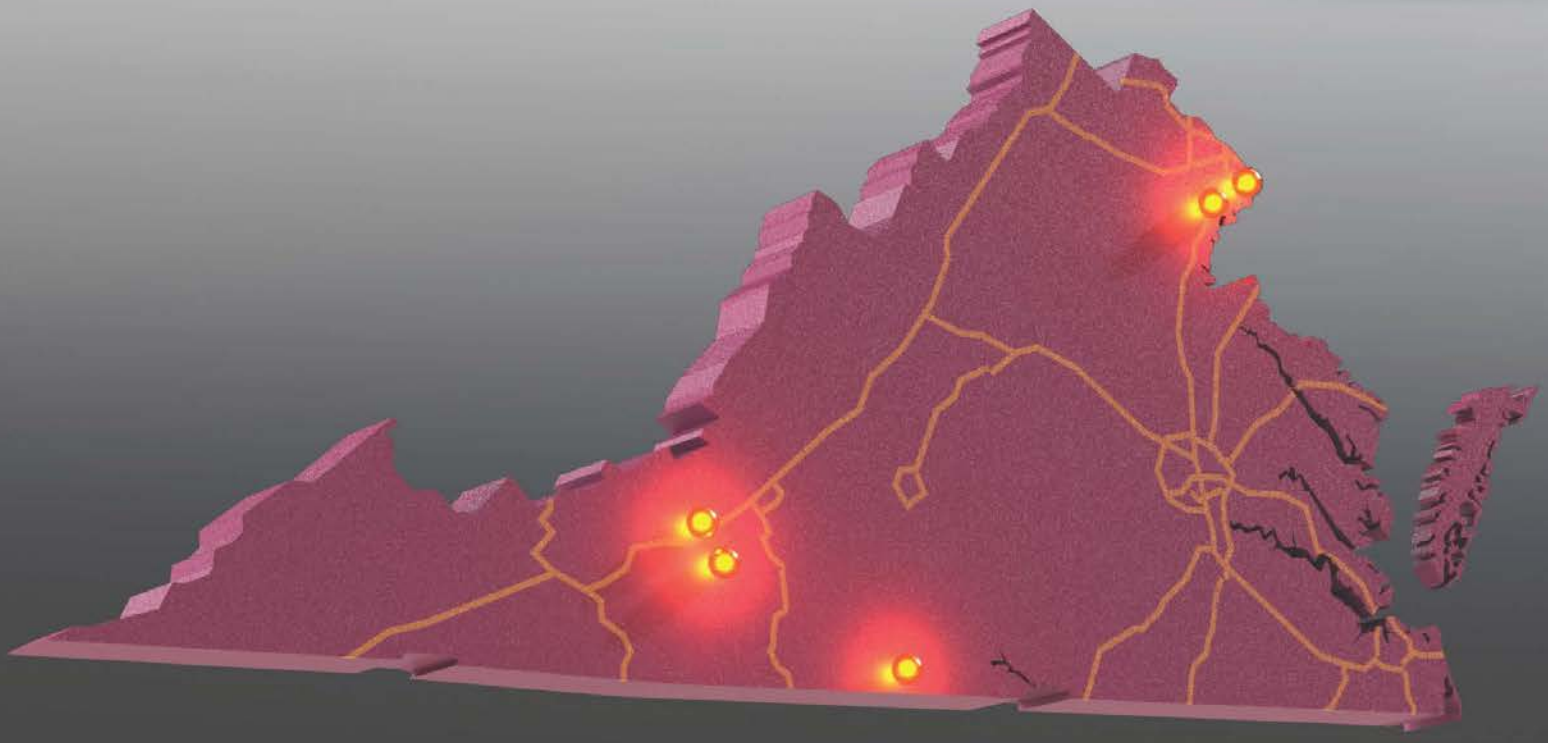
USDOT Automated Vehicle Proving Grounds



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VirginiaTech. Transportation Institute

VDOT Virginia Department of Transportation

VTRC Virginia Transportation Research Council

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Introduction

The Virginia Department of Transportation (VDOT), in partnership with the Virginia Tech Transportation Institute (VTTI) and the Virginia Department of Motor Vehicles (DMV) and on behalf of the Commonwealth of Virginia, is pleased to submit this proposal for the designation of the *Test Facility Consortium* as a U.S. Department of Transportation (USDOT) Automated Vehicle Proving Ground. The *Test Facility Consortium* spans the Commonwealth and includes closed test beds, academic campus roads, an urban city center, and public roadways. In collaboration with USDOT, VDOT, and other key partners, VTTI actively uses these facilities for the development, evaluation, and deployment of automated vehicle systems with the goal of improving safety and mobility. In combination with VTTI's research expertise in automated technologies and established relationships with relevant public and private-sector partners, the resources of the *Test Facility Consortium* make it an ideal entity for this designation.

