Final Report

Autonomous Shuttle Pilot

10/21/2019

Submitted To:

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PROPRIETARY STATEMENT

Purpose

This document is prepared by Perrone Robotics, Inc. (PRI) for Albemarle County (County) and the Economic Development Authority of Albemarle County (EDA) and serves as the final report regarding the piloting of an autonomous electric shuttle vehicle for use by the general public in Crozet, Virginia from July 9, 2019 through October 8, 2019.

This report is limited to work performed by PRI and the information gathered for communication to the County and the EDA. It is submitted as part of PRI's reporting obligations to the County and the EDA, but also in the spirit of broadly sharing information gathered during this pilot.

Crozet Autonomous Shuttle called "AVNU" on the job in Old Trail Community

Summary

The PRI-outfitted AVNU shuttle operated autonomously on public Crozet roads offering rides and transportation to citizens during pilot operations. AVNU also operated in Florida during an autonomous vehicle conference. AVNU drove over 534 autonomous miles in this period and had no safety disengagements (where the operator needs to take control). Approximately 750 people were given rides ranging in age from small children to senior citizens. The overall feedback was uniformly positive with many riders expressing an interest and need for a regular service. From this data and the feedback received, we are able to provide this final report of a very successful autonomous shuttle pilot in the County.

The pilot has also achieved a few milestones and historic firsts not only for Albemarle County and the State of Virginia, but also in the U.S. and worldwide. For one, this pilot represents, to our knowledge, the first autonomous shuttle operating on public roads for the public in the state of Virginia. Secondly, the level of autonomous capability of the shuttle technology inclusive of operation across complex intersections and roundabouts, without requiring safety disengagements and interventions during operations represents, to our knowledge, as defined below in this report, the first autonomous shuttle with Full Autonomous Capability operating on public roads for the public in the U.S. and worldwide. As there were no safety disengagements or interventions during public operations, while there was a safety operator onboard, the vehicle can also be said to have operated as a Level 5 autonomous vehicle under the operational design domain for this shuttle as described in this report.

Background

Representatives of PRI and the EDA began discussions in the Summer of 2018 regarding PRI's business and the substantial economic opportunities presented by the autonomous vehicle space not only for PRI, but also for communities with active business and operations in the space. We discussed the concept of an all-electric autonomous shuttle service for County residents as a pilot and demonstrator program to gain first-hand experience in the rapidly evolving space of autonomous transit. We discussed benefits such as enhanced safety, less congestion, the use of environmentally clean modes of transportation, and minimizing capital expenditures on garages and other transportation infrastructure. The pilot would also serve an economic development purpose by helping fuel PRI's business expansion objectives in the autonomous transit of people and goods -- and its growth within the county -- using PRI's TONY (TO Navigate You) kit-based approach to retrofitting existing vehicles.

Representatives from JAUNT, Inc. ("JAUNT"), a regional transit service provider, joined the conversation to research potential benefits to communities it serves, assess cost savings on future testing and launching of autonomous transit services, understand and implement risk mitigation strategies for such services, and to eventually launch a commercial autonomous shuttle service in its service areas. The result of these discussions was that the County and JAUNT formed a new autonomous mobility entity -- a subsidiary of JAUNT named Smart Mobility Inc. (SMI).

The expected outcomes and likely follow-on activities from the program included:

1. Development of a communications plan for the program.
2. Development and funding of an autonomous electric shuttle for use in Crozet, Virginia and potentially elsewhere in the County.
3. Pilot testing of a shuttle at Perrone Robotics' facility and on agreed upon routes in Crozet, Virginia.
4. Exploration of further pilot projects for autonomous shuttles elsewhere in the County and in other counties served by JAUNT.
5. A retrofit of an existing JAUNT van to operate autonomously, and pilots of the van on routes in the counties served by JAUNT.
6. Solicitation and compilation of community feedback and advice on the program.
7. Coordination of shuttle launch events involving press and VIPs to help draw attention to the program.
8. Regular meetings among the parties and additional invited parties to discuss broader rollout and expansion of the program using a phased approach.
9. Knowledge base creation and refinement regarding autonomous transit to assist the parties to collaboratively seek funding from state and Federal sources of funding for JAUNT's and SMI's local autonomous shuttle services.

