 or above on public roads under real-world driving conditions. In 2013, CMU's self-driving SRX autonomously drove Bill Shuster, then Chairman of the US House Transportation and Infrastructure Committee, and Barry Schoch, then Secretary of PennDOT for 33 miles from Cranberry Township north of Pittsburgh to the Pittsburgh International Airport with the aid of 11 traffic signals equipped with DSRC. In 2014, CMU's SRX was used to provide demo rides at Capitol Hill in Washington DC for Chairman Shuster, and 20 members of the US Congress, USDOT officials and NSF officials. There were two types of demo rides: one a 3.5 mile loop around the Capitol with 23 traffic signals (of which 6 broadcast DSRC signals), and one ride for 6.5 miles each way down I-395 South to the Pentagon exit and back. In 2015, through CMU spinoff Ottomatika Inc. (and partnering with Delphi), demo AV rides were given around the Las Vegas Convention Center during the 2015 Consumer Electronics Show. In March 2015, again through spinoff Ottomatika Inc.(and partnering with Delphi, CMU's AV technology was used to power the first cross-country AV drive from San Francisco to New York City (a distance of about 3500 miles) with the AV driving itself about 98.6% of the time on interstate highways. In 2016, SRX demo rides were provided around the State Capitol in Harrisburg, PA, each ride about 3 miles with 10 traffic signals (8 of which were DSRC-equipped) and multiple stop intersections. In September 2017, demo rides were provided on the Penn State Test Track (a 1-mile oval) for about 130 attendees to the inaugural Pennsylvania AV Summit. In October 2017, demo rides were given in Gettysburg, PA at a multi-state meeting of Police Commissioners. Next-gen Level-4 functions are the focus of the current CMU CAV platform.
- The MAVEN demonstration is expected to generate a total of around 12-16 TB of data during the period of performance. Data gathered from cameras and lidars will be made available to the USDOT within a day of their collection. CMU will ensure that the data will be available for at least 5 years after the project period of performance. The user interface on the ADS will enable the choice of different routes through a touchscreen.
- The MAVEN approach is *not* customized to the demonstration locale, and its approach to V2X, first-mile/last-mile support and surface coatings can be scaled and applied across the country. We view MAVEN as a forward-looking proof of concept that demonstrates safety enhancements in a context that is challenging for today's AV technology. The MAVEN team

has a designed Outreach Director, whose role is to share demonstration status, results and lessons learned with other jurisdictions and the public. SAE International's Demo Days are specifically designed to get the public both involved and become aware of advances in technology and standards.

APPROACH

Technical Approach to Implement and Evaluate the Demonstration

The tasks to be performed under MAVEN and the roles played by team-members and partners are listed in Table 2. We describe these tasks next to capture our technical approach to implement and evaluate the MAVEN demonstration.

Task 1: Planning and Preparations. The MAVEN demonstration will follow the system engineering "V" process shown in Figure 3. Specifically, the **subtasks 1.1 through 1.6** correspond to various phases of the system engineering process.

