U.S. Department of Transportation NOFO # 693JJ319NF00001

sAVvy Mobility

Demonstrating Safe Autonomous Vehicles For Everyday Commute

Submitted by:

University of Virginia
Charlottesville, VA

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Charlottesville/Albemarle, VA

Sonny Merryman, Inc.
Evington, VA

Perrone Robotics, Inc.
Crozet, VA

ARBOC Specialty Vehicles
Middlebury, IN

U.S. Department of Transportation (USDOT)
Federal Highway Administration (FHWA)
1200 New Jersey Avenue, SE
Washington DC 20590
Attn: Sarah Tarpgaard, HCFA-32

Dear Ms. Tarpgaard:

We are excited to respond to the U.S. Department of Transportation's Automated Driving System Demonstration Grant (NOFO Number 693JJ319NF00001) with our enclosed proposal entitled: **SAVvy Mobility - Demonstrating Safe Autonomous Vehicles For Everyday Commute** submitted by the University of Virginia in collaboration with JAUNT Inc, Perrone Robotics Inc., Albemarle County, VA, Sonny Merryman, and ARBOC. We are requesting a total budget of $10M for a demonstration period of 24 months (Sep 2019-Aug 2021).

Automated vehicles are rapidly becoming significant components of our nation's critical infrastructure. While they hold promise for considerable benefits, they also bring with them urgent safety-critical challenges that must be addressed.

In addition, as journeys become fully automated, the experience itself will need to become more accessible to all in our population. The safety, mobility, and economic benefits of highly automated vehicles should be accessible to everyone, and everywhere. The majority of automated driving demonstrations to date have focused on operation and impact in urban settings, with the testing of automated cab services. The perspective of the proposed demonstration is much broader: Automated transit vehicles could be the key to catalyzing the mobility for people living in small and medium sized suburban areas.

SAVvy Mobility will advance the state of data-driven safety assessment for automated vehicles, automated public transportation, and public trust in automated driving systems technology, all while adopting an accessibility-first transportation model inclusive of passengers of all ability levels. The demonstration focuses on showcasing multiple SAVvy automated public transit vehicles which will be driven on routes in the Crozet-Charlottesville, VA area, spanning rural, suburban, and urban environments, and, therefore, presenting rich and diverse demonstration conditions.

The SAVvy Mobility demonstration project will be executed by an experienced team of collaborators including the University of Virginia, JAUNT Inc., Perrone Robotics Inc., Albemarle County, VA, Sonny Merryman, and ARBOC with guidance and support from Virginia Department of Transportation (VDOT) through their organization, the Virginia Transportation Research Council (VTRC).

The Automated Driving System (ADS) Demonstration Grant demands a team capable of successfully handling large complex projects with multiple delivery methods. Our team is well qualified for this project, offering the synergy of previous USDOT experience and expertise in specific subject areas. In addition, the team has the data infrastructure and collaborative interaction environment to enable us to be ready to begin sharing valuable data.

One of our primary goals for the demonstration is to provide value to US DOT that comes with transparency and data sharing for automated vehicle operation. We confirm that the recipients will sign a mutually agreeable data sharing agreement with USDOT as a requirement for award. By distilling and disseminating the large volume of data collected during this demonstration, we will push the envelope on data-driven safety assessment of automated vehicles, in a manner that can facilitate and inspire wider adoption.

The following documents are included in the proposal submission:

1. Project Narrative and Technical Approach: *Filename: University_of_Virginia_Part1*
2. Management, Staffing approach and Capabilities: *Filename:University_of_Virginia_Part2*
3. Draft Data Management Plan: *Filename: University_of_Virginia_Part3*
4. Letters of commitment from VTRC, JAUNT, Perrone Robotics, and County of Albemarle: *Filename: University_of_Virginia_Part4*
5. Application Standard forms: *Filename: University_of_Virginia_Part5*
6. Budget breakdown and justification: *Filename: University_of_Virginia_Part6*

We are delighted to bring this expertise and collaboration together at such a pivotal moment in transportation and are ready to go to work immediately!

Should you have questions or clarifications, please contact me, Dr. Madhur Behl (madhur.behl@virignia.edu) at the University of Virginia.

Thank you for your consideration,

Dr. Madhur Behl
On behalf of the entire SAVvy Mobility team

Summary Table

Summary Table	
Project Name / Title	Demonstrating Safe Autonomous Vehicles for Everyday Commute
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	The Rector & Visitors of the University of Virginia P. O. Box 400195, 1001 N. Emmet St. Charlottesville, VA 22904-4195
Point of Contact (Name/Title; Email; Phone Number)	Name: Dr. Madhur Behl Email: madhur.behl@virginia.edu Phone: 434-924-1021
Proposed Location (State(s) and Municipalities) for the Demonstration	Crozet, VA; Albemarle County, VA Charlottesville, VA
Proposed Technologies for the Demonstration (briefly list)	a. Demonstrating Level 4 public transit vehicles. b. Demonstration on suburban, and rural road topologies and traffic conditions. c. Accessibility first service design. d. Data-driven safety metrics assessment with context. e. Fair and transparent safety comparison between human driven and automated vehicles f. Cybersecurity and risk assessment g. Safety driver, and passenger monitoring h. Commitment to manage and share data at varying timescales.
Proposed duration of the Demonstration (period of performance)	Sep. 1, 2019 – Aug. 31, 2021 24 months
Federal Funding Amount Requested	$ 9,786,130
Non-Federal Cost Share Amount Proposed, if applicable	$ 213,870
Total Project Cost (Federal Share + Non- Federal Cost Share, if applicable)	$ 10,000,000

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Section 1: Executive Summary

The SAVvy demonstration project will be executed by a team of collaborators including the University of Virginia, JAUNT, Perrone Robotics Inc., Albemarle County, Sonny Merryman, and ARBOC with guidance and support from Virginia Transportation Research Council (VTRC) and Virginia Department of Transportation (VDOT).

1A: Vision, Goals, and Objectives

The proposed demonstration will deepen the understanding of safe integration of automated driving systems (ADS) into the on-road transportation network by applying Level 4 ADS to public transportation services. Through this demonstration we will develop tests and metrics to facilitate safe integration of ADS, apply those tests to transit services on public roads, collect and share data measuring vehicle safety under diverse operating conditions, compare the performance of automated vehicles with human drivers under identical conditions, and advance an "accessibility-first" transportation model inclusive of passengers of all ability levels.

The demonstration has the following key objectives:

1. Demonstrate automated vehicles in public transit - as opposed to the more widely tested urban autonomous cab services.
2. Deploy across a mix of rural, sub-urban, and urban roads and traffic conditions, providing diverse testing conditions which can complement tests in other locations.
3. Serve the elderly and disabled populations through an "Accessibility First" service design usable by any ability level.
4. Integrate level 4 autonomous capability demonstrated by Perrone Robotics into new public transportation contexts - in the presence of trained safety operators.
5. Demonstrate value to US DOT, the public, and the AV community that lies in data-driven safety assessment of AVs, in a manner that can facilitate and inspire wider adoption.
6. Leverage University of Virginia's research expertise to perform data-driven safety assessment, perform human/passenger behavior analysis, and investigate cybersecurity challenges.
7. Compare automated technology to a clear safety baseline by running transit vehicles, one manual and the other automated, under identical operating conditions.

1B: Key Collaborators, Stakeholders, Team Members, and Participants

The SAVvy Mobility project will build on an existing automated transit shuttle partnership established in 2018. This team includes key collaborators (detailed below) with expertise in autonomous vehicles research and data analysis, public transportation (including transportation-challenged populations), Level 4 ADS software and hardware, public outreach, and governance.

The groundwork laid by the strong existing collaboration will allow for the demonstration to start collecting and sharing data for safety assessment right from the get-go.

University of Virginia (UVA) - UVA is an established leader in transportation research, autonomous driving systems, and cybersecurity for autonomous systems. The UVA team comprises of research faculty, and data scientists who have expertise in safety of connected and automated vehicle technology, driver and passenger behavior monitoring, and data handling, storage, and sharing at scale. UVA has a successful record of managing and conducting large scale research with the US DOT.

JAUNT, Inc. - A regional transportation provider in central Virginia, JAUNT provides over 300,000 trips each year to passengers of all ages, personal mobility, and travel purposes. JAUNT covers a 2,600-mile service area and brings extensive public transportation experience, including urban paratransit, rural demand-response, commuter routes and human service transportation coordination.

Perrone Robotics, Inc. - Perrone Robotics is the creator of the MAX platform for mobile autonomy and robotic control. MAX technology has been developed for fully autonomous automotive applications for over 16 years. Perrone Robotic's autonomous shuttle technology can be applied to a wide range of vehicles. Perrone Robotics will undertake the task of integrating their vetted and proven autonomy kit, and MAX software with the SAVvy mobility shuttles.