Meetings

Meetings between representatives from PRI, the County, and JAUNT were scheduled and stewarded by PRI through May of 2019. After the formation of SMI, SMI coordinated the meetings through the Summer of 2019. Representatives from the University of Virginia Engineering School also participated in a supporting role during the initial meetings.

Broader Rollout and Expansion

During weekly meetings, participating members discussed broader rollout and expansion concepts for the program. In April 2019, A "Virginia Autonomous Shuttle Vision and Roadmap" document in presentation format was drafted. This concept document represents a phased plan and vision for bringing autonomous transit shuttles to Albemarle County, the Central Virginia Region, and generally to the Commonwealth of Virginia. This concept document formulated a broader vision and plan intended to be presented to larger forums across the Commonwealth. JAUNT and SMI also facilitated discussions with key stakeholders at the state and local level who could provide information and open doors to potential funding sources. The targeted sources included state innovation funds for this broader rollout effort. JAUNT and SMI representatives also invited PRI representatives to transit conferences and other fora where such rollout efforts could be discussed and vetted.

Vehicle Platform Types

The group reviewed a series of different vehicle platform types suitable for transit applications. The vehicle types discussed were:

- **Neighborhood Electric Vehicles (NEVs)**: 1-6 passenger low speed electric vehicles (EVs) for local community and neighborhood use.
- **Passenger Vehicles**: 2-8 passenger vehicles for short- to long-range commuter applications inclusive of all electric vehicles.
- **Transit Vans**: 10-15 passenger vans for medium capacity transit inclusive of all electric vans.
- **Small EV Buses**: 10-15 passenger EV buses.
- **Body on Chassis (BOC) Vans**: 10-23 passenger capacity vehicles for longer range commuter applications and special purposes.
- **Buses**: 30-40 passenger vehicles for fixed service commuter applications inclusive of all electric buses.
- **Articulated Buses:** (60-70 passengers) for larger capacity transit.