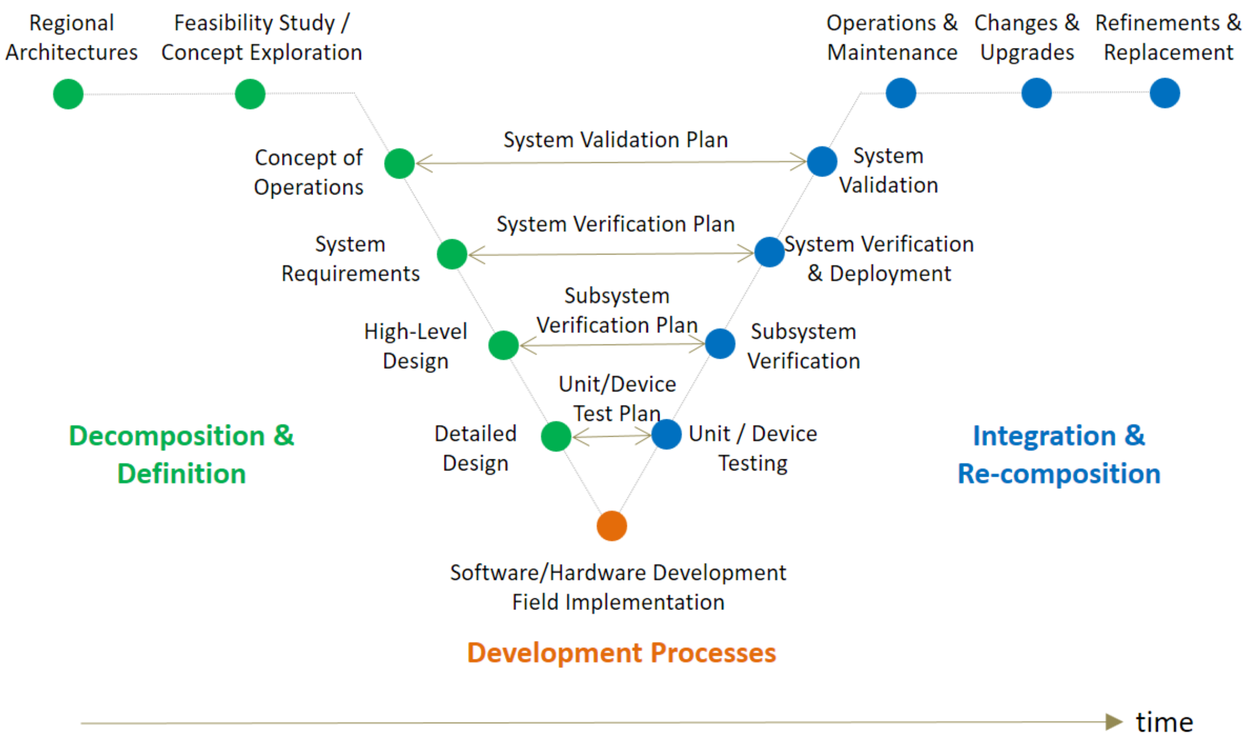

Figure 3. The System Engineering "V" Process

Task 2: Smart Infrastructure

This task corresponds to the first of the 3 pillars of MAVEN, and will focus on adding infrastructure support for making ADS safer and more robust. In **Task 2.1**, V2I capabilities using both DSRC and CV2X Road-Side Units (RSUs) will be added to 18 traffic signals along the MAVEN demonstration corridor, including its urban canyon segment. Hence, AVs, connected vehicles or CAVs that traverse the corridor will directly benefit. In **Task 2.2**, V2V capabilities using both DSRC and CV2X RSUs will be added to 170 city-owned fleet vehicles (including refuse vehicles, law enforcement vehicles, fire trucks, and public-works vehicles) that traverse the demonstration corridor. Many of these vehicles are already based in and around the MAVEN demonstration corridor. These vehicles in turn will communicate with the ADS and provide location information that can be used to make the AV safer even under stressful conditions including poor lighting and weather conditions. Earlier USDOT projects like CAMP and the Safety Pilot have demonstrated the improvements offered by V2V communications. It must also be noted that, due to the networking effect, the benefits multiply very rapidly as V2V penetration increases. In **Task 2.3**, smart surface coatings from PPG will be applied to the demonstration corridor – lane markings, curb markings and signage. We describe this technology next.

Smart Surface Coatings

MAVEN will evaluate four innovative technologies proposed by team-member PPG that can improve the safety of ADS in urban areas:

1. Coatings that "light up" dark colors to Lidar detectors,
2. Coatings that "tone down" the return Lidar signal from a retroreflective street sign,
3. Coatings that encode information hidden to the human eye but critical for an AV,
4. Coatings that keep sensors clean and operational.

Coatings that "light up" to Lidar: PPG, a leading supplier of automotive coatings, identified an opportunity to improve the safety of AVs by developing automotive coatings that "light up" under Lidar but retain the visual appearance of typical paint. This problem is significant as nearly a fifth of all cars built in North America last year were black, a color that is unfortunately nearly invisible to Lidar (Figure 4).