The Commonwealth of Virginia has selected VTTI to manage and lead the *Test Facility Consortium* due to the Institute's vast experience in this field. VTTI is a research institute of Virginia Tech and the second largest university-level transportation institute in the U.S. Since its inception in 1988, VTTI has been at the forefront of advanced vehicular research and development, and the results of VTTI's work have been translated into significant technology advancements and changes in public policies related to driver, passenger, and pedestrian safety. Currently, the development of vehicle automation is progressing at a rapid pace, with pre-deployment testing requiring complex scenarios and operational roadway environments. In response, VTTI has partnered with VDOT and the Virginia DMV to create state-of the-art facilities and processes that support automakers, suppliers, researchers, and government agencies working in the realm of automated vehicles. These partnerships have generated significant progress in the development, testing, and deployment of advanced and automated vehicle systems and led to the establishment of infrastructure throughout the Commonwealth to help accelerate automation. This existing infrastructure includes the Virginia Connected and Automated Corridors, which were initiated as a collaboration between VDOT and VTTI to speed the implementation of connected and automated vehicle systems.

VTTI has studied advanced vehicular technology for over two decades; since 2001, VTTI has conducted more than $200 million of research and development related to advanced safety technology, including connected and automated vehicles. In recognition of these efforts, VTTI's director, Dr. Tom Dingus, was honored by the White House as a Champion of Change in 2013. In the same year, VTTI unveiled the Center for Automated Vehicle Systems, which was created specifically to work collaboratively across the Virginia Tech campus and the Commonwealth to address issues related to the development and deployment of automated vehicles. In 2014, this center partnered with 32 team members to obtain up to $25 million in National Highway Traffic Safety Administration (NHTSA) funding over five years to conduct research in three key areas, one being vehicle automation. With partners VDOT, Texas A&M Transportation Institute, and San Diego State University, VTTI was also recently awarded a University Transportation Center (UTC) grant for a national center focused on disruptive technologies, with a particular emphasis on automation. In combination with VDOT's commitment to technological innovation to enhance mobility and safety on the Commonwealth's transportation network, VTTI's expertise and experience in automated vehicle development and testing create the ideal environment for a successful proving ground.

Test Facility Consortium

As a collection of resources including closed test tracks, campuses, an urban city center, and open roads, the *Test Facility Consortium* is an ideal entity for designation as a USDOT Automated Vehicle Proving Ground. The cover image shows the locations of the primary *Test Facility Consortium* resources used by VDOT, VTTI, and their partners to test automated systems. These facilities are detailed below.

Virginia Automated Corridors

In direct response to the March 2015 Governor's Proclamation (see page 5) regarding automated vehicle testing in the Commonwealth of Virginia, in which the Commonwealth affirmed its support for VTTI's research and commitment to the deployment of automated technologies on its roads, VTTI partnered with VDOT, Transurban, the Virginia DMV, and HERE (a high-definition mapping business) to launch the Virginia Automated Corridors (VAC). The VAC includes a challenging Northern Virginia roadway environment, including 48 miles of Interstates (Interstates 66, 495, and 95), 30 miles of arterials (U.S. 29 and 50), and limited-access high-occupancy toll lanes. The VAC is designed to support the work of those seeking to test automated vehicles and provide a system migration path from test tracks to public roadways. The varying roadway environments of the VAC promote multiple use-case scenarios that accommodate the testing of automated cars, trucks, and buses on freeways, express highways, and urban routes.

VTTI and its partners test automated and connected vehicles outside of Washington, D.C. as part of the Virginia Automated and Connected Corridors.

Virginia Connected Corridors

In late 2014, VTTI and VDOT launched the Virginia Connected Corridors (VCC), comprising the Virginia Smart Road and the Northern Virginia Connected Vehicle Test Bed. The latter covers Interstates 66 and 495 and U.S. 29 and 50, widely considered to be among the most congested corridors in the U.S. The combined roadways and surrounding environment provide considerable transportation challenges that may be addressed and mitigated by advanced vehicle technology. The VCC is equipped with 57 roadside equipment units installed on both freeways, arterials, and the Smart Road. Arterial roadside units will soon be connected directly to intersection controllers and to a central control system to support the broadcast of signal phasing and timing data, which will facilitate the rollout of higher-level automated vehicles. VDOT, along with researchers from VTTI and its partners, have used this facility to implement 30 connected vehicle applications that can be used by a wide range of vehicles (e.g., passenger, transit, emergency vehicles, motorcycles) to provide a variety of information, including traveler information, lane closure alerts, work zone alerts, incident management, and merge management. The VCC infrastructure includes a developer-friendly, cloud computing environment that supports the development and deployment of third-party applications; data exchange services; application program interfaces and reference applications for developers; support for the migration of applications from the Smart Road to public roadways; and instrumentation and data acquisition systems for the post-deployment safety assessments.

Commonwealth of Virginia Roadways

As indicated by the Governor's proclamation shown below, the Commonwealth of Virginia is fully supportive of VTTI and VDOT in accelerating the deployment of vehicle automation, and Virginia is open for business when it comes to automated vehicles. VTTI has approval to use any Virginia roads for automated vehicle testing, and the VAC can be expanded to include any public Virginia roadway that satisfies test requirements. Unlike many states, Virginia provides a wide variety of terrain and weather

conditions along with opportunities for rural, small-town, urban, and megacity driving. These options provide the somewhat unique capability to test in many different combinations of conditions.