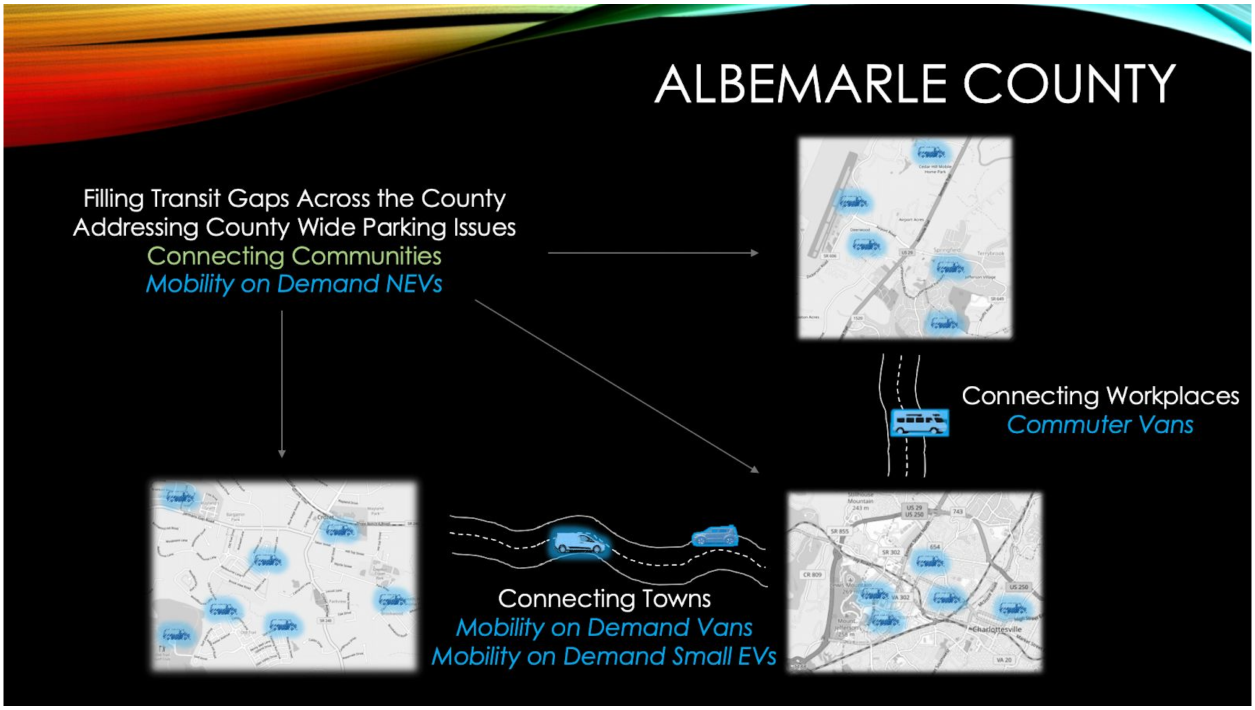
Connecting Neighborhoods

The initial autonomous shuttle pilot proposed for operation in Crozet, Virginia offered an economical last mile solution that could be managed and serviced from the PRI headquarters in downtown Crozet, Virginia. A single NEV was selected for the initial pilot as an economical and accessible stepping stone for future development. The autonomous NEV also represents a practical low-cost last-mile transit solution for neighborhood access transit gaps and for short range transit to/from remote parking locations. A natural follow on phase 2 would include multiple NEVs connecting neighborhoods in and around Crozet, Virginia, as an example model that could be replicated in other communities and neighborhoods.

Mobility on demand using ride-hailing apps would be essential to expand a last-mile service to enable citizens to hail transit from their homes to take them to downtown locations, to longer-range transit service stops, and to other destinations