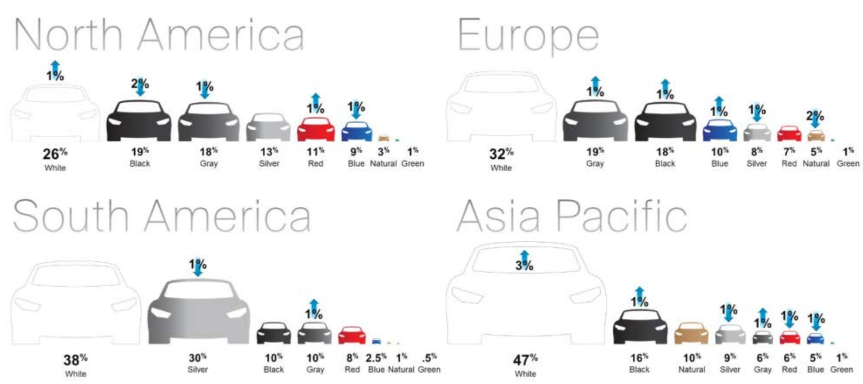

Figure 4. 2018 Global Color Trend Popularity by Region. Over half of the 2018 model year cars built in North America are colors known to absorb Lidar signals. For black cars, the standard black pigment absorbs LIDAR so strongly that < 5% of the signal is often returned.

Black coatings strongly absorb at the Lidar wavelengths of 905 nm and render the coated object nearly invisible. PPG has demonstrated proof-of-concept dark coatings that enhance IR reflectivity in a range of colors that are ready for demonstration (Figure 5). In addition to Lidar detection, PPG is evaluating how coatings interact with various radar units. It needs to be determined whether coatings that reflect or transmit radar are needed to improve ADS safety. In summary, PPG is developing a range of coating technologies that improve the reliability and safety of typical ADS sensors.

PPG's NIR-reflective coatings can also be used to make vehicles, infrastructure, and signage more easily detected by Lidars. The MAVEN demonstration will be used to evaluate questions like the following: "Does this coating increase the range of detection"? "What is the new accuracy of detection"? "Does it enhance contrast"? "Is it more effective under different weather or lighting conditions"? Ultimately, the evaluation data will determine the answer to the most important question: "Does it improve safety"? The results shown in Figure 6 provide tantalizing evidence but need to be confirmed in real-world conditions.