By virtue of the authority vested by the Constitution of Virginia in the Governor of the Commonwealth of Virginia, there is hereby officially recognized:

SUPPORT FOR VIRGINIA TECH TRANSPORTATION INSTITUTE AND AUTOMATED AND AUTONOMOUS VEHICLES

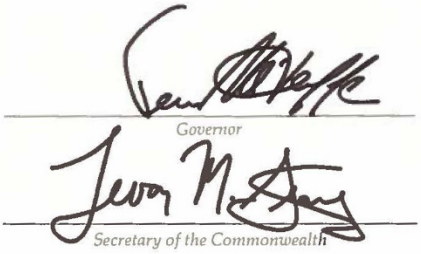
WHEREAS, the Commonwealth of Virginia is on the cusp of the next revolution in the automobile industry with automated and autonomous vehicles, also known as "self-driving" cars; and

WHEREAS, the Commonwealth has an unparalleled higher education system with world recognized research facilities and a mission to be leaders in innovation; and

WHEREAS, the Commonwealth is in a position to be a leader in welcoming, supporting and developing the automated vehicle industry, the emerging technologies used in such vehicles, and the business that will provide the support necessary to make the innovations a reality; and

WHEREAS, the Virginia Tech Transportation Institute Center for Automated Vehicle Systems is providing the necessary leadership to study all aspects related to automated and autonomous vehicles, and to develop partnerships with groups involved in researching, planning, and producing automated vehicles;

NOW, THEREFORE, I, Terence R. McAuliffe, do hereby declare that the **COMMONWEALTH OF VIRGINIA** supports the mission of the Virginia Tech Transportation Institute Center for Automated Vehicle Systems and its self-driving on-road studies, and is open for business for the vehicle and technology manufacturers and researchers committed to the development, testing and deployment of automated and autonomous vehicles, and I call this observance to the attention of all our citizens.



Governor's proclamation affirming the support of the Commonwealth of Virginia for the development, testing, and deployment of automated vehicles under the leadership of VTTI.

Virginia Smart Road

VTTI has successfully operated the Virginia Smart Road, a 2.2-mile closed test bed owned by VDOT, for over 16 years. During this time, the Smart Road has seen significant growth along with more than 26,000 hours of research conducted by institute peers, automakers, suppliers, and government entities. The Smart Road is built to Federal Highway Administration interstate specifications and was created with the development and testing of advanced transportation systems in mind. The road has evolved across the years to answer the ever-changing needs of the transportation community and now features:

- Ubiquitous dedicated short-range communications (DSRC) coverage with seven roadside equipment units that enable vehicle-to-infrastructure communications
- An optical fiber system that allows sensor and data acquisition access every 60 meters
- A connected vehicle-compatible intersection with customizable signal controller
- A differential GPS base station that allows cm-level positioning accuracy for all test vehicles
- Built-in road features to allow crash avoidance research

- Seventy-five custom weather-making towers capable of producing myriad inclement weather scenarios (e.g., snow, rain, and fog)
- A variable lighting section of roadway capable of reproducing approximately 95% of roadway lighting configurations found on U.S. highways

The Smart Road is also a Federal Aviation Administration-approved unmanned aircraft systems test site, and Virginia Tech is actively engaged in the testing of automated systems in the air domain via the Mid-Atlantic Aviation Partnership and the Virginia Center for Autonomous Systems. In September 2016, Google X's Project Wing tested Unnamed Aerial System (UAS) delivery services at VTTI. The Smart Road presents a unique opportunity to test UAS applications for transportation, including crash reconstruction, incident management, and bridge inspection.

The Virginia Smart Road is equipped with weather-making towers capable of producing snow, rain, and fog

Planned Smart Road Expansions

Surface Street Expansion (underway, expected completion date October 2017)

In collaboration with VDOT, VTTI and Virginia Tech are in the process of building the Surface Street Expansion, a $3.5+ million facility that represents a partnership between academia, the Town of Blacksburg, Virginia Tech, and the Commonwealth of Virginia. The expansion will support the testing of multiple platforms, including automated vehicles and UASs. In combination with the existing Smart Road features and future endeavors (see below), the expansion will facilitate a full range of roadways, driving environments, and testing scenarios. Some key features and capabilities include:

- Residential/suburban layouts (portable, reconfigurable buildings and other infrastructure elements)
- Multiple actor (e.g., multiple vehicles, pedestrians, and cyclists) scenarios
- Roundabout/stop-controlled intersections
- Multiple merge areas
- Automation-compatible pavement markings
- Highway layouts
- Signalized intersections with various geometries and numbers of lanes
- Multiple parking and passenger pick-up/drop-off areas
- Ubiquitous connectivity to backend computational networks via cellular and DSRC modes

Planned December 2017 surface street expansion of the Virginia Smart Road on the campus of VTTI

The facility will be secured from public access and monitored 24/7 by the Smart Road Control Room, thus naturally supporting work with early automation systems. The infrastructure will include cellular technology, WiFi, and DSRC throughout; a

storage warehouse with secure vehicle storage; a large, flat paved area/skid pad (approximately 1100 feet long and five lanes wide); water supply for weather making; a vehicle dynamics area; towers for observers, cameras, antennae, and unmanned aerial vehicles; power for lighting and electric-vehicle charging; and an experimental prep area.

Rural Roadway Expansion (expected completion date December 2018)

Additional test tracks that include hilly and flat winding roads, interfering terrain, natural foliage, small bridges, narrow sections, off-road segments, and rural intersections are planned within a recently-purchased expansion to the Smart Road's current right-of-way. The design and construction will be completed in consultation with current partners, future potential clients, and other stakeholders. The roadways will be built to older (e.g., 1965) standards to represent roads that are currently found in much of the nation and that present unique challenges for automated vehicles.