within a short distance of their homes (and back home again). As part of its autonomous vehicle operations, PRI also investigated third party ride-hailing apps against the program's future needs.

Connecting Communities

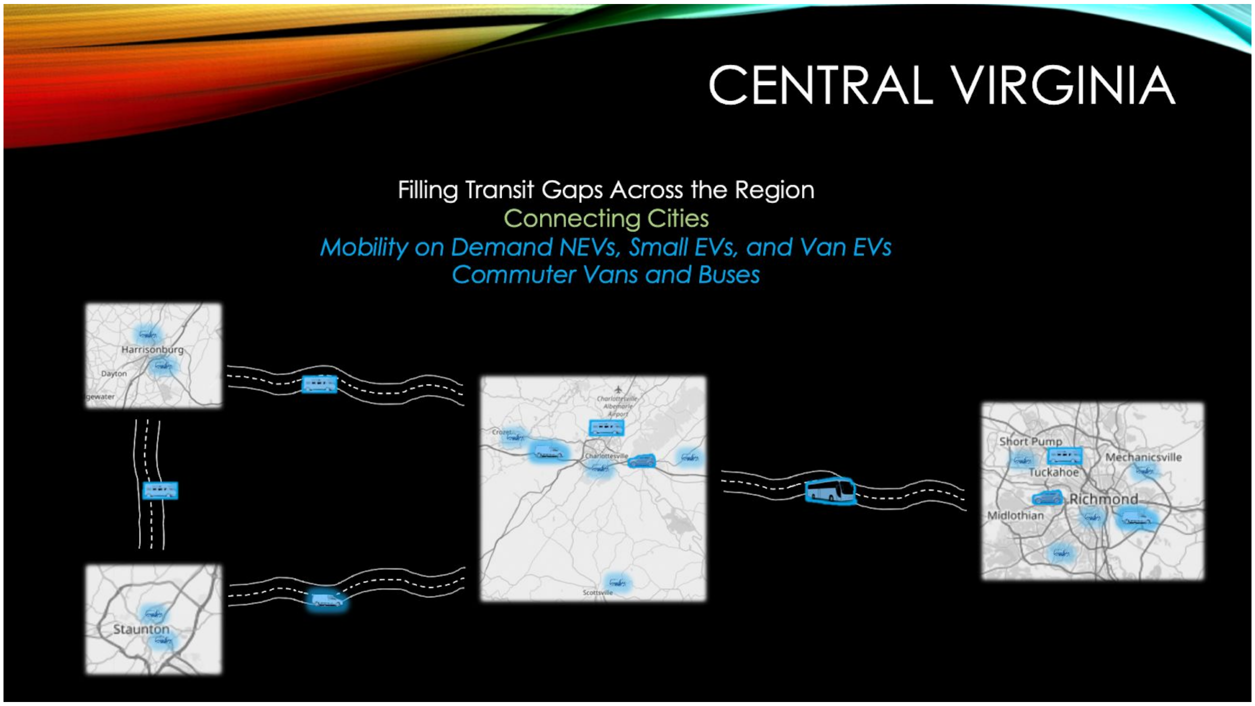
Given the model of localized and clean neighborhood transit via NEVs in Crozet, the collaborating parties discussed how such a solution could be replicated across Albemarle County. Other communities could be connected with mobility on demand autonomous transit vans carrying commuting passengers to/from Charlottesville. For off-peak operational needs, smaller autonomous passenger EVs would be deployed to service small capacity transit between towns. Furthermore, larger capacity autonomous commuter vans could be deployed and demonstrated along such corridors like Route 29 north to/from destinations in Charlottesville. These services would be more route-based, and then last-mile autonomous NEVs would deliver commuters to their individual homes.