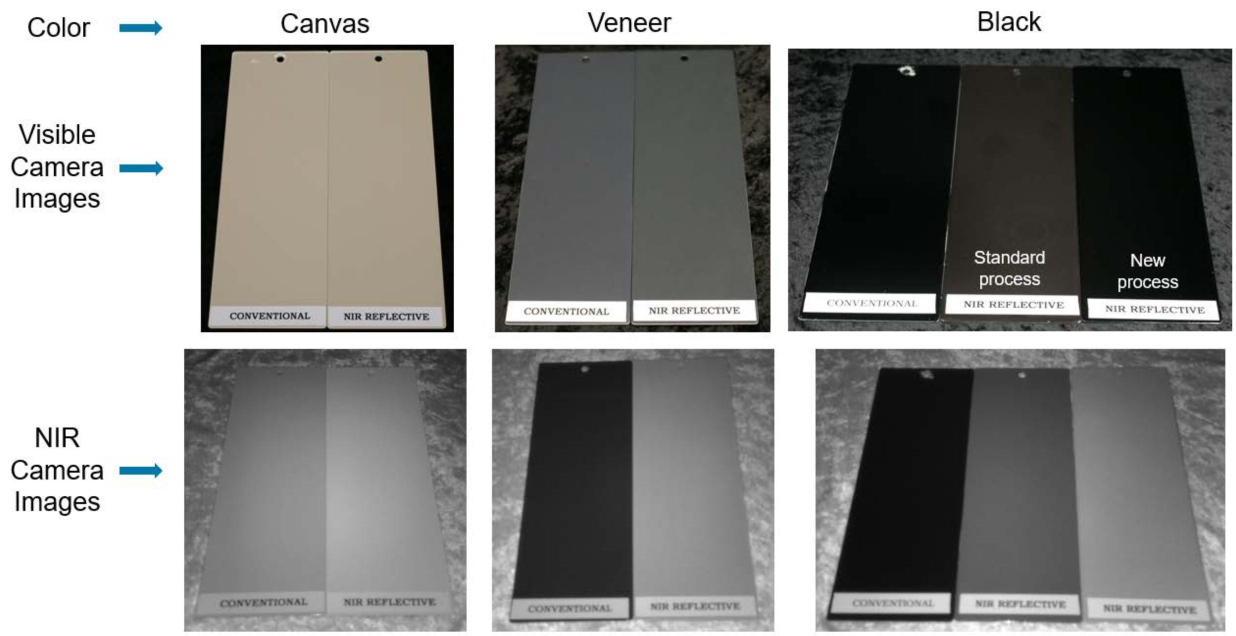

Figure 5. PPG has developed a palette of Lidar-enhanced colors that appear the same to the human eye, but reflect strongly in the near-infra red (NIR) region of the light spectrum commonly used by AVs. Samples that appear black to a NIR camera go nearly undetected to a Lidar sensor.

Coatings that "tone down" the return Lidar signal from a retroreflective street sign: ADS safety may also be impaired by the potential for retroreflective signs to 'swamp' AV sensors or blind them from receiving other signals. PPG has received conflicting feedback on whether this is an issue. A controlled evaluation of this phenomenon needs to be conducted whether this blinding effect is a safety issue or not.

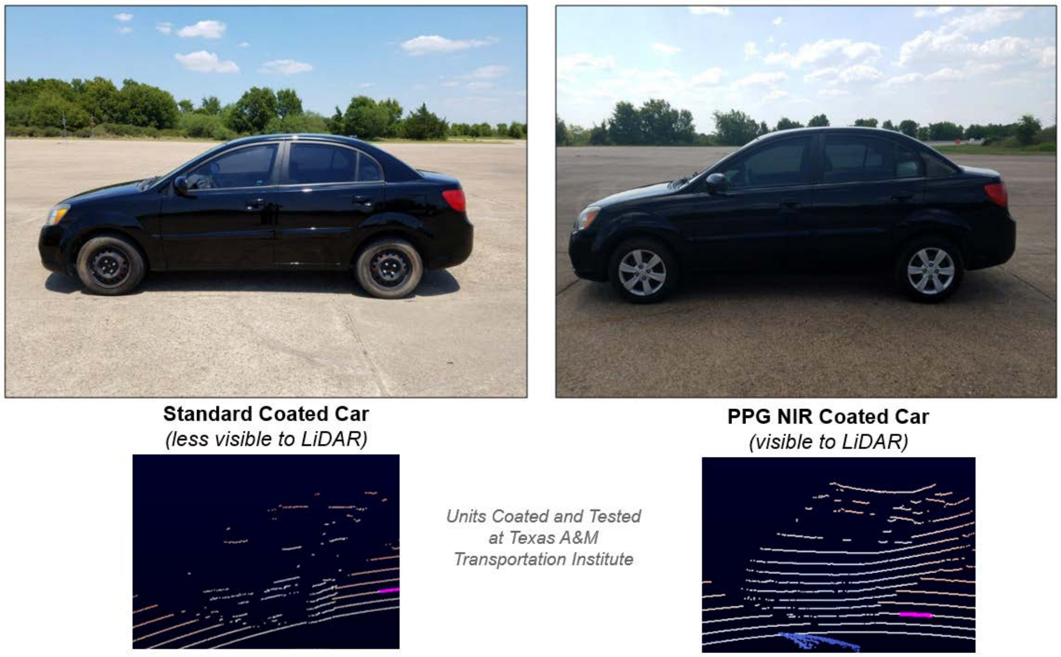

Figure 6. Lidar finds *some* features of a car but detects an NIR-coated car more accurately.