Two views of the planned Smart Road rural roadway expansion. Red: 1.67-mile loop with quick elevation changes, two bridges, and a level creek area. Orange: 1.4-mile loop with minimal elevation change, a 3,200-ft straightaway, and no bridges. Blue: Connector from the Smart Road bridge to the rural expansion. Vehicles can move continuously between all three sections.

Live Roadway Connector (under construction, expected completion date Spring 2017)

A new roadway connector will link the Smart Road directly to U.S. 460 Business in Blacksburg, Virginia. With proper traffic control devices and protocols, this connector will allow VTTI to route test vehicles seamlessly from the live roadway onto the Smart Road; that is, researchers can test naïve driver-subjects in instrumented vehicles around Blacksburg and then route them, largely unknowingly, onto the Smart Road. This unique feature will allow the creation of a variety of scenarios, including long-duration driving and staged scenarios, to test advanced and automated safety features in complete safety. In addition, the Live Roadway Connector will have a turn-around built at the far end, extending the length of the Interstate section of the Smart Road to 2.5 miles.

Virginia Tech Campus

As a research institute of Virginia Tech, VTTI and its partners can also use the Virginia Tech campus for the evaluation of automated systems. The campus of Virginia Tech encompasses approximately 2,600 acres and includes an expanding array of smart infrastructure along with a planned multi-modal transit facility, providing opportunities for the evaluation of automated transit.

Virginia International Raceway

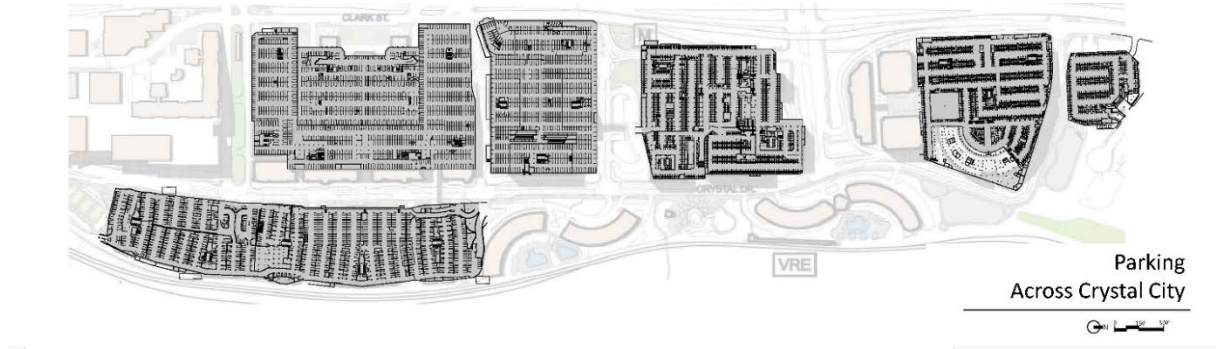
VTTI has an agreement with the Virginia International Raceway (VIR) to purchase track time at the facility for research. VIR offers four configurations, two of which can always be run simultaneously. VIR facilities include two separate paddocks with timing towers, covered bays, classroom/meeting spaces, restaurant, race fuel, pro shop, and restrooms with showers. During off-peak seasons, the entire facility can be closed to the public, allowing testing on the off-track grounds and the creation of a virtual test town.

Aerial view of the Virginia International Raceway

Crystal City Urban Testing Site

Located adjacent to Reagan National Airport and Washington, DC, Crystal City is an automated vehicle proving ground specifically designed to test automation in a dense urban setting. Crystal City will provide an urban proof of concept for automated first- and last-mile connections that serve a diverse group of workers, residents, and visitors in a travel shed that encompasses a range of neighborhoods and employment centers in Virginia, Maryland, and DC. The Crystal City facility consists of nearly four miles of private underground and street-level roads along with below-ground parking facilities. The testing facilities are proximate to public roadways, a dedicated transitway, and curbside transit lanes. Military facilities including a base with a campus-like environment provide additional opportunities for testing, demos, and pilots. With about two miles of underground roads and more than 12,000 below-ground parking spaces, this facility represents the challenges of connectivity in underground structures. Crystal City will serve as the Virginia test site for Olli, the self-driving shuttle developed by Local Motors, and provides an ideal environment for VTTI and VDOT to test automated shuttles, automated vehicle platooning, and parking systems for autonomous cars.