Albemarle County -The County has been involved from the early stages of an existing shuttle deployment project so they have a complete understanding of the system's capabilities and the challenges that may arise in real-world operation. The county will assist the team in guiding and establishing incident review protocols, planning transit routes, and coordinate with law enforcement.

Sonny Merryman & ARBOC - Sonny Merryman provides a variety of public transit, school bus and general utility bus sales and maintenance services throughout Virginia. ARBOC is the Body-on-Chassis (BOC) transit vehicle division of New Flyer Company, the largest bus manufacturer in the United States. Between ARBOC being the manufacturer and Sonny Merryman a large body-on-chassis distributor, they will leverage their experience and knowledge to ensure vehicle safety and integrity and help evaluate how autonomous technology vehicle modifications are impacted by applicable state and federal regulations.

1C: Issues and Challenges

The proposed demonstration will advance the state of data-driven safety assessment of automated vehicles, and public trust in ADS technology along several dimensions:

1. *Challenges with acceptance and adoption of ADS and bringing the technology to the masses*: Repeated studies by the American Automobile Association (AAA) have indicated that the majority of the American public remains fearful of autonomous vehicles. In their

most recent findings[1] released in March 2019, 71 percent of respondents said they would be afraid of riding in a self-driving vehicle. By focusing on automated transit vehicles - offered to the general public - we will improve the public's awareness and acceptance and address their concerns with ADS technology while simultaneously evaluating the impact on public transportation and the associated economic impacts.

2. *Challenges with enhancing mobility for transportation challenged populations.* Through the experience of the partnership with populations who have limited mobility, an outcome of the proposed demonstration will be a better understanding on how future rulemaking should account for the needs and opportunities for the transportation challenged populations in the context of ADS.

3. *Lack of transparency and data sharing:* It is no secret that safety assessments for automated vehicles need to evolve beyond the existing voluntary self-reporting. One of the major bottlenecks to achieve that is the lack of transparency in AV operation, improvements methodology, and handling of disengagements and interventions. Our primary goal for the data collection and sharing is to demonstrate value to US DOT that lies in data-driven safety assessment of AVs, in a manner that can facilitate and inspire wider adoption

4. *Challenges with operating automated vehicles in diverse conditions:* Rural and suburban communities offer very different transportation infrastructure and traffic conditions as compared to urban scenarios. Testing under such conditions will serve as a different litmus test for the underlying ADS technology and the challenges that need to be overcome for everyday commutes.

1D: Geography and Jurisdictions

The SAVvy demonstrations will take place in Albemarle County in Central Virginia. The service will cross into the urban area of the City of Charlottesville, and along one of Virginia's primary non-interstate corridors. These jurisdictions offer numerous advantages for ADS testing:

- Diverse rural, suburban, and urban environments for testing ADS safety.
- Vehicles will operate in diverse traffic densities and multimodal conditions (including vehicular and bike/pedestrian traffic).
- Vehicles will operate on diverse road topographies including rural roads, interstates, parking lots, university campuses, suburban roads, and urban downtown.
- Virginia experiences four seasons, providing for safety testing data in a variety of weather and road conditions including rain, snow, leaf litter, and other debris.

1E: Demonstration Period

The duration of the proposed demonstration is 24 months (Sep. 2019 - Aug, 2021), over which we will deliver valuable data for safety assessment for Level 4 automated transit operations. By building on proven partnerships and technology, we are confident in our ability to begin

[1] The American public is still very afraid of self-driving cars: https://www.autonews.com/mobility-report/american-public-still-very-afraid-self-driving-cars

demonstrations shortly after grant award. This brings critical value because automated driving technology is evolving so quickly (both hardware and software); a demonstration that lasts too long or starts too slowly risks the underlying technology changing substantially enough to undermine the value of the demonstration results.

JAUNT anticipates purchasing and outfitting transit vehicles with Perrone Robotics ADS kits in early summer of 2019. A two-year demonstration and testing period will allow for extensive data collection under diverse annual weather and operating conditions. An overview of the proposed project schedule is presented in the Project Management, Staffing, and Capabilities Plan.

Section 2: Alignment with Demonstration Goals:

In this Section, we outline the alignment of the proposed demonstration activities with the three goals of the ADS Demonstration - Safety Metrics, Data Assessment for Safety, and Collaboration.

2A: **Safety**

The biggest unanswered question for automated vehicles is the following:
"When is a fully autonomous vehicle safe enough to operate on public roads?"

Through the course of the proposed demonstration, we will help define the canonical safety metrics which are critical towards answering this question. The notion and metrics of safety as described below, in combination with empirical data, will allow the key stakeholders to converge to a useful safety standard.

2A.i: The Scope of Safety

Comprehensive safety metrics, such as the ones outlined in the NHTSA's ADS 2.0 [2] and US DOT AV 3.0[3] must examine much more than vehicles in motion. Passengers utilizing automated driving systems must remain safe through the entire trip lifecycle: summoning the vehicle, approaching the vehicle, boarding the vehicle, riding the vehicle, alighting the vehicle, and returning to pedestrian right of ways. In addition, automated driving systems must operate safely around non-users including cyclists, pedestrians, and passengers in other vehicles (automated or otherwise).

2A.ii: Current Safety Context

Due to the pervasive secrecy of the autonomous vehicle industry, it is difficult to assess how robust the safety cases for such vehicles actually are – or even if credible safety cases have been created at all for any particular vehicle that is being tested.

There is an urgency and desire to implement clear standards as soon as possible. An expedient approach could be to extend existing safety standards (e.g. ISO 26262[4]) to specify AV safety compliance, but these standards have disadvantages. For example, the majority of safety

[2] NHTSA, 2017 - Automated Driving System - A Vision for Safety

[3] Preparing for the future of transportation - Automated Vehicles 3.0 US DOT, 2018

[4] International Organization for Standardization. (2018). Road vehicles -- Functional safety (ISO/DIS Standard No. 26262)

assessment today is self-reported by the testing companies, in good faith. These companies, without clear input from regulators, may develop different interpretations of what constitutes safe driving behavior. Safety of the Indented Functionality (SOTIF[5]) is another example of an emerging standard which covers verification of systems with complex sensing and algorithms. Such new standards must not only cover more complex technology, but also parts of the automated trip lifecycle for which non-automated vehicles are de facto safe (such as boarding the vehicle). The lessons learned from the data and safety assessment reports generated by the SAVvy project will help guide the evaluation and development of these and future AV safety standards.

2A.iii: Defining Safety Metrics

Autonomous miles driven and miles per disengagements/intervention are two metrics closely watched by industry observers to provide a high-level view of AV safety. Interventions happen when either a safety operator detects bad behavior and takes control of an automated vehicle, or the vehicle itself detects something wrong and calls for a human to take over.

Low rates of intervention do not necessarily indicate higher safety, they indicate only high *agreement* between drivers and automated systems. Humans can sometime fail to detect hazards and if the automated vehicle fails too, they will agree without being safe. Overly focusing on human emulation also obfuscates the differences between human and automated systems - hazards which are easy for humans to detect but difficult for automated systems and vice versa. Therefore, disengagement is only an appropriate safety metric if the goal is to make ADS as safe (but not safer) than human drivers. This is a good first step, but objective ADS safety metrics should allow for more.

One-way disengagement/intervention metrics can be improved is by providing context to better understand the safety implications. Currently, the reported context of disengagements either varies from company to company or is missing altogether. Consider two automotive companies: one that tests their vehicles on straight highways with predictable traffic and another that tests in a major city with complex roads and traffic. The first may have many fewer miles per intervention, but without knowing that they are operating in a less complex environment, we cannot conclude that they are operating more safely. Furthermore, some interventions may be deliberate to test the automated system's response under complex circumstances. Such intricacies of safe operation can only be identified by looking at the context in which the disengagement occurred.

Another limitation of current metrics is the possibility not to report incidents which are perceived as small. Such subjective impressions prevent us from reaching objective measures of safety. By including the severity of the incident in the safety data context and weighting incidents accordingly, we can better incentivize complete and accurate reporting.

2A.iv: Context-based data-driven safety metrics

To improve on current metrics, the SAVvy project will develop comprehensive, context-based metrics to systematically measure system safety. Our proposed safety metrics criteria and evaluation categorizes safety assessment metrics into three predominant areas summarized here:

[5] International Organization for Standardization. (2019). Road vehicles -- Safety of the intended functionality (ISO/DIS Standard No. 21448).

1. **Operational Safety Metrics** measure the environmental context in which the system is operating, including road infrastructure, environmental factors, and object detection.
2. **System Safety Metrics** measure the automated vehicle itself, including vehicle movement, vehicle subsystems information, and passengers on board.
3. **Human Safety Metrics** include both the feedback human safety supervisors provide regarding automated systems and data on supervisor training and attentiveness during operation. These are further detailed in section 5A.