Coatings to encode information hidden to the human eye but helpful to an AV: Coatings can also be used to broadcast one message to the human eye while sending additional information to the sensors of an AV. For example, speed limit, weight limit, and "Do Not Pass" signs are all the same size, shape, and color. They are easily distinguished by human drivers but could be potentially confusing to an AV. But what if those same signs also include a hidden image easily detected by AV sensors, such as a large, bold and unique shape that corresponds to the meaning encoded in the vehicle's software? Alternatively, signs can be designed to be high visibility in not only the visible spectrum but also other wavelengths used by typical AV sensors to provide detection redundancy. PPG can embed these "hidden" images in traffic infrastructure, such as signs used in urban areas as shown in Figure 7.

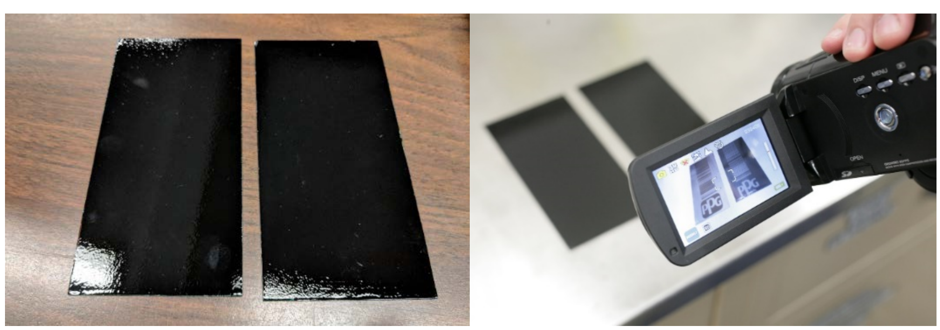

Figure 7. At left, two black panels appear the same to the human eye. At right, when viewed through an imaging sensor, "hidden" information is revealed. Non-black colors can be used.

PPG will work with the MAVEN team to decide what messages and images to embed in urban infrastructure for demonstration purposes. Metrics to be measured include the range and accuracy of detection, usefulness of additional or redundant data, and cost effectiveness.

Coatings that keep sensors clean and operational

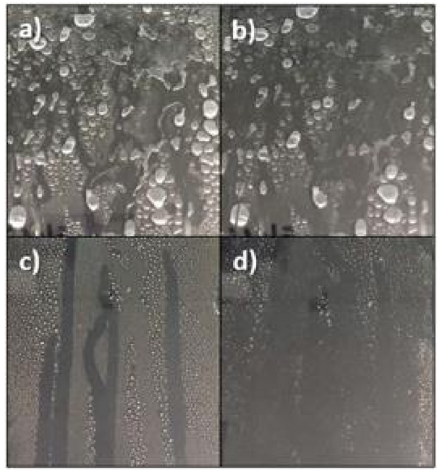

Figure 8. Uncoated (top) and coated (bottom) glass samples soiled with dust (left) and then cleaned with a water spray (right). The coated glass resists soiling and cleans easily.

The performance of AV sensors can be seriously degraded during wet, dusty, or frosty conditions. Unfortunately, AV sensors are not robust enough to operate in all environments needed for safe operations. In addition, most easy-to-clean coatings for transparent surfaces are designed for applications such as mobile phones, and not for rugged use such as driving down a highway with uneven surfaces. We propose to demonstrate easy-clean coating technology under development by PPG to reduce the difficulty and frequency of sensor cleaning. AV developers are investigating a number of methods to keep AV sensors clean, such as blasts of liquid cleaners, air, or wiping systems. An automotive-grade, easy-clean coating can keep sensors cleaner for longer in more situations and reduce the need for heavy and expensive cleaning systems. As the images in Figure 8 show, glass samples with PPG coatings have better cleanliness and give 9 times less haze than uncoated glass after running an automotive-standard soiling test.

First-Mile and Last-Mile Access: In **Task 2.4**, we will explore options to facilitate first-mile and last-mile access in the MAVEN demonstration corridor. Buses pick up and drop off passengers at designated stops, trains do so at specified stations, delivery vehicles are assigned loading zones, Zipcars have their own dedicated parking spaces, as do bike-share systems. At airports and hotels, taxicabs have their own locations too. We will explore marking specific curb locations along the corridor for pickups and drop-offs to facilitate first-mile and last-mile access to AVs. Specific rules of operation can also be studied.