Olli, Local Motors' self-driving shuttle, to be tested at Crystal City. Source: http://www.ibtimes.co.uk/meet-olli-self-driving-3d-printed-mini-bus-controlled-by-ibm-watson-that-talks-you-1565900



Aerial views of the Crystal City urban testing facility for automated vehicles

Eligibility Criteria

Proposed Contributions

The partnerships between VTTI, VDOT, the Virginia DMV and other entities within the Commonwealth allow for unparalleled research efforts. For example, VTTI has developed prototype infrastructure for real-world testing to advance the communication of safety-relevant messages on I-66 and established a closed test track facility where a torrential downpour can be created to evaluate how new sensor technology performs during adverse weather conditions. VTTI researchers have demonstrated their leadership in the vehicle safety field for close to three decades. Research performed at VTTI has impacted regulations at national and international levels, and VTTI researchers are involved in multiple standard-developing organizations [e.g., the International Organization for Standardization (ISO) and the Society of Automotive (SAE) Engineers]. VTTI and its partners routinely perform research for the manufacturers and suppliers of new automated vehicle technologies. Moreover, VDOT and the Virginia DMV have partnered with VTTI to test the limits of new systems via safe experiments on public Interstates (e.g., Transurban's dedicated lanes at I-395; see video example here: https://vimeo.com/142905461). The Commonwealth is also building automation-related communities of practice within Virginia, as evidenced by the strategic plan for automated vehicles, which is currently being developed by the Secretary of Transportation, the Commonwealth's Transportation Board, and the Connected and Automated Vehicle Program at VDOT.

VTTI's Safety Board will provide relevant information to the Community of Practice designated for the Automated Vehicle Proving Grounds. Input from this Community of Practice is expected to be instrumental in optimizing established safety management plans and determining appropriate ways to access testing data and comply with the requirements for personally identifiable information. Our engagement with stakeholders, including international, federal, state, professional, and private organizations, will allow us to generate results with broad applicability. Furthermore, VTTI's past and current research collaborations with the USDOT demonstrate a commitment to maintaining working relationships with the USDOT's relevant research program offices. VTTI researchers routinely organize and participate in conferences, meetings, and joint research efforts related to vehicle automation and submit activity reports to USDOT on a monthly basis.

Commitment to Safety

Safety is at the forefront of VTTI's research and development efforts. Before involving participants in any study, the vehicles to be used are tested on a closed test track, and the experimental protocols are verified by both VTTI's internal IRB and the Virginia Tech IRB. Trained researchers, engineers, and experimenters conduct preliminary testing to ensure that the vehicle or prototype system performs as expected. If needed, VTTI then works with the vehicle/system provided to make and document any necessary changes. All personnel accessing the test track facility are required to complete safety training (a class offered once a month or by appointment at VTTI). For on-road studies, test and prototype vehicles are driven by trained professionals through edge cases for the particular system of interest to ensure that it repeatedly performs as intended. All research vehicles are equipped with VTTI-developed data acquisition systems to record information about the circumstances that might trigger unintended responses. VTTI has deployed over 5,000 research vehicles in a combination of test-track, on-road, and naturalistic studies without any breaches in safety.

Research, Application and Data Sharing

The Commonwealth of Virginia has a diverse geographic landscape, making it attractive for the real-world testing of true system capabilities. Virginia encompasses dense roadways (I-66; part of the VCC), safety-critical areas such as the Pentagon, and windy roads that are at times deeply secluded and provide challenges related to connectivity (e.g., Blacksburg and Alton). To represent these varied conditions in a secured environment, we have developed testing scenarios that take advantage of the Virginia Smart Road, Surface Street Expansion (opening Dec. 2017), VIR, and portions of the VAC and VCC and designed experiments to ensure that prototype vehicles and systems can withstand the myriad of real-world conditions. In addition to conducting groundbreaking research related to the testing and deployment of automated vehicles, VTTI is implementing real solutions based on the findings of this research, both within the Commonwealth of Virginia and nationwide. The close collaboration between the Virginia Transportation Research Council and VTTI ensures that all the latest advances are recognized by the Commonwealth and adopted in a timely manner. Moreover, under the tenure of the current commissioner of the Virginia DMV [Richard Holcomb, also the past chair of the American Association of Motor Vehicle Administrators (AAMVA)], the Model State Policy (incorporated in USDOT Federal Automated Vehicle Policy) has been developed.

Outreach efforts are an important component of VTTI's research and development in the arena of vehicle automation. Some examples include the National Surface Transportation Safety Center for Excellence, past and current UTCs, including the new *Safety Through Disruption* UTC, and professional conferences organized and attended by VTTI and partnering organizations (e.g., the International Symposium on Naturalistic Driving Research, Automated Vehicle Symposium, Fatigue Management Conference, AAMVA annual meeting, World Congress on Intelligent Transport Systems, and other regional and national events). It is important to highlight the Virginia Governor's Transportation Conference, an event that gathers agencies and stakeholders in one location to discuss various factors that will affect transportation in the short and long terms. Automated vehicle technology, policy implications, and other related topics have consistently been at the forefront of this event in the Commonwealth, with great support received from the state police, DMV, VDOT, and other agencies.