2B: **Data for Safety Analysis and Rulemaking**

We confirm that the recipients will sign a mutually agreeable data sharing agreement with USDOT as a requirement for award. Our primary goal for the data collection and sharing is to demonstrate value to US DOT that lies in data-driven safety assessment of AVs, in a manner that can facilitate and inspire wider adoption. Our autonomous SAVvy commute shuttles will be fitted with data recording devices capable of capturing data from sensors and control systems associated with the automated features of the vehicle, as well as other information concerning vehicle movement, perception, planning, mapping, and external and internal environment. University of Virginia will work closely with Perrone Robotics and JAUNT to facilitate secure collection and storage of all data. Experienced data scientists and researchers will ensure that any Confidential Business Information (CBI) and personally identifiable information (PII) is removed before public access.

Examples of Data collected for Safety Analysis and Public Access

Operating model: Manual, automated, override;
Longitudinal acceleration in direction of travel;
Lateral acceleration;
Vertical acceleration :speed hump or other object;
Vehicle speed;
Steering command and activation;
Braking command and activation;
Operation of the vehicle's lights and indicators;
Operation of the vehicle's ignition;
Software version;
Hardware configuration of sensors;

Geo-location;
Weather; (visibility, rain, snow)
Road Condition and type;
Ambient light conditions;
Connectivity, network access, and latency;

Use of any visual and/or audible warning system (for example a horn);
Sensor data concerning the presence of other road users or objects in the vehicle's vicinity;
Remote commands which influence the vehicle's movement (if applicable);
Intervention made by the safety driver or safety operator, including the time of such intervention.
Data from all the onboard sensors.
All trajectories computed by the planning system - and which were chosen.
All control actions and messages exchanged
The extent to which any mis-classifications were made on the perception.
Measure system failures to detect, a lane marking, traffic sign, light.
Measure system failures on object and event detection.

Figure 1: Examples of data and context the Savvy transit vehicles will collect

Our demonstrations are expected to generate a huge volume of data during the duration of the project (on the orders of 10s of Petabytes with a few months of demonstrations). While data is the key to developing reliable self-driving cars; it is about having the right data, not necessarily the most data. Through machine learning methods, we aim to identity the most critical combination of operating conditions that could lead to a failure/crash for an autonomous vehicle. Consequently, our focus for data analysis for safety assessment will be on providing the following:

1. Making the data easily searchable based on metadata tags and context which complement the safety metrics; Develop a tool that can be used to screen large datasets and filter the data points according to specific study parameters.
2. Providing data to establish a reliable baseline performance to compare automated driving systems with human drivers under similar conditions.
3. Developing a corpus of edge cases - wherein, we capture the severity of intervention by the safety operator along with the infrastructure, environment, and AV operation tags.
4. Measuring and reporting failures: Mis-classifications in perception, failures to detect, a lane marking, traffic sign, light; failures on object and event detection etc.
5. Contribute to the Work Zone Data Exchange (WZDx)[6] in Virginia.
6. A variety of data is expected to be generated at different time-scale, we will make the data available at multiple time-scales.

2C: Collaboration

2C.i: Collaborative partnership

The SAVvy demonstration project will be executed by a team of collaborators including the University of Virginia, JAUNT, Perrone Robotics Inc., Albemarle County, Sonny Merryman, and ARBOC, as described in section 1B.

The University of Virginia and Perrone Robotics have been engaged in innovation exchanges for more than a year. In September 2017, UVA hosted an event exploring "The Driverless Future: Asking the Big Questions," along with Perrone Robotics and the Virginia Autonomous Systems Center of Excellence.[7] UVA and Perrone Robotics have continued to explore the developments needed to implement autonomous vehicles as a safe, reliable transportation element.

In parallel, Perrone Robotics, Albemarle County, and JAUNT are implementing an autonomous shuttle pilot and demonstration project in Albemarle county during spring and summer 2019. This effort focuses on utilizing small, neighborhood electric vehicles to test AV deployment and acceptance in downtown Crozet, Virginia. In addition to establishing an engaged team among the collaborators, this pilot project will afford the team the opportunity to evaluate the potential impact of autonomous vehicle integration into public transportation and explore the critical implementation and safety elements that need to be addressed. The team meets regularly, has established project-management tools and team communication methods, and has determined stakeholders and approvers critical to project success in each organization.

JAUNT, Perrone Robotics, and Albemarle County have provided letters of support emphasizing their total commitment towards the proposed Savvy demonstration. In addition, we also have strong support for the proposed demonstration from the Virginia Transportation Research Council (VTRC), which serves as the research division of the Virginia Department of Transportation VDOT). VTRC and VDOT will actively participate in this project and provide technical advice and review on all aspects of safety, data analysis, and vehicle demonstrations.

[6] US. DOT Data for Automated Vehicle Integration (DAVI) - Work Zone Data Exchange for Automated Vehicle Safety

[7] https://news.virginia.edu/content/driverless-cars-are-coming-how-will-they-affect-charlottesville

2C.ii: Stakeholder engagement

In order to represent the multiple stakeholders with vested interests and accountability for an autonomous transit vehicle on public roads, the project team anticipates participation from several key external stakeholder groups. These stakeholders include the Virginia Department of Transportation, Department of Motor Vehicles, Virginia State Police, Albemarle County and Charlottesville Police Department, Albemarle County and Charlottesville Fire and Rescue, Jefferson Area Board on Aging, Region 10, and other human service agencies.

The primary goals of engaging stakeholders are to: 1) raise awareness of the project and autonomous technology, 2) seek help with exploring the barriers and impacts of applicable regulations related to each stakeholder's area of interest, 3) develop real-world safety test scenarios based on actual agency experiences, and 4) ensure emergency services are prepared for ADS incident response and that ADS does not interfere with current emergency response operations.

The SAVvy project will also benefit from a stakeholder engagement approach called "Project Delivery Advisory Panels" used by Albemarle County, JAUNT's CEO, and other stakeholders to publicly communicate and vet significant road projects along the Route 29 corridor[8]. The approach was structured around the use of facilitators and diverse stakeholder panels. The group met regularly to discuss and answer questions about each project phase, design decisions, and community impacts. The project team will leverage this experience to ensure successful stakeholder engagement throughout the SAVvy project.

2C.iii: Public communication and engagement

The SAVvy project team will conduct extensive public engagement with the goals of 1) raising awareness of the project and ADS in general, 2) soliciting comments regarding safety, 3) soliciting feedback on the SAVvy project in general, and 4) seeking feedback specifically from passengers of the automated vehicles.

Engaging the public on the topic of automated technology presents a few unique challenges. With multiple automated driving projects going on around the country and the technology evolving so rapidly, the public may develop opinions and perspectives based on outdated information or information unrelated to this project.

In anticipation of these challenges, the project team will implement proactive communication approaches that educate and inform the community before automated vehicles operate on public roads in our community. This will include a series of public information workshops on the concept and application of autonomous vehicle technology, held throughout the project application area. For the small communities and neighborhoods that exist along the route corridors, the project team will meet with neighborhood associations and local-government-formed citizen councils regularly to keep them informed and to solicit feedback on the project's progress and impacts.

For those passengers actually using the autonomous service, focus groups will be organized to gauge the rider's awareness, communication with others in the community, comfort and safety, and comparison to other transportation options. These focus groups will have an especial focus on passengers from transportation-challenged populations who might best benefit from automated driving systems.

[8] http://www.route29solutions.org/

In order to ensure as broad a reach as possible, we will complement these focused initiatives with wide-cast media, such as online communication and discussion on local TV and radio outlets.

Section 3: Alignment with Focus Areas:

3A: Significant Public Benefits

Applying ADS to the context of public transportation is essential to finding the greatest public benefit of this technology. Without this focus, AV technology could lead to autonomous empty vehicles circulating endlessly for parking, or waiting in long queues in traffic or to drop off passengers at scarce curbs. Any environmental advantages would be lost in increased Vehicle Miles Traveled (VMT). Without ride sharing and vehicle consolidation, some projections predict ADS may increase traffic congestion and vehicle miles traveled.[9] Without incorporating public transit and ADS, we risk losing not only these transportation benefits, but also the potential land use benefits of repurposing the parking infrastructure necessitated by personal automobile ownership.

The collaboration with JAUNT will offer additional context and understanding of ADS benefits to public transit. JAUNT is already recognized as benefiting the public, having been named as one of fourteen innovative rural transit systems by the Transportation Research Board for connecting passengers to work, medical appointments, errands, social advancement opportunities, and other destinations in their community.[10] Building on its success, JAUNT will use this project to explore both the ways ADS can enhance its own operations and then expanded broadly to the public transportation industry.