CAV Driving: In **Task 2.5**, the MAVEN demonstration will use an AV to leverage all of the above and evaluate ADS capabilities and limitations in real-world conditions. Safety will be paramount throughout the testing and evaluation process, with two safety operators in the vehicle at all times, and an abundance of caution over-riding any and all concerns to show better performance metrics. Safety, in other words, will be Goal #1.

Task 3. Voluntary Testing Standards

This task focuses on the second MAVEN pillar. Agencies that can regulate ADS face two striking dilemmas. On one hand, leadership in testing AV technology will not only improve safety in the long term, but, in the near term, can stimulate significant economic activity, attract talent and create jobs. Achieving these outcomes, however, necessitates permitting ADS developers to test on public roads so that the technology can evolve and mature. On the other hand, however, if things go wrong (which remains a risk with any emergent technology), it can be a tremendous detriment to both the technology innovators as well as the local public officials. There is a mutual vested interest to ensure that safety protocols are followed by all on-road testers.

Next, to complicate matters further, a set of required protocols or regulations put in place one day may be outdated the very next year, since the technology can change significantly. Regulatory agencies simply cannot act at the rapid pace of technological change and many legislatures and agencies are understandably reluctant to weigh in prematurely.

Nonetheless, it is now also widely understood that full automation of vehicles is many years away, meaning human safety operators will likely be needed in the foreseeable future particularly in complex urban cores. While ADS hardware and software may vary widely across testers and evolve significantly over time, what will remain constant, at least for the near future, is the presence of a human driver in the vehicle or at remote controls. Standards to ensure the readiness of this safety driver to intervene, and systems that allow rapid intervention, can be the safety constant.

At this nascent stage of development, the industry itself is as vested in the public safety of on-road testing as are the public regulators who may oversee them. In **Task 3.1**, we will work with partners, other AV testers and standards bodies to specify standards for safety operators that can be voluntarily adopted by testers. In **Task 3.2**, we will explore broader standards for how testing can be conducted safely. We will build off the unique Executive Order released recently in Pittsburgh that is premised on such a system of voluntary compliance and mutual collaboration.

Task 4. Raising Public Awareness

This task focuses on the third pillar of MAVEN. The public need to gain confidence that AV technology will be safe enough for regular use. Clearly, there are early adopters who want to use the technology. There are also hard-core skeptics. A third group, which is perhaps a silent majority, are open-minded but would need to be convinced that ADS technology is safe before they will use it. In particular, they are concerned about distracted drivers who are too often a common sight, and intuitively understand that computers will not become angry, emotional, drunk or distracted. **Task 4.1** will target engaging the public in creative ways. A key step of this will be Demo Days conducted by SAE International to be described next. In **Task 4.2**, we will produce pithy articles and digestible/entertaining pieces to inform the public about the foundations of ADS technology.

SAE Demo Days: One SAE Demo Day per year will be conducted during the period of performance, for a total of three such events. Each “SAE Demo Day” will provide a neutral platform for all levels of the ecosystem to come together to allow the public to experience the future of transportation and provide feedback that will be invaluable to industry leaders and policy makers who will chart a course toward a shared, electric, and autonomous future. This public-facing event will give people hands-on experience with automated vehicles and associated technologies to:

- build comfort, confidence and trust,
- reinforce engineering advancements designed to enable safety,
- demonstrate differences between ADAS and automated functions, and
- gather feedback to aid industry, cities and states in enhancing product functions, developing operational guidelines and accelerating adoption.

While each event is customized, there are 4 main elements: (1) a pre- and post-ride survey, (2) an AV ride, (3) engagement with interactive technology displays, and (4) a chat with AV experts.

Task 5. Evaluation of the MAVEN Demonstration

In this task, we will perform a detailed evaluation of the metrics shown in Table 3.