Connecting Cities

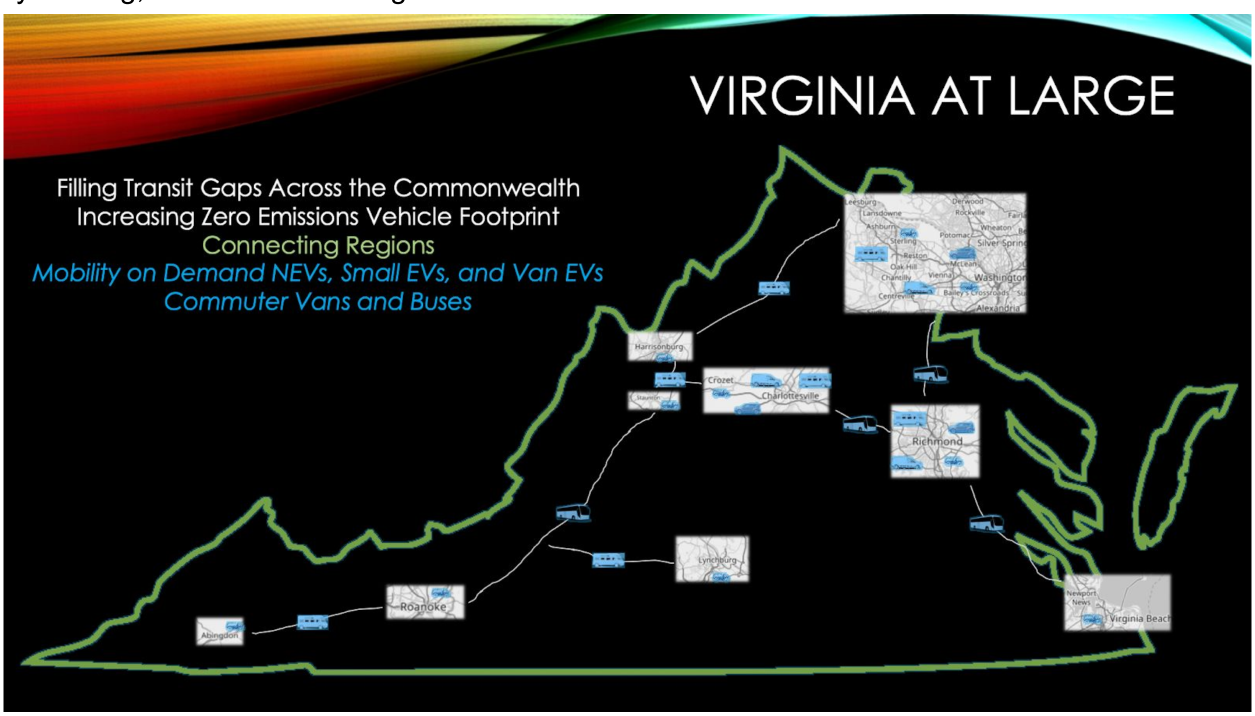
Having met with other cities and counties in Virginia and many other states, PRI is aware of the broad interest in autonomous transit. Programs for connecting neighborhoods and communities that could be piloted and operated in and around Albemarle County would have obvious application to other localities in Central Virginia and beyond. Within the Central Virginia region, a next stage would be connecting areas such as Staunton, Harrisonburg, Charlottesville, and Richmond. Autonomous transit vans, body on chassis vehicles, and buses that link cities could help form a seamless network for transit across the Central Virginia region.