The data collected by this project will offer the USDOT, its partners, and the public transportation industry the first practically applicable insights highlighting the challenges and opportunities that ADS offer for the future of mobility. These applications include assessing ADS safety, improving the acceptance of ADS by the general public, understanding how ADS effects equity of access and mobility, enabling transit vehicle manufacturers to better understand current production modification needs, understanding how public transportation staff's roles and responsibilities will evolve, and knowing how regulatory aspects need to evolve.

3B: Addressing Market Failure and Other Compelling Public Needs

The private sector has focused largely on two aspects of the automated mobility market: ride-hailing passenger vehicles, and freight vehicles. These were natural market candidates because they offered opportunities for operator cost savings, but neither offers the same benefits as automated public transit as described in section 3A above. This project focus on public transit vehicles will fill this market gap and help secure the greatest possible public benefit.

As a public transit operator, JAUNT has long been providing government supported mobility services for transportation-challenged populations for whom the market has produced no affordable options. Unlike many other paratransit-only operators, JAUNT goes above and beyond by collaborating with rural government partners to extend transportation services beyond the

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[9] World Economic Forum, 2018: Reshaping Urban Mobility with Autonomous Vehicles Lessons from the City of Boston

[10] National Academies of Sciences, Engineering, and Medicine 2011. Innovative Rural Transit Services. Washington, DC: The National Academies Press. https://doi.org/10.17226/14605.

federally mandated ADA service area. JAUNT will bring its full experience, passion, and commitment to bear exploring ADS applications that improve future mobility for everyone.

The project will also leverage the research expertise of the University of Virginia to explore topics not being pursued in depth by the industry thus far, including automotive cybersecurity, and behavioral modeling of drivers and passengers. To build trust and clear the path to widespread adoption, automakers, technology firms, and regulators must address a variety of threats related to cybersecurity. Auto manufacturers have begun taking some steps to mitigate cybersecurity risks in their vehicles and these precautions should help address some vulnerabilities in the short term. However, just like with safety, the lack of consensus for cybersecurity creates an elevated risk of exploitable security gaps. Focusing on security from the very beginning is a crucial step toward reassuring consumers that self-driving cars are safe. By embracing transparency and data sharing, the team will investigate several cybersecurity challenges as outlined in Section5A.iv

3C: Economic Vitality

The transit vehicles proposed in this project (ARBOC Spirit of Mobility) already exceed the Buy America requirements. These vehicles are being purchased by JAUNT and other transit systems across the country using federal transit funds, so they've met Buy America regulations before this Notice of Funding Opportunity was released. Sixty-nine percent of these vehicles are manufactured from materials made in the United States. Further details on this are included in the Management, Staffing, and Capabilities Plan document of the proposal.

This proposed project will also foster American economic vitality by supporting US based ADS development (Perone Robotics) and vehicle manufacturing (ARBOC). This continues a long-standing American tradition of excellence in both manufacturing and software development and fosters economic growth through US job creation, one of the most important factors motivating the vehicle demonstration in Crozet, VA being undertaken by Perrone Robotics, JAUNT, and Albemarle County.

By examining the evolution, not elimination, of public transit operator jobs in an ADS context, we can help avoid the labor disenfranchisement seen in the US manufacturing industry. By leveraging ADS to improve affordable, public transportation mobility, we can serve populations without private automobiles for whom transportation is a barrier to job retention or accessing goods and services. Finally, by leveraging ADS in ways that reduce the demand for personal automobile parking, jurisdictions stand to gain by reallocating parking into new land uses providing greater economic and tax value.

3D: Complexity of Technology

This project will demonstrate two Level 4 automated transit vehicles operated with trained safety operators. At Level 4, these vehicles will be fully autonomous on difficult terrain and while traversing roadways alongside human drivers. The vehicles will be equipped with multiple data collecting devices, as discussed in section 2B, producing large data sets for safety assessments.
Perrone Robotics is the Autonomous Vehicle Technology collaborator on this project. Perrone Robotics will use the combination of its bolt-in autonomy kit (BAK) and its patented MAX™ autonomous software engine to convert a standard Body on Chassis transit vehicle into an autonomous shuttle vehicle.

3E: Diversity of Projects

The proposed demonstration contributes to the diversity of projects in three distinct and significant ways:

1. The demonstration focuses on automated public transit vehicles – as opposed to the more widely tested urban autonomous cab services.
2. The routes chosen span rural, suburban, and urban environments, presenting rich and varied demonstration conditions. This means that the ADS will interact with situations with no curbs and a variety of changing topographical conditions. Further, the variations in speed and congestion between suburban and rural environments will demonstrate the vehicles capability to adapt to new roadway conditions.
3. The project examines the human aspects of automated transit:
    a. Safety throughout the trip lifecycle, not just vehicle in motion.
    b. How ADS serve populations of all ability levels.
    c. Public trust in ADS and willingness to ride.
    d. Comparison and safety assessments between automated and manned vehicles.

3F: Transportation-challenged Populations

Accessibility is essential to large-scale and broad automated vehicle deployment and user adoption. This project involves the servicing of public transportation needs to all users along the two proposed routes, including transportation-challenged populations such as the elderly and individuals with disabilities.

JAUNT has been nationally recognized by the Federal Transit Administration[11] for their successful approach to serving those with limited transportation options in the region since 1975. This means JAUNT is thoroughly knowledgeable of the accessibility requirements of public transportation services, the mobility needs of residents and the importance of inclusion in how transit services are offered. For this project, both of the proposed transit vehicles will be fully accessible to anyone with a disability. As with all of JAUNT's services, those vehicles will meet all of the requirements outlined in the Americans with Disabilities Act of 1990, Circular 4710.1, and 49 CFR Parts 27, 37, 38 and 39.

The combined experience of JAUNT serving the transportation-challenged population and its understanding of the federal accessibly guidelines provide this project a unique opportunity to explore both the challenges and changes that are needed to make autonomous technology accessible, and the assessment of how current accessibility regulations might evolve to incorporate ADS guidance. For example, what does "reasonable accommodation" of a disability mean in the context of automated systems? This project will explore an "accessibility first" design philosophy, in which all ADS services are designed to accommodate all users and the line between paratransit and "regular" public transit will blur or disappear.

The proposed project will also assess passenger and transit operator interaction to identify non-driving aspects of paratransit service that might not be possible or desirable to automate without compromising the rider experience. Preserving that experience is a higher project priority than the potential operator cost savings of eliminating operator jobs all together. Our Savvy transit vehicles will be equipped with camera(s) that will be used to detect such interactions with consent;

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[11] 2014 FTA Administrator's Award for Outstanding Public Service - Link:
https://www.dailyprogress.com/eedition/mapping/neighbors/article_ba85d645-6cb5-50fe-a90a-789c8da659c3.html

and our team of data scientists will ensure that any PII or sensitive information is removed from these video recordings. The UVA research team will work closely with JAUNT to process this data and conduct the aforementioned assessments.

3G: Prototypes

Perrone Robotics has over 15 years of experience creating autonomous solutions in automotive, industrial, and commercial spaces and its technologies are well beyond the limited prototype state. They will use the combination of its bolt-in autonomy kit (BAK) and its patented MAX™ autonomous software engine to convert a standard Body on Chassis vehicle into an automated driving system. The vehicle will be deployed driving the designated routes autonomously at L4 operation (with at least safety operator always present).

The BAK system integrates using "over the top autonomy" allowing vehicles to still be driven normally by drivers after installation. The MAX autonomy engine can be interrupted by a safety operator at any time for any reason and resumed or restarted as desired for a safe, controlled, transition between autonomous and manual mode.

Perrone Robotics already has a fleet of operational, Level-4-capable autonomous passenger vehicles. A new Neighborhood Electric Vehicle will begin operating in Crozet, Virginia in April, 2019 as part of the collaboration between Perrone Robotics, JAUNT and Albemarle County described in section 2C.i. Simultaneously, the team anticipates integrating a BAK with a full-size, BOC transit vehicles. Thanks to this groundwork, the SAVvy project will be able to quickly assemble and operate L4 capable vehicle prototypes early after project launch.

Section 4: Requirements fulfillment

4A: Research and Development of ADS Technology

As described in Section 3G above, the proposed demonstration entails operating and collecting/analyzing data from L4 capable JAUNT transit vehicles fitted with Perrone Robotics BAK and MAX software. The project will contribute to four key areas of ADS Research and Development:

1. **ADS in Diverse Driving Conditions:** The SAVvy project will test vehicle automation in a variety of road topographies, congestion levels, and weather conditions. This will help demonstrate which contexts are easiest to automate safely and which are hardest. This will help guide the direction of future ADS research ensuring safe automation under all conditions.
2. **ADS in Public Transport:** Examining ADS in the public transportation context will help broaden the scope of automated safety to the full trip lifecycle, including vehicle hailing, boarding, riding, alighting, and return to right of way. It will also afford the chance to explore vehicle and service design considerations necessary to make automated public transport accessible to all and desirable relative to other transport modes.
3. **ADS Safety Data Collection:** The SAVvy project will explore what types of information to collect to evaluate ADS safety and how best to collect it. In the case of data volume challenges, the project will explore appropriate data polling frequencies, whether all data is valuable enough to keep, and whether new compression algorithms might be required.