VTTI is committed to developing, maintaining, and disseminating data and results so that they can be leveraged by other researchers, public agencies, and transportation professionals. The wealth of data collected during VTTI-led naturalistic driving studies are routinely made available for further analysis; for example, VTTI created the InSight website (https://insight.shrp2nds.us/) to provide access to data collected during the Strategic Highway Research Program NDS. In addition, VTTI has led ISO task forces focused on the standardization of automated vehicle and naturalistic driving research and assisted researchers and practitioners across the globe on how to effectively bridge gaps in existing data. VTTI intends to extend

this commitment to data sharing to research conducted using the *Test Facility Consortium.* In addition, VDOT's cloud-based data portal, scheduled for release in July 2017, will provide access to VDOT data generated using the *Test Facility Consortium.*

Demonstrated Investments

The Commonwealth of Virginia wants to ensure the safe future of highly automated vehicles. This high-priority goal is demonstrated by its capital investments at VTTI, which include over $35M to date in the existing Smart Road infrastructure, $10 million for the new Surface Street Expansion in 2016 and 2017 (see pages 6–7), and Virginia Tech's investment in programs and facilities to develop Intelligent Infrastructure for Human-Centered Communities (over $75 million dollars). At a higher level, VTTI strives to incentivize organizations to visit the Commonwealth and collaborate with institutions that are well-versed in safety implications; the Commonwealth of Virginia has already recognized VTTI as a leader in automated vehicle development and provided its full support in the evaluation of automated systems on the Commonwealth's roads (as exemplified by the Governor's proclamation on page 5). VTTI is also poised to become a leader in research on the regulatory challenges associated with automation; VTTI is leading an NCHRP effort in collaboration with AASHTO and AAMVA to evaluate the implications of automated vehicles on the motor vehicle code across the nation. Finally, as mentioned throughout this proposal, VTTI has completed and is currently carrying out a variety of studies designed to evaluate the feasibility of different automated vehicle technologies.

Readiness

The Virginia Smart Road, VIR, VAC, and VCC are currently active and used for research. The Smart Road surface expansion will be available by the end of 2017, and the rural roadway expansion will open in 2018. VTTI is currently engaged with all major automobile manufacturers, their suppliers, and other entities involved in the development of heavily automated vehicles. Currently, VTTI has seven active indefinite delivery/indefinite quantity (IDIQ) contracts with USDOT agencies (FHWA, FMCSA, NHTSA), and the contracts under these IDIQs involve more than 60 organizations (including vehicle manufacturers, suppliers, research organizations, and academic institutions). In addition, the newly awarded, VTTI-led UTC entitled *Safety Through Disruption* will soon open its doors and these facilities to a new generation of researchers.

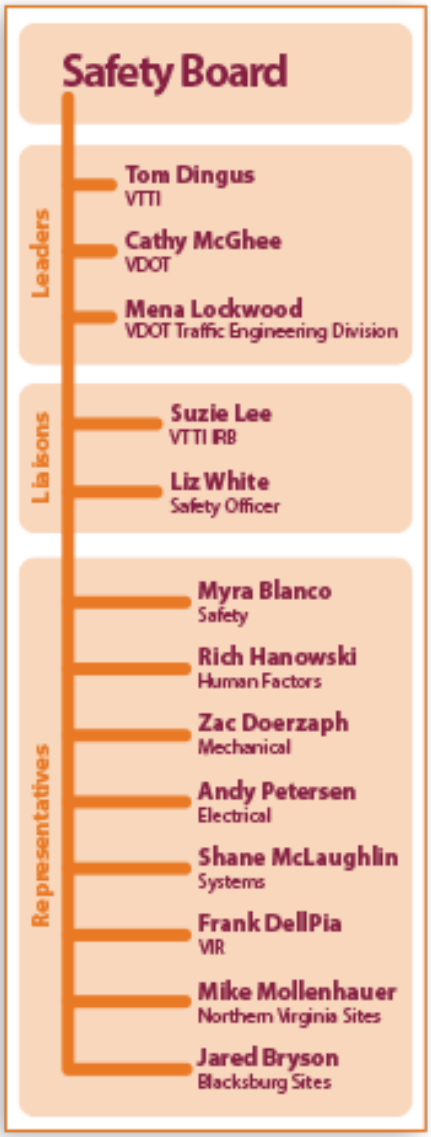
As discussed below, the Safety Officer will be the designated point of contact for the USDOT and all other organizations performing research using the *Test Facility Consortium*. VTTI's annual reports already provide a means to communicate important information to the public. VTTI has also established a process to safely conduct testing on public roads; this process involves both internal and university Institutional Review Board (IRB) approval along with the engagement of relevant partner organizations (e.g., DMV and state police).

Adherence to Laws, Regulations, and Federal Policy

As attested by an impeccable record of safety in the development, testing, and evaluation of different vehicle technologies, VTTI has been successful at performing research with federal, state, and private partners in adherence to all existing laws and regulations. The Safety Board and VTTI/Virginia Tech IRBs will be instrumental to ensure that this record of safety continues through all future testing and research efforts. As the requirements for the Safety Assessment Letter to NHTSA are finalized (pending Office of Management and Budget approval), the documentation needed will be provided for the applicable sections of the 15 safety assessment areas for highly automated vehicles. Moreover, VTTI is leading an effort for NCHRP in collaboration with AASHTO and AAMVA to evaluate the implications of automated vehicles on the motor vehicle code across the nation.

Safety Board and Safety Officer

VTTI will provide a designated Safety Officer who will be responsible for VTTI's safety management plan and serve as the designated point of contact with USDOT and with other organizations performing research using the Test Facility Consortium. The Safety Officer will participate in all Community of Practice regular quarterly meetings of Safety Officers and will report information from these meetings to the public through VTTI's annual reports. In this way, the VTTI annual reports will be used to share VTTI's approaches to safety and safety data generated through testing and operation.