Technology or Task	Evaluation Metrics
PPG Surface Coatings	The **reflectance and absorbance** of lane markings, curb markings and signs.
	Detection range for lane markings, curb markings and signs.
	Detection accuracy for lane markings, curb markings and signs.
	Improvements in the **classification accuracy** of signs.
Vehicle-to-Anything (V2X) Communications	Detection accuracy of correct traffic signal status.
	The **minimum distance** between CAV and other obstacles in the environment.
	Stopping distance and **deceleration/jerk**.
	Manual intervention count for safe navigation through an urban core.
Vehicle-to-Vehicle (V2V) Communications	Number of **V2V messages received**.
	Distance at which V2V messages are received.
First-Mile and Last-Mile Access	**Acceptance** of access zones.
	Use of access zones.
Voluntary Testing Standards	Receptivity to and **adoption** of standards.
Public Awareness	Public **attitudes** towards ADS technology.
	Count of those with access to information generated by MAVEN team and partners.

Table 3. Evaluation Metrics for the MAVEN Demonstration.

Task 6. Post-Analysis

In Task 6.1, we will promote the adoption of safety operator standards among the AV tester community. In Task 6.2, we will promote better testing practices based on our studies.

Approach to Address Any Legal, Regulatory, Environmental and/or Other Obstacles

CMU will use its self-driving Cadillac SRX to perform the physical ADS demonstrations required by the USDOT. CMU has obtained a formal approval from PennDOT to conduct AV testing within Allegheny County (among many other counties in Pennsylvania), and is required to have two safety operators in the front seats of the vehicle during testing. CMU was also present along with four other AV testers in Pittsburgh (including Argo AI and Uber) when Mayor Bill Peduto signed an Executive Order requiring AV testers to follow a set of guidelines and principles. Requirements include the submission of comprehensive mileage data to the Department of Mobility and Infrastructure, which is leading this grant application. CMU is yet to go through the formal approval process for this step, but will apply for the same soon.

A successful MAVEN demonstration requires City permission and approval to apply smart surface coatings to signs, lane-markings and curbs. Given the City of Pittsburgh's leadership on and commitment to MAVEN, we expect that the approval process is likely to be expeditious.

CMU has received formal approval from PennDOT to test AVs in Pennsylvania's Allegheny County, where the MAVEN demonstration corridor is located. CMU has already agreed to respect the guidelines and principles outlined by the recent Executive Order signed by the Pittsburgh Mayor for AV testing within the City. Therefore, CMU also expects to receive approval from the City of Pittsburgh for AV testing in Pittsburgh. As a result, per current understanding, CMU does not need an exemption from FMVCSA, FMSS or any other federal regulatory agency.

The MAVEN team is committed to be compliant with the Buy American Act, and agrees not to expend grant funds to purchase a motor vehicle assembled outside the US.

Commitment to Provide Data and Evaluation Participation

The MAVEN team commits to provide demonstration data to the USDOT and the public. In turn, the data can be used to identify challenges, new opportunities for innovation and safety standards that may be required. The Data Management Plan included in this grant application lists the data items that will be made available from this demonstration. Manual interventions, one (imperfect) metric for safe ADS operations, will be reported, for example. Data shared from the effort will be (a) freely available to the USDOT and the public through an open data portal under a promiscuous license, (b) well-specified and machine-readable, and (c) readily accessible for 5 years after the period of performance. We believe that, since technologies like CV2X are still evolving, MAVEN data on both DSRC and CV2X will be beneficial in evaluating the efficacy and safety enhancements of both technologies under similar conditions. Likewise, the enhanced ability of AVs to leverage innovative new coatings is expected to be of considerable interest to safety-conscious AV testers, transportation agencies, and the public. It must be noted that data not relevant to the demonstration itself (such as the proprietary and protected composition of surface coatings) are not sharable. Our conclusions regarding the impact on mobility in general for transportation-challenged populations in particular will also be reported.