In conjunction with area four below, the project will explore the most important ways to clean and tag data to make it actionable.

4. **ADS Data Evaluation:** The SAVvy project must advance not only data collection standards, but also methodologies for evaluating that data. Data analysis methodologies will be developed to expose evidence of safe and unsafe operation, as well as methods for relating multiple datasets to each other to compare the relative safety performance of different vehicles of automation algorithms.

4B: Physical Demonstration Elements

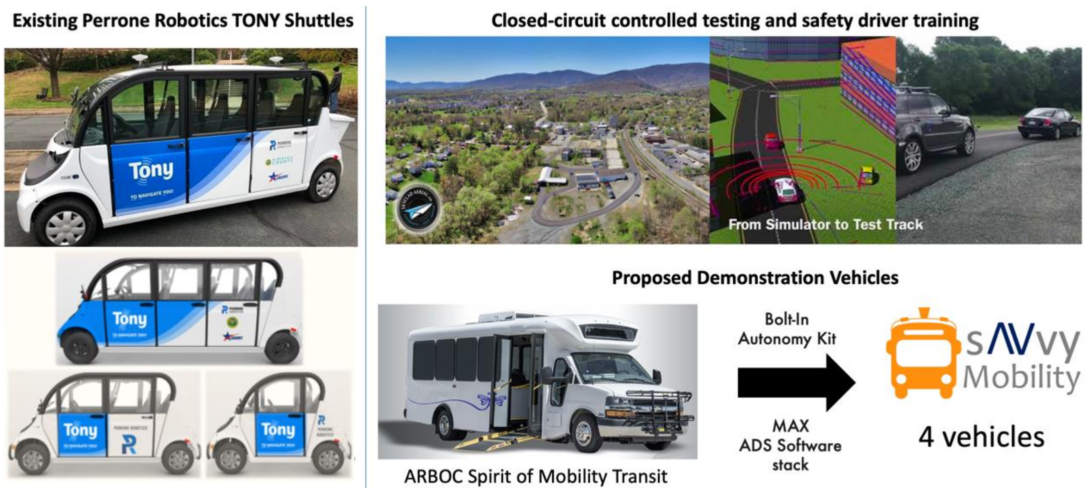

Figure 2: Physical Demonstration - Perrone Robotics will integrate their Bolt-In Autonomy Kit with ARBOC Spirit of Mobility Transit Vehicle to produce 4 Savvy Mobility Vehicles

The Savvy Mobility project will operate four physical transit vehicles on public roads performing real world public transit service. The vehicles will be the "Spirit of Mobility" body-on-chassis (BOC), manufactured by ARBOC Specialty Mobility. The focus of the service will be commuters traveling to Charlottesville from suburban towns 20-30 miles away. Specifications of the vehicle are included in the Management, Staffing, and Capabilities Plan document.

4C: Gathering and Sharing Data

The team confirms that the recipients will sign a mutually agreeable data sharing agreement with USDOT as a requirement for award. As part of the demonstration team we will have Data Managers and a team of Data Scientists dedicated to this project both at Perrone Robotics and University of Virginia, affirming our commitment towards data sharing and access as required by US DOT.

Data generated as part of this project, including AV demonstration data and safety assessment reports, data analysis code, etc. will be managed using existing University of Virginia [Details in the Data Management Plan and Sections 2B, and 5C] infrastructure for administering and maintaining digital research, with automatic nightly back up of source-code and documentation repositories. Many of the resources and data management practices are already in place, and being utilized by the principle investigators (PIs)s in their research groups. We will adopt and extend these practices for short- and long-term data collection, retention and management. Data from the in-vehicle recording device will be moved to local fast storage at Perrone Robotics. It will be then transferred to the University of Virginia's high-performance computing and storage infrastructure. We have budgeted and provisioned for approximately 8-10 petabytes of storage and management at UVA. Beyond that capability, if the demonstration requires, we would rely on secure storage provided by US DOT.

A project website will be established as the main point of access to the generated artifacts including data, source code, publications, videos, and safety assessment reports resulting from the project, and the primary insights obtained within the project. Details on data handling, storage, access, and removal of CBI and PII information are outlined in the Data Management Plan document.

4D: User Interfaces and Accessibility

The Savvy transit vehicles are expected to run in a geo-fenced manner, on fixed routes. Our initial focus is on repeatability of operation which allows us to establish a reliable baseline performance for both human driven and automated vehicles. Therefore, in the beginning of the demonstration period, given that the routes are fixed, the passengers will have the ability to use an on-vehicle touch screen interface to specify and choose their stop on the route. Pull cords for stop requests are a feature that is already ADA compliant and familiar to passengers on transit vehicles. We will leverage our partnership with ARBOC to have stop cords that talk to the ADS software. This will also help gather data on popular route choices and stops which will inform the team to re-evaluate the routes as necessary. In addition, the current route, estimated time of arrival to the next route, and other relevant route characteristics will be made available to the passengers at all times. This will be done via both a display, and an audible announcement. As the technology evolves transit times and route choices may expand to meet the community's desire for longer operating hours and more coverage, in which case it will be accompanied by the appropriate changes made to the input/output interface.

We anticipate that the demonstration will result in a series of lessons learned and best practices for such input/output interfaces specifically required for public transit vehicles. E.g. figuring out the difference between providing the interface on every passenger seat, in a few select locations, or just one location in the vehicle.

A separate console will be made available to the safety operator, which allows the operator to inspect and visualize the decisions made by the vehicle, and clearly understand the intended operation in a given traffic situation. The safety operator I/O interface will allow the operator to easily check the operating mode of the vehicle, and bring the vehicle to an emergency stop, if needed.

4E: Scalability

The team will hold several demonstrations during the project period showcasing the data collection, safety assessment ability, and the performance of the Savvy transit vehicles. In addition, we will host multiple workshops for safety operators, and public engagement events which will help both inform the attendees to the capability of the ADS shuttles and inform the project team of the public concerns and questions.

We will hold a *'Future of Automated Public Transit'* workshop to bring together a variety of experts to assess the holistic impact of AVs on the public transportation sector and develop solutions for mutually beneficial relationships. It will address issues in policy, planning, funding, technology, procurement, market development, testing and deployment of AVs. Transit agencies and cities thinking about engaging early in automated vehicle technologies stand to benefit significantly from this demonstration and the proposed outreach activities. In addition, the University of Virginia research team will disseminate the data and safety analysis form this project at premier autonomous systems, machine learning, automotive cybersecurity, and cyber-physical systems venues.

The proposed service is expected to continue beyond the end of this proposal's anticipated funding. And, because of the demonstrated interest by the Commonwealth, there is expected to be continued efforts to build on this project's success and replicate efforts throughout the state. This means this project will go beyond provide the anticipated data and information sought by USDOT, it will also create a foundation for on-going opportunities to expand the knowledge of how autonomous technology will impact public transportation and our transportation infrastructure. While it is uncertain how the use of the autonomous technology will evolve with this specific service, it is certain that Albemarle County will provide sufficient funds to continue the commuter transit service. In turn, continuing to operate the transit service will allow for the autonomous vehicle operation context to remain in place for ongoing collaboration with the state, such as the VDOT Research Council, and UVA.

Section 5: Demonstration Approach

5A: Technical Approach

5A.i: Safety Baseline and Benchmarking:

For any form of safety assessment for autonomous vehicles, it is imperative to first define and establish the nominal operating conditions, or a reference against which safety will be evaluated.

During the demonstration period, we will run the Savvy transit vehicle(s) along two careful chosen routes. However, for each route, we will run two vehicles [so, 4 Savvy vehicles in total] - which are identical to each other in terms of capability, sensor configuration, and software stack - except that one vehicle will operate under manual mode while the other will operate under automated mode. By subjecting the vehicles to the same routes, and traffic conditions, a fair assessment can be derived about the vehicles baseline operation. Since the two vehicles will be identical in their autonomous capability, we will also change periodically, which vehicles operates in manual mode and which of the two operates autonomously. This is to remove any vehicle specific bias. Similarly, the drivers of the manual and (safety operators) of the autonomous vehicle will also be randomly distribute to capture average nominal behavior rather than any driver specific bias. This differential testing will give us the potential to compare the data of human vs automated driving in an unbiased form.