PRI engaged stakeholders in Harrisonburg and Richmond and received strong interest from both business and non-profit groups hoping to serve both traditional business communities and underserved communities in those cities through autonomous transit solutions. While commuters would benefit from these services, the elderly, poor, and disabled citizens would benefit even more as the autonomous shuttles would provide on-demand rapid transit to their essential services.



Connecting Regions

The natural evolution of a connected Central Virginia region would be to connect regions across the Commonwealth of Virginia. The same modes of transportation connecting cities, such as autonomous transit vans and buses, can be applied to the connection of regions throughout Virginia such as to/from Central Virginia, Northern Virginia, Richmond, Newport News, Roanoke, Lynchburg, and Southwest Virginia.

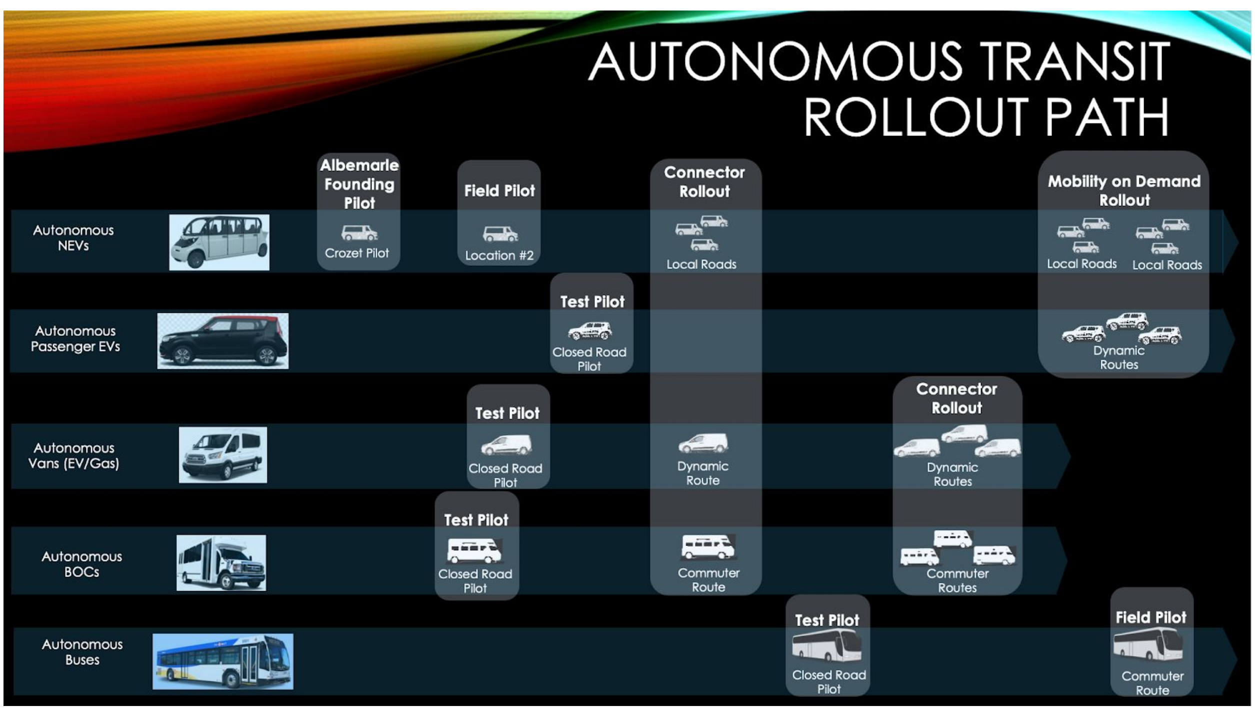


Rollout Path

The broad vision and plan for mobility would involve multiple entities across the County, region, and state for further evolution and iteration. An important objective of the pilot program was to highlight what is possible both regionally and statewide. The local program would demonstrate how existing stock vehicles with Federal motor vehicle safety and ADA compliant certifications can be leveraged to deliver autonomy to new or legacy fleet vehicles using a replicable retrofit autonomy kit. These vehicles can also satisfy any “Made in America” criteria.

The same autonomy approach applied to the NEV in Crozet has been proven to operate in a wide range of other vehicles. So not only is the autonomy approach demonstrated in Crozet a template for operation of autonomous NEVs elsewhere, but outfitting and operating these vehicles is a template for other vehicle types for a wide range of autonomous transit applications.

As a conceptual framework, a practical path to rollout needs to be considered. The diagram below depicts one such rollout path concept for creating and evaluating various vehicle types for the various contexts discussed above. This rollout path provides a tangible and achievable plan for deploying practical autonomous transit at a scale that provides meaningful positive environmental and social impact sooner than what other AV companies can deliver.



NEV Pilot Program

The foregoing broad visions and plans are bold, but achievable as illustrated by our pilot program. In Crozet, PRI obtained a stock Neighborhood Electric Vehicle (NEV), acquired the sensor hardware, computing hardware, and related parts and components, and integrated them with the PRI MAX software platform and its bolt-in autonomy kit to deliver SAE Level 4 autonomy to the vehicle. The engineering tasks for this work were performed at PRI's headquarters and workshop in Albemarle County. Once the outfitting was finished, PRI tested the vehicle extensively on its test track including passing quality assurance reviews. When the safety and reliability of the vehicle had been vetted to PRI's satisfaction, PRI tested the vehicle on less-travelled County roads, with a safety driver on board at all times. PRI then arranged for acceptance testing by the County and SMI, and ran a series of tests. Once those tests had been completed to the satisfaction of the County, the collaboration partners arranged a launch event. Then at that event on July 9, the inaugural runs of the shuttle with local, public passengers were completed.

Low Speed Vehicle Class

The NEV selected for the pilot is a Polaris GEM e6 vehicle. The GEM e6 is a fully electric vehicle that seats 6 and is classified as a Low Speed Vehicle (LSV) under federal and state law. A LSV operates at speeds of 25 mph or less and can operate on roads with speed limits of 35 mph or less. LSVs are required to have head-lights, brake lights, tail lights, reflectors, e-brakes, rearview mirrors, windshields, wipers, seat belts, and certain other equipment. More information about LSVs under Federal law here: https://www.law.cornell.edu/cfr/text/49/571.500
And how LSVs in the Virginia Code here:
https://law.lis.virginia.gov/vacode/title46.2/chapter8/section46.2-908.2/
https://law.lis.virginia.gov/vacode/title46.2/chapter8/section46.2-908.3/