Before USDOT automation testing begins in studies that use public roads or naïve drivers/users, VTTI's Safety Board and any other organizations deemed appropriate by the Safety Board (e.g., DMV, state police) will review the experimental protocol. All proposed testing will also be subjected to IRB review. VTTI has an internal IRB, and Dr. Suzie Lee, a Project Director within the Center for Data Reduction and Analysis Support at VTTI, also serves on Virginia Tech's IRB. These resources help ensure the safety and compliance of all projects carried out using the *Test Facility Consortium*.

VTTI's Safety Board is comprised of safety experts from VTTI with relevant background (safety, mechanical, electrical, and systems engineering along with human factors and behavioral science) and representatives from each of the testing facilities. The board is led by Dr. Tom Dingus (chair) and Cathy McGhee (co-chair). Mrs. McGhee is the Director of the Virginia Transportation Research Council and responsible for all research at VDOT. The Safety Board will consult with IRBs as needed during experimental development and research. The Safety Officer, Liz White, will serve as the liaison between the board and the USDOT. Dr. Suzie Lee will serve as the IRB liaison.

Key Impact Areas

Automated Vehicles

As mentioned earlier, in partnership with VDOT, VTTI has successfully operated facilities for testing advanced and automated vehicle systems for over 20 years and has already established infrastructure throughout the Commonwealth to realize these systems. VTTI has been supporting both government and private-sector stakeholders in the design and testing of advanced vehicular technology for over 20 years. VTTI's automation-related work bridges numerous functional areas and is led by the Center for Automated Vehicle Systems (CAVS). VTTI's CAVS applies an interdisciplinary approach to studying all aspects of the automation life cycle in the field of transportation. CAVS efforts are anchored in applied research and strengthened by collaborations with national and international partners in vehicle automation, including groups involved in research, planning, policy, and the production of automated vehicles. Examples of recent VTTI work in the automated vehicle realm are given below in the *Sample Related Contracts* Section.

Connected Vehicles

VTTI has completed or is currently working on over 30 connected vehicle projects that involve vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-device communications using both cellular technology and DSRC. The Center for Advanced Automotive Research (CAAR) at VTTI focuses on the research, development, and evaluation of next-generation automotive systems. CAAR works cooperatively with industry and governmental partners to solve complex transportation problems through technological advancement. The research performed under CAAR's connected vehicle portfolio has given VTTI experience in simultaneously coordinating hundreds of participants among several sites during testing efforts. In addition, CAAR work has provided the foundation for the development of the complex scenarios that are needed to thoroughly evaluate advanced vehicle systems.

Heavy Vehicle Research

The Center for Truck and Bus Safety (CTBS) at VTTI focuses on the development and evaluation of heavy vehicle systems. CTBS designs, delivers, and implements leading-edge research and development efforts aimed at improving the health and safety of heavy-vehicle drivers. Connected and automated vehicle technologies are expected to be critical components in the future of heavy vehicle transit, and VTTI has studied applications of connectivity/automation in heavy vehicles, including truck platooning. VTTI has established key relationships with manufacturers and operators of heavy trucks, and the designation as an Automated Vehicle Proving Grounds will further assist with heavy vehicle research needs.

Vulnerable Road Users

Vehicle automation stands to usher in great advances in the safety and mobility of vulnerable road users. VTTI's Center for Vulnerable Road User Safety conducts research and outreach to enhance safety for all vulnerable road users, including senior and teen drivers, bicyclists, and pedestrians. The *Test Facility Consortium* is expected to be instrumental in determining how vehicle automation can serve vulnerable populations in the future.

Naturalistic Data Collection

View of the unobtrusive instrumentation installed in VTTI's automated Cadillac SRX

Although test-track and controlled-road experiments are valuable tools for the evaluation of automated systems, naturalistic driving studies (NDSs) on open roads are ultimately needed to evaluate and refine the next generation of automated technologies. VTTI is internationally known as a leader in NDSs and naturalistic data analysis. By using sophisticated in-vehicle cameras and instrumentation, NDSs provide researchers with immense amounts of data on real-world behavior. VTTI's Center for Technology Development (CTD) produces and installs unobtrusive data acquisition systems (DASs) on a wide variety of vehicles to accomplish specific research objectives. VTTI also has a fleet of vehicles outfitted by an in-house team of engineers for the testing of connected and automated systems; these vehicles include a connected motorcycle and Cadillac SRX, an automated Cadillac SRX, and a recently purchased Lone Star tractor-trailer that will be equipped with an automated system in the near future. VTTI continues to develop vehicle-to-vehicle and vehicle-to-infrastructure capabilities as well as test-bed applications to accommodate the growing body of research in autonomous vehicle technologies.

VTTI's current DAS iterations include the Next Generation (NextGen) DAS, the MiniDAS, and the recently developed FlexDAS. The MiniDAS, which is ideal for large deployments, fits within a system roughly the size of a sandwich and enables naturalistic studies of all vehicle sizes operating on the roadway, from motorcycles and bicycles to tractor-trailers. FlexDAS provides more computational power for new automation sensing, algorithms, and control functions and can be configured to interface with the latest high-data-rate sensors. VTTI has successfully deployed thousands of DASs in a myriad of vehicles at sites throughout the U.S. and Canada. Through this experience, VTTI has become well-versed in planning and executing NDSs, and an experienced team of data reductionists and analysts is already in place to store, process, and interpret NDS data. These capabilities will prove invaluable in future naturalistic evaluations of automated systems.