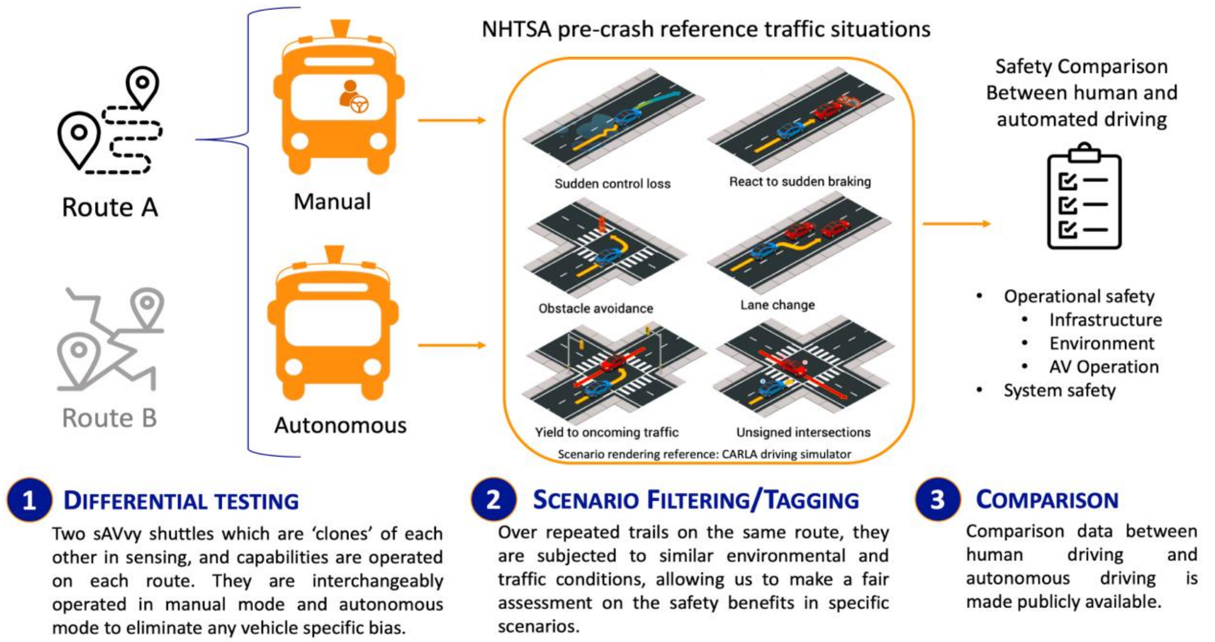

Figure 3:Safety Benchmarking - Framework for comparing human driven and automated transit vehicle performance for safety assessment.

Although, we can compare manual vs automated driving fairly; the question remains how do we ensure that the comparisons are made for the same context. To ensure this we will develop algorithms to analyze the context for the data-sets from the two vehicles and find equivalent traffic scenarios in both the data-sets. Equivalence is described in terms of the infrastructure, environment, and sensor data-sets. Examples of such scenarios include the NHTSA's Pre-Crash Typology for Crash Avoidance Research[12]. The resulting outcome of this analysis will compare performance metrics like minimum safe distance, braking profile, steering profile, lane positions, lane change behavior, total trip time, etc. between the human driven and the automated vehicle. Such a data-set will be immensely valuable to paint a clear picture of safety, especially in the context of public transit vehicles.

[12] W.G. Najm, J.D. Smith, and M. Yanagisawa, "PreCrash Scenario Typology for Crash Avoidance Research". DOT-VNTSC-NHTSA-06-02, U.S. Department of Transportation, National Highway Traffic Safety Administration, December 2006.

5A.ii: Safety Metrics in Detail

Operational Safety Metric: Miles per Intervention with Context (MPIC)

Infrastructure context:
- Road conditions
  - Dry/wet
  - Paved/unpaved
  - Lane detection accuracy
- Distance from curb
- Special Zones (construction/school etc.)
- Signs and road features and their positions and inferences
- Traffic light state
- Bridge, underpass, tunnel, zebra crossing, road hump
- Arrow markings, chevron markings, bus lanes detection
- Pickup/drop-off points

Environment context:
- Weather
- Visibility
- Dirt on the road
- Non infrastructure Signaling
- Gesturing
- Traffic info
- Event/V2x message
- Map info
- Origin and destination waypoint
- Light conditions
- Rain Intensity
  - Daylight – bright/cloudy
  - Dusk/dawn
  - Night –illuminated/dark

AV Operation context:
- Localization output
  - Lat/long, heading, speed, and magnitude of uncertainties, lane estimation
- Object and Events detected
  - E.g. pedestrian, motorcycle, bicycle
  - With status: static vs moving
  - Vehicle type detected, and reported distances to each vehicle.
  - Position and velocity vector estimates of objects.
- Special vehicles detected
  - Police, fire engine, ambulance

*Each context is reported with an associated uncertainty/confidence level wherever applicable.

Figure 4: Data-Driven Safety Assessment - Miles per intervention with context

1. ***Operational safety metrics:***
   a. We propose a metric where 15-30 seconds of data leading to every disengagement/intervention, followed by another 15 secs after the disengagement will be logged and tagged with the infrastructure, environment, and AV operation context:
      i. Weather conditions, road conditions, special zones (schools, construction etc.), attention score of the safety operator, cabin condition, objects detected, events detected, signaling, gesturing, lane marking, curb etc.
   b. *MPIC : Miles Per Intervention with Context*. The Figure above presents a snapshot of the context captured by this system and assigned to every intervention - regardless of its inferred severity.
   c. We will also report traffic infractions: tracking how often an AV violates traffic laws. And present the context in which it occurred.
      i. Soft traffic violations are sometimes required to maintain free movement of traffic. For instance, the AV's path of travel may be obstructed by road works, parked vehicles etc. In such circumstances, to avoid the obstruction crossing the centerline may break other driving rules, however, it is recognized that when there is no other alternative for continuing the route other rules may be broken as long as extra care (i.e. the presence of safety operator) is taken.

2. ***System safety metrics:*** Operational safety metrics (which includes context of infrastructure, environment, and AV operation) alone do not present a complete picture of the intricacies of the safe operation of the AV. Therefore, additional system level details are also required to be logged and reported. Examples include
   a. Software name and version
   b. Vehicle ID, gross weight, and dimensions

c. People on board
d. Fuel type and fuel level - gasoline, diesel, battery
e. Mode of operation (level 3/4), and driving mode - manual, autonomous, override, teleoperate
f. Status of lights, wipers, hazard and turn indicator, brake lamp, reverse lamp.
g. Electrical systems and CAN bus status
h. Tire pressures
i. AV subsystem warnings and status messages
j. Position, speed, and heading estimation: using GNSS, IMU, LIDAR, Vision, and HD maps links
k. Anti-collision, ABS, and lane departure status.

3. ***Human safety metrics:*** safety operators and safety operators should be aware of the situation in which it may be necessary to intervene. Training should cover potentially hazardous situations that may be encountered and the appropriate action to take when resuming manual control of the vehicle. We will measure and report the following human safety factors:
   a. Indicators sent by the AV such that the operator can look up the state of the AV.
   b. Interface, and nominal time required for transitions from manual control to automated mode.
   c. Interface, and indicators presented to the operator to go from automated mode to manual mode (i.e. the intervention interface): Take over demands should be audible, visible, and/or haptic as appropriate,
   d. We will monitor and report the situational awareness of safety operators and capture information regarding driver distraction and inattention.
   e. We will report feedback from drivers from each trip.
   f. We will report and assess the training procedure given to safety operators. They will be trained in:
      i. Safety for pedestrians and passengers
      ii. Resolving and reporting any system errors
      iii. Startup and shutdown procedures for the vehicle
      iv. When and how to use the emergency stop button
   g. Frequent and periodic meetings will be held for presentation and discussion of operational updates, with designated time for safety operators to share best practices with each other. Safety operators will receive a weekly email that includes reminders, information from other safety operators, and upcoming events.

Safety oversight and guidance continues to be a significant concern of the Department of Transportation and, as applicable to this project, the Federal Transit Administration. Additionally, there is significant levels of regulatory guidance for transit vehicle operation, operator training and passenger accommodations (specifically the American with Disabilities Act). Many of the regulatory aspects of what is required of public transportation systems will apply to the ADS vehicles. This means that the data and qualitative information collected from the project will provide insight into what barriers exist in those regulations that significantly limit public transportation systems from exploring the application of ADS to their tradition services. While a good deal of latitude and exceptions are provided for projects funded under the parameters of "pilot programs" this project offers a chance to assess those regulations in the context of a fully practical and on-road operation of ADS. Further, by using public transportation as a demonstration project, information will be gathered on compliance with federal regulations ranging from driver qualifications to standards of vehicle operation, and passenger assistance to vehicle safety inspection assurance.

5A.iii: ADS Technology:

MAX AUTONOMY ENGINE

The Perrone Robotics MAX engine is a full-stack autonomous engine that takes inputs from sensors, perceives obstacles and waypoints, understands vehicle position, orientation, and speed, performs desired or required maneuvers, determines the correct path, and sends commands to vehicle controls to set movement. The MAX engine expresses all of this functionality as services so that the application for a given implementation is high-level and task-focused. This services-based model is important as MAX's underlying routines are used consistently and repeatability in every solution we've created – thus building confidence in the underlying functions, minimizing errors created when duplicating similar functionality, and minimizing the amount of testing required for simple changes.