Cost Share Approach

Reflecting the important that they place on ADS, the City of Pittsburgh and several members of the MAVEN team are pleased to contribute non-federal resources as cost share for the proposed demonstration. The Department of Mobility and Infrastructure (DOMI) of the **City of Pittsburgh** is directed by Karina Ricks, MAVEN team lead. DOMI will contribute significant resources to the demonstration by modernizing 18 traffic signals along Liberty Avenue in order to be able to host DSRC/CV2X Road-Side Units and cameras. **CMU** will contribute usage of its AV and software development platform for the Maven demonstration, at no cost to this project. The **City of Pittsburgh** is also volunteering 170 heterogeneous city-owned vehicles in its fleet that traverse the MAVEN demonstration corridor to be equipped with DSRC/CV2X On-Board Units. **PPG** will contribute personnel time and effort for testing the effectiveness of its surface coatings in the urban context. **SAE International** will also contribute personnel time and effort to share the cost of conducting its Demo Day events. MAVEN partner **Argo AI** will provide inputs to the City and other stakeholders regarding testing standards and public education about AV technology. MAVEN partner **Ford** supports the development of the digital, physical, and policy infrastructure that will support the efforts of the mobility industry nationally in achieving the goal of safe integration of automated driving systems into the on-road transportation system.

Risk Identification, Mitigation and Management

MAVEN's risk register is presented in Table 3below. We have a good grasp of risks involved, the means to identify risks (thanks to the close physical proximity and regular communications among team-members) and have mitigation plans to manage these risks.

Risk Category	Risk	Expected Probability	Mitigation strategies if the risk materializes	Impact on budget, timelines and project goals as a result of the mitigation strategy
Personnel	**Loss of senior PI and research personnel**	0.25	Pittsburgh is a hotbed of AV developers and is a very attractive location for attracting new talent. MAVEN will enhance our continuing efforts both to retain the talent already committed and to recruiting additional talent.	Low
Personnel	**Loss of MAVEN support personnel**	0.2	We have a talented team in place for supporting the coordination, communications and relationship functions vital to the success of MAVEN. We also have existing depth at MAVEN and its team-members should we lose any of this team and additional funding to supplement the team if needed.	Low
Community relationship	**Permit and approval roadblocks**	0.2	The City of Pittsburgh and the Mayor are committed to the success of MAVEN. The City also has strong working relationships with CMU, the Port Authority Transit and local companies like PPG. Relying on these relationships, we expect to resolve and expedite required permitting.	Low
Community relationship	**Citizen opposition to platform site deployments.**	0.33	We will be staffing and maintaining existing close relationships and communications with community groups. We will ensure clear community benefits through our community outreach efforts.	Low to medium.
Deployment	**Insufficient staffing**	0.1	The MAVEN effort has been carefully planned and will have the necessary funds to accomplish project objectives.	Medium on budget.

Deployment	**Regulatory Approval Roadblocks**	0.1	The V2X components of MAVEN use frequencies approved for use by the FCC. Our procurement processes will meet Buy America requirements.	Low
Deployment	**Technology and Equipment**	0.3	The MAVEN technology components are off-the-shelf components and no new hardware will need to be built. The AV targeted for demonstration is already in place and has been used for demonstration for several years in high-profile locations and neighborhoods. Additional plans to acquire a backup vehicle are in place, but may require supplementary funds.	Low to medium.
Maintenance	**Insufficient staffing**	0.4	The MAVEN team has multiple participating organizations, and each organization is strong and deep enough to attract new hires if the situation arises.	Medium on project schedule and goals.
Operations	**Federal funding**	0.2	If federal funding is reduced, our deployment and operations plans can be scaled down. If any equipment or installation costs end up being costlier than envisioned, we can scale back the number of sites with guidance from the USDOT.	Medium on timetable and goals.
Operations	**Usage**	0.1	The MAVEN team has a well-defined set of roles and responsibilities to meet project objectives. Other AV testers in the city will also benefit from the MAVEN deployment.	Low
Operations	**Security**	0.3	Any security attacks can result in shutting down V2X deployments, causing them to misbehave. The V2X technologies themselves are designed to be protective of privacy. For any cameras deployed at any intersection, video stream segments will not be stored until they are anonymized (with faces blurred, etc.).	Low

Table 4. The Risk Register for MAVEN