The Vehicle

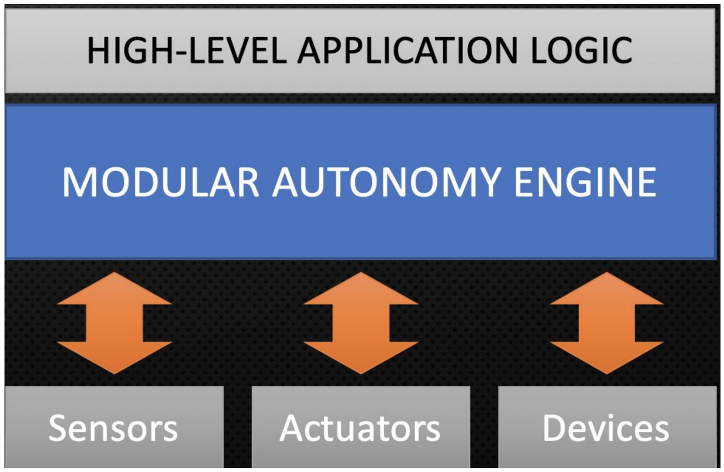
The Polaris GEM meets the applicable federal motor vehicle safety standards (FMVSS) for LSVs. It weighs 1,670 lbs and with its small footprint serves as a more approachable but realistic form of autonomous transit for pedestrians and residents of the County than larger and higher speed vehicles. PRI's view was that the smaller size and lower speed of this autonomous vehicle would be more well-received by residents as the vehicle travelled through their communities and neighborhoods. For the pilot phase and immediate future, the vehicles are manned at all times by a trained safety operator in the driver's seat who is ready to take control of the vehicle at any time. This GEM e6 model includes an extended range battery pack, solar panels, heater, and rear trunkback carrier.

The AV Platform

Since 2003, PRI has been developing and evolving a comprehensive full stack autonomous vehicle (AV) software platform: MAX®. MAX has been used for fully autonomous vehicles since 2005 when a MAX-powered vehicle was fielded in the DARPA Grand Challenge events with no driver onboard and no remote control capability. Since then, MAX has been applied to over 29 different vehicles and has been used in vehicles with over 33,500 autonomous miles traveled. MAX was designed from the outset with full autonomy and driverless vehicles in mind.

MAX

PRI's patented General Purpose Robotics Operating System is a software platform that integrates with underlying robotics, device, and computing hardware. It provides a set of common reusable software services that can be called by application software running on MAX. The application services provided are a set of software building blocks that enable rapid, portable, and robust development of robotics and other autonomous applications. MAX is a full stack AV software platform that provides the ability to swap in or out different underlying sensors, computer platforms, control solutions, communication networks, and vehicle mobility platforms without having to change the application for a given task.



TONY

TONY™ is an autonomous transit kit, built on top of MAX, that includes software configurations for autonomous shuttling applications and a flexible selection of onboard sensor, control, and communication configurations. TONY provides a vehicle-independent approach for autonomous shuttling that can be applied to NEVs, passenger EVs, regular passenger vehicles, transit vans, trams, buses, service vehicles, and a wide range of other vehicles to create turn-key solutions. Stock vehicles can be controlled using drive-by-wire controls or by PRI's Bolt-in Autonomy Kit (BAK) solution for mechanical control integration of steering, brake, accelerator, and gear state.

Full Autonomy

MAX contains a comprehensive suite of services that deliver autonomy into target vehicles. These services include:

- **Sensor integration** for receiving data from sensors such as LiDAR, RADAR, camera, ultrasonics, GPS, inertial, and a wide range of sensors.
- **Noise Filtering** in sensor data including environmental noise such as rain and snow.
- **Perception** for identifying physical objects within raw sensor data.
- **Fusion** of perceived objects from all sensors over time to create a coherent picture of the physical objects around a vehicle.
- Position and orientation estimation (**POSE**) to establish vehicle position and orientation, and the rates of change of these values (e.g. speed, acceleration, and yaw rate).
- **Controls** for open and closed-loop feedback control of actuators (e.g. steering, brake, and throttle). Control accomplished via drive by wire (DBW) or by direct actuation control, such as using PRI's drop-in or bolt-in autonomy solutions.
- **Speed and steering controls** and configurable limits based on external conditions (e.g. limit steering based on speed, limit speed based on curved path).
- **Mobility platform** adapters which allow application plug and play with different underlying vehicle platforms. Furthermore, mobility platform abstractions also allow different underlying mobility methodologies such as Ackerman-based steering, skid-steering, tracked, omni-directional, and other pluggable mobilization approaches.
- **Mapping** translation of standard and hi-def maps into internalized course representation data.

- **Route planning** given a map, current POSE, and desired end point, plan an optimal and valid route to the end destination reaching any desired checkpoints along the way.
- **Path planning** of smoothed vehicle trajectory based on map data, current POSE, and vehicle dynamics.
- **Movement planning** that triggers one or more concurrent maneuvers the vehicle should use based on external conditions. A particular maneuver (e.g. stop sign handling) may become active based on an external condition (e.g. mapped stop sign within some distance of the vehicle). Then the maneuver pursues a sequence of steps to achieve the desired behavior (e.g. slow down, stop, look for cleared intersection, proceed). Maneuvers can be prioritized and arbitrated so that one maneuver takes precedence over another (e.g. collision avoidance over parking maneuver).
- A suite of pre-defined and configurable **maneuvers** for automated driving. Examples of maneuvers include: vehicle and general collision avoidance; adaptive following/pacing; pedestrian/cyclist collision avoidance; bumping around roadside objects; lane keeping; stop intersection handling; merge intersection handling; traffic signal handling; roundabout handling; passing; parking (variety of these maneuvers); boarding/alighting; and a variety of other maneuvers.
- Pluggable A.I. Layer (**PAIL**) services to plug-in different underlying A.I. modules to enhance the perception and movement planning of the vehicle.
- **Safety & Security watchdog** monitoring of the Level 4/5 AV system for hazardous and malicious conditions that are independently checked to assess when to fail-safe.

Operational Design Domain

The deployed operational design domain for the pilot included the following:

- Operation from a starting location to an entered end destination on a map.
- Operation on roads with speed limits of 35 mph or less.
- Operation at speeds not to exceed 25 mph.
- Operation with two-lane bi-directional travel.
- Operation with single lane one way directional travel.
- Operation with 3-way and 4-way intersections.
- Operation with secondary lanes for left or right hand turns.
- Operation with roundabouts and multiple entry/exits.
- Operation with stop points (i.e. stop signs).
- Operation with yield points (i.e. implied or explicit yield signs).
- Operation within the boundaries of defined or marked lanes.
- Operation according to defined speed limits for a road.
- Operation with pedestrians, cyclists, and stopped vehicles in lane.
- Operation with moving pedestrians, cyclists, and vehicles in lane.
- Operation with objects on the side of the road encroaching on lane.
- Operation with inclines and declines and hilly roads.
- Operation in residential communities, neighborhoods, and main roads through town.
- Operation in light to moderate rainy weather.
- Operation during sunny, cloudy, daylight, or night-time conditions.

The underlying AV technology deployed may be configured to handle a wide range of situations. But for the pilot, any operational design domain element not described above was deemed to be outside the scope of the pilot program, and therefore warranted manual intervention if encountered.

Outfitting

PRI outfitted the NEV with a TONY Autonomous Transit retrofit kit configuration suited for the pilot operational design domain described above. This outfitting included:

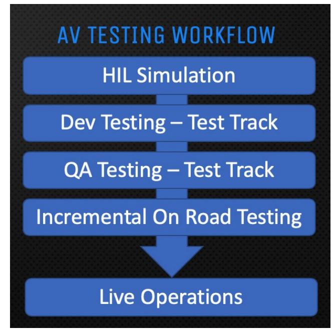
- Bolt-in Autonomy Kit (BAK) for control of steering, brake, acceleration, and shift state.
- Onboard E-brake, ignition cut-off, and E-stop controls by onboard operators.
- Onboard manual takeover controls by onboard operators.
- Onboard operator’s user interface (UI) for selection of maps and desired destinations, starting and stopping autonomous operations, and for monitoring operations.
- Onboard equipment enclosure containing the AV electronics.
- GPS/IMU with speed signals, differential corrections, redundant features, and dead reckoning for reliable positioning, orientation, speed, acceleration, and other inertial information about the vehicle.
- LiDAR for high-resolution forward and side detection of objects in conjunction for collision avoidance, stopping, pacing, passing, intersection handling, parking, and roundabout maneuvers.
- RADAR for redundant and longer range functions of the same maneuvers.
- Camera for traffic signal detection.
- Camera for lane keeping (in conjunction with other