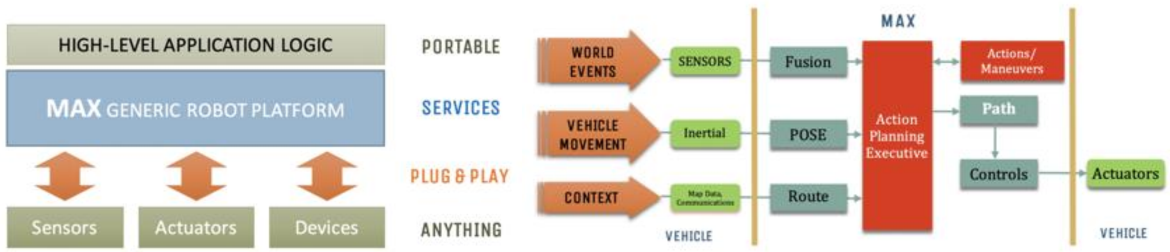

Figure 5: ADS Technology - MAX ADS engine developed by Perrone Robotics

MAX takes data from sensors, from the vehicle, and from outside sources and integrates all of that data together for the core action planner to decide what to do next.

The MAX engine contains:

1. Abstracted sensor and control interfaces – world event data and actuator behavior are configured separately and MAX creates the interfaces dynamically.
2. Modular, extensible maneuvering model able to adapt to any scenario: Existing maneuvers are called by the Action Planning Executive or invoked by events from sensors, vehicle, or other communications they subscribe to; MAX uses a robust prioritization scheme to ensure that highest priority maneuvers act when needed.
3. A configurable sensor perception and fusion model accepts data from a wide range of sensors. Normalized objects with attributes (e.g. location, speed, size) are created that are fused in time and space.
4. Support for a wide range of communications (Ethernet, serial, WIFI, 3-4G, CAN, etc.) and interfaces to machine learning systems for perception, and planning.
5. Every single movement or function with MAX has the ability to be configured by parameters such as how long to delay, how quickly to stop, how fast to turn, etc.
6. Built-in operations and data analysis tooling: MAX comes with an operator interface to easily create, deploy, and execute missions as well as interpret the data from runs in a visual fashion. Data from operations, and raw data from sensors can be collected and

synchronized for later analysis and playback through the MAX engine or through a Webots simulator.

Perrone Robotics's MAX technology has been integrated in a variety of vehicles such as the TONY GEM shuttle in Crozet, VA. The shuttle is capable of moving up to 25 mph and operating on roads where the speed limit is less than 35 mph.

5A.iv: Cybersecurity for automated vehicles:

One of the biggest challenges in cybersecurity for automated vehicles is an accurate and automated assessment of risk and vulnerabilities in AV software[13][14]. Each manufacturer and supplier must create long-term, sustainable, and scalable security solutions that are based on an analytical, and data-driven risk assessment[15]. In the context of safety assurance, both manufacturers and regulators must be able to reason about the (physical) effects of potential vulnerabilities. It may not be economically viable for a manufacturer to patch every known or new vulnerability, but the public must be assured that those vulnerabilities with significant safety effects have been adequately and thoroughly addressed

While a vast amount of data about cyber-attack patterns (CAPEC), weaknesses (CWE), and vulnerabilities (CVE) is available for general purpose software and hardware, but a very limited proportion of such data is directly applicable to the perception, planning, and control stack on an autonomous vehicle. The data generated from this demonstration will allow researchers and regulators to better understand the cybersecurity vulnerabilities for autonomous vehicles.

UVA researchers (Dr. Cody Fleming, and Dr. Madhur Behl) will investigate how the data generated from the demonstration maps potential vulnerabilities in software to physical and safety-critical effects. The data collected can serve as a baseline standard for automated weakness identification, mitigation, and prevention efforts. A proposed outcome of such an analysis will be a common taxonomy for describing software security weaknesses in architecture, design, or code. For e.g. we would provide, the input/output specification that each perception, planning, and control software executable on the car must adhere to during the programming phase, so that an attack on the software stack can be detected at run-time.

A cybersecurity analysis of the data from this project can serve as a measuring stick for software/hardware security tools that target known weaknesses in safety-critical scenarios.

5A.v: Cultivating trust in autonomous vehicles

The core of the problem of assessing human's ability to supervise autonomy lies under the concept of trust. With the increase in automation in driving, people tend to over-trust such systems [16]. In the situation of over-trusting, drivers may overestimate the capabilities of the system and engage

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[13] 2016 NHTSA report "Cybersecurity Best Practices for Modern Vehicles"

[14] 2014 NHTSA report "Characterization of Potential Security Threats in Modern Automobiles"

[15] The Key Principles of Cyber Security for Connected and Automated Vehicles, UK Govt. 2017

[16] M. Cunningham and M. A. Regan, "Autonomous vehicles: human factors issues and future research," in Proceedings of the 2015 Australasian Road Safety Conference, 2015.

in the secondary activities. The engagement in secondary task becomes unsafe when the driver is needed to take control of the car in the event of failure[17].

In order to allow autonomous vehicles to keep the safety operator engaged, the AVs need to be able to monitor and understand the level of the engagement of the safety operator. Specifically, we will test the design on methods and interface that: (1) Alert the driver to situations that require increased attention - such as entering a school zone, entering a road with less lane marking, and etc. (2) measure different levels of driver distractions (and their associated context) to inform and converge on a method to keep the safety operator alert.

We will also investigate the variance in the preferences of different cohort of passengers in the transit shuttle, and how can the preferences best inform the AV operation itself. For example, we will analyze the data to answer the following research questions:

1. *Can passenger preferences inform route selection?* When there are elderly people onboard, the type of route one might take may be different than when the passengers are predominantly younger. Some people may want to go to their destination through the fastest route but others may want to talk to each other more and would not mind if they take the slower route.

2. *What type of interactions and feedback do passengers prefer?* We will explore varying levels of visibility into the AVs performance and gauge what passengers want based on surveys and observations. We will also investigate the design of feedback, and interfaces that enhances their trust vs raise more questions.

It is our goal to be able to use empirical data to establish a canonical set of feedback, and preference mechanisms that will allow people to adopt automated transit vehicles.

5B: Legal, Regulatory, and Environmental Approach

The collaborators intend to use Perrone Robotics private track to do initial testing and demonstrations of the vehicles under this project. No legal rules or regulations prevent the testing of autonomous vehicles on private property in Virginia. Perrone Robotics' closed-circuit track is a two-lane road with a range of intersections and signals that can be controlled to perform detailed testing of various aspects of the autonomous technology at issue in this project. Moreover, Virginia law does not prohibit autonomous vehicles on public roads at this time.[18] Rather, Virginia has taken the policy approach that it is "open for business" for autonomous vehicle developers.[19] Virginia has also designed certain segments of its highway systems specifically for the testing and operation of autonomous vehicles. The Virginia Automated Corridor offers autonomous vehicle developers the opportunity to test their technologies on 70 miles of interstate and arterial roads in

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[17] M. Dikmen and C. Burns, "Trust in Autonomous Vehicles," 2017 IEEE Int. Conf. Syst. Man, Cybern., pp. 1093–1098, 2017

[18] Secretary of Transportation Aubrey Lane, as quoted in *The Washington Post* (April 24, 2017) ("We have no rules that prohibit autonomous vehicles, no law. A lot of [other] states do.") *as further cited in* Automated Vehicles in Virginia: The Policy and Regulatory Environment, p.3, presented at the 2017 Virginia Highway Safety Summit (May 18, 2017).

[19] Governor Terry McAuliffe's Proclamation (March 4, 2015) ("Virginia . . . is open for business for the vehicle and technology manufacturers and researchers committed to the development, testing and deployment of automated and autonomous vehicles").

the Northern Virginia region, including interstates 66, 495 and 95, and US Routes 29 and 50.[20] Thus, the collaborators will be able to test and also operate the autonomous shuttles on Virginia public roads that have been designated specifically for such testing.

The collaborators on this project have worked closely with the County and with Fire/Police groups in the area so that they are informed about the autonomous vehicle activities and the capabilities of the vehicles developed by Perrone Robotics. All of these points will also be true for the shuttles covered under this project.

In addition, there is no federal statute or regulation to date regarding autonomous vehicles. Several bills on autonomous vehicles have been proposed in Congress, but not have been enacted thus far.[21] As noted above, the collaborators intend to follow the guidance provided by NHTSA in its two reports "Automated Driving Systems 2.0 - A Vision for Safety" and "Automated Vehicles 3.0 - Preparing for the Future of Transportation".