Sample Related Contracts (Recent and Ongoing)

Mixed-Function Automation Naturalistic Driving Study

VTTI is currently investigating real-world driver interaction with market-ready, mixed-function automation through an NDS. The vehicles being used in this study have the capability to simultaneously activate automated lateral and longitudinal functions, allowing drivers to operate the vehicle with their hands off the steering wheel and feet off the pedals for several seconds. VTTI will observe and evaluate how drivers operate five different commercially available vehicles equipped with mixed-function automation. Slated for completion in late 2017, this study will provide the first naturalistic data on the use of mixed-function automation, and the findings will support the identification and refinement of human factors requirements to encourage the safe operation of highly automated vehicles.

Testable Cases and Scenarios for Highly Automated Vehicles

VTTI was recently awarded a 16-month NHTSA contract to identify relevant automated vehicle functions, the operational domains in which these functions are expected to operate, and the behavioral component of the software that processes data to produce a response. This project will ultimately develop a set of preliminary objective tests or evaluation methods for automated vehicle systems. The findings are expected to be critical for the optimization and evaluation of next-generation automated vehicle systems in a wide variety of environments.

Driver Expectations for System Errors and Crash Avoidance in Mixed-Function Automated Vehicles

This recently awarded NHTSA project will use test-track facilities and a VTTI-customized vehicle to present different levels of automation quality to participants. The study will test the effects of different levels of user expectations for automation and the performance levels of automation on the secondary task involvement of users and their readiness to intervene.

Implications of Automation for Motor Vehicle Codes

This ongoing project sponsored by the Transportation Research Board aims to improve our understanding of how automated driving systems affect motor vehicle codes and help regulatory agencies adapt to the increasing prevalence of automated vehicles. Existing motor vehicle codes have been developed based on implicit assumptions about drivers maintaining continuous involvement in the driving task and continuous responsibility for managing traffic safety hazards. Automated driving systems significantly reduce the role of the driver, which means that some of these codes will need to be reconsidered. The incorporation of driving behavior into in-vehicle software also generates pressure to harmonize the rules of the road across jurisdictions. The results will provide state DOTs and DMVs with guidance and resources to handle the legal changes resulting from connected and automated vehicles.

Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts

In this NHTSA-sponsored project that ran from 2012 to 2015, VTTI investigated user interactions with Level 2 and Level 3 partially automated vehicles through three experiments using prototype partially automated vehicles on controlled test tracks in mixed traffic. Overall, the results indicated that effective human-machine interaction elements can help operators resume control of vehicles in a relatively short period of time. The operators also greatly trusted the capabilities of the automation before, during, and after they experienced it, with some evidence that trust decreased when automation failures occurred without an alert.

Automated Vehicle Crash Rate Comparison Using Naturalistic Data

This Google-commissioned project aimed to address various limitations in currently available data to definitively determine whether self-driving cars are more or less prone to crashes than traditional vehicles. VTTI examined national crash data and data from NDSs to estimate current crash rates and then compared the results to data from Google's Self-Driving Car program. When controlling for unreported crashes and crash severity, the results suggested that the crash rates of self-driving cars operating in autonomous mode are lower than the national crash rate (3.2 vs. 4.2 crashes per million miles driven).

Overview of Proprietary Work (L2–L4)

VTTI's outstanding facilities for the testing of advanced transportation systems have encouraged 14 of the major automobile manufacturers and many of their suppliers to work with the Institute to evaluate and develop their products. The center regularly works with NHTSA, automakers, and suppliers on proprietary projects that serve as a key step in automated vehicle development. For example, in 2014, VTTI's Center for Automated Vehicle Systems partnered with 32 teaming members, including the Virginia Tech-based Virginia Center for Autonomous Systems, the Hume Center, TORC Robotics, General Motors, and Google, to submit a successful proposal to NHTSA for up to $25 million across five years to research three key areas (electronics safe reliability, cybersecurity, and vehicle automation).

Light-Vehicle Builds and Model Deployment Support for the Safety Pilot Program

Through the Crash Avoidance Metrics Partnership, VTTI has supported all phases of the USDOT Safety Pilot Model Deployment, which aimed to accelerate the introduction and commercialization of connected vehicle systems designed to enhance safety. The Model Deployment program, which ran from 2010 to 2013, comprised five major stages: device development, driver clinics, pre-model deployment testing, model deployment, and post-model deployment evaluation. VTTI equipped a wide variety of light vehicles with its custom DASs for the Model Deployment and worked with CAMP to develop testing protocols for the safety applications. VTTI also developed materials to train the drivers of the integrated vehicles for the Model Deployment. During the Deployment, VTTI monitored the condition of every vehicle and was responsible for collecting, storing, processing, and transferring data. VTTI also support CAMP in data analysis, driver clinics to evaluate driver acceptance of connected systems, and post-deployment decommissioning.

Summary

VDOT and VTTI are pleased to submit this proposal on behalf of the Commonwealth of Virginia. The *Test Facility Consortium* meets all the criteria necessary to be named as a USDOT Automated Vehicle Proving Ground. We are pleased to assist in moving the state of knowledge forward and collaborating in future efforts to develop methods for test-track, field operational tests, and naturalistic studies related to vehicle automation.