At Perrone Robotics, the founder Paul Perrone was the chair of the SAE On-Road Automated Driving Committee[22] that created the levels of autonomy mentioned above. As such he, and others at the company, have contacts throughout the industry and monitor new guidelines or best practices as they emerge.

5B.i: Demonstration Routes:

The Savvy mobility transit service will operate on two separate transit routes, transporting passengers from approximately 6am to 7pm, 5 days a week, including most holidays. The routes have been chosen carefully, spanning suburban and urban traffic, speed, and road conditions; designed in mind to increase mobility and access for transportation challenged populations. The first route will be from Crozet-Charlottesville on the US 250 Corridor, and the second route will be on the US Route 29. We will conduct extensive safety and slow speed tests and slowly phase into the demonstration deployment.

[20] See http://www.vtti.vt.edu/facilities/vac.

[21] See, e.g., H.R.3388 - SELF DRIVE Act, 115th Congress (2017-18).

[22] See https://www.sae.org/works/committeeHome.do?comtID=TEVAVS

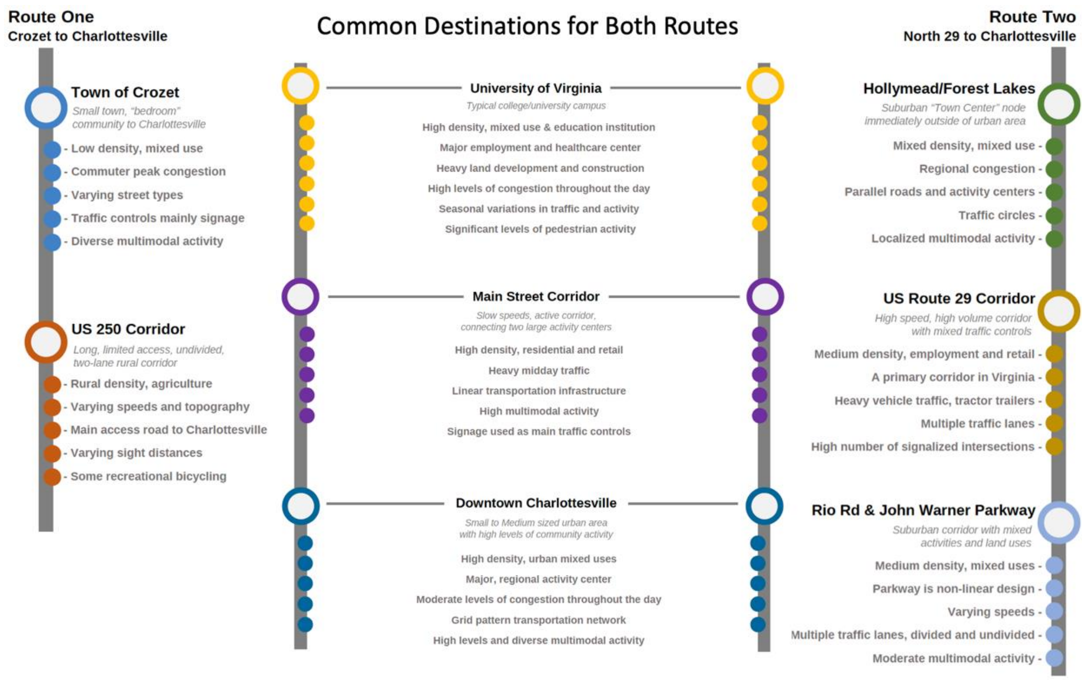

Figure 6: Diverse Demonstration Routes - Spanning suburban and urban traffic, speed, and road conditions; designed in mind to increase mobility and access for transportation challenged populations.

5B.ii: Motor Vehicle and Buy American Exemptions

The collaboration includes a leading Virginia transit bus vendor, Sonny Merryman, and one of the nation's largest bus manufacturers, ARBOC, a New Flyer company. These companies build their vehicles to meet the Federal Motor Vehicle Safety Standards (FMVSS) and Federal Motor Carrier Safety Regulations (FMCSR) safety standards and regulations. As such, when purchased from the factory, the ARBOC Spirit of Mobility will not require any type of exemption from federal regulations. As noted above, the federal safety standards do not address autonomous vehicle safety. Rather NHTSA has issued the safety guidance documents mentioned above. At such time as NHTSA issues mandatory federal safety standards for autonomous vehicles, the collaborators fully intend to comply with them. Additionally, both of these collaborators will be engaged in the modifications needed to adapt the BOC vehicles with PRI's autonomous components. This approach is intended to ensure that any changes made to the vehicles will similarly meet existing FMVSS and FMCSR safety standards and regulations.

JAUNT is a public transportation operator. As an aspect of that function in the community, JAUNT regularly purchases transit vehicles with Federal Transit Administration funds. This means they are thoroughly familiar with the Buy America regulations. Specifically, the ARBOC Spirit of Mobility transit bus meets the Buy America requirements with 69 percent of the materials used to manufacture the vehicle are made in the United States and the vehicle's final assembly is in the US, Middlebury Indiana.

5C: Evaluating and Sharing Data

As outlined in Sections 2B and 4C, the team is committed to provide secure, and timely access to the vast amount of data generated in the project. As part of the demonstration team we will have Data Managers and a team of Data Scientist dedicated to this project both at Perrone Robotics and University of Virginia affirming our commitment towards data sharing and access as required by US DOT. The University of Virginia Data Center (UDC) provides a professionally managed, secure, enterprise-wide, reliable, and redundant infrastructure to meet the growing information technology needs of research.

The University of Virginia Advanced Research Computing Services (ARCS) group will provide high-performance computing and storage expertise and service for this demonstration. ARCS is experienced at working with researchers from across the university who are ready to take advantage of the university's high-performance resources.

The ARCS UVA team will provide professional advice, hands-on training, and constructive feedback at every stage of the demonstration and also work closely to facilitate the sharing and storage of demonstration data using any resources provided by US DOT.

Since a variety of data is expected to be generated at different time-scale, we will make the data available at multiple time-scales as well:

a. **Real-time streaming data** - This includes geolocation, vehicle mode, and other vehicle status data, route info etc. This will be streamed and made available in near real-time.
b. **Post processed data** - Varies from being updated daily to several times a week. We plan on mining the data and annotating it with 'context' using automated techniques. The output of this analysis can take time depending on the data ingestion rate and therefore for maximum value it will be shared several times a week, rather than real-time.
c. **Anonymized data** - Any data containing PII will be anonymized before sharing. This process is also time consuming and can vary from a few hours to several days. Examples include data related to monitoring the safety driver and the passengers.
d. **Reporting and safety assessment data** - A unique approach of our demonstration is a fair comparison between human driven transit vehicles and automated transit vehicles. Such analysis and the output reports generated from these analyses will be shared sporadically.

5D: Risk Identification and Management

Detailed emergency preparation and risk mitigation is essential when deploying and testing automated vehicles. Any emergency will require an immediate, well-executed response appropriate to the severity of the incident. All stakeholders and partners in the proposed demonstration understand their role in an emergency and will undergo through training and practice.

Perrone Robotics, JAUNT, UVA and County of Albemarle along with local stakeholders will be briefed on incident response procedures and we will also conduct in mock emergency scenarios. Safety operators will receive extensive training, including whom to communicate with in a timely manner, what to record, and how to override any operations of the vehicle. The range of possible risks include small incidents (scraping the side of the garage door, a passenger incident on the shuttle), to more serious situations (collisions, injuries, and fatalities).

5D.i: Albemarle Autonomous Driving Safety Task Force

The ADS-TF will be formed by the key participants from each of the collaborators and it will ensure that the demonstration is safely and ethically conducted. The task force will use an iterative process in reviewing our safety, testing, operational plans, and work closely with the UVA IRB representatives regarding compliance with the removal of CBI, and PII information form any data. In an early stage of our project, we will work with transit bus drivers and share with them expected autonomous behavior of the vehicles, including training on Perrone Robotics' close-circuit testing. For instance, large and heavy buses should not follow too closely behind the autonomous shuttles, which can stop quickly. Law enforcement officials from the Albemarle County have been included in the early stages of a shuttle deployment project so they have a complete understanding of the system's capabilities and the challenges that may arise in real-world operation. We will take added measure of safety and precautions during the nascent stages of the demonstration (i.e. gathering the map data, waypoint planning etc.) and ensure that the transit vehicle travels below posted speeds during data collection. The phased approach will help to identify any issues which can be addressed and remedied leading to a safe and smooth public launch.

5E: Cost Sharing

To accomplish Albemarle County's scope of work for this project, the County will be using its existing personnel to perform this work except for (1) a specialized contractor, chosen in accordance with the Virginia Procurement Act, to develop and publish an emergency response guideline (ERG) and (2) a temporary part time employee, a contractor, who will provide project management support to ensure the project is delivered on time and within budget and scope.
The County will provide $213,870 as cost share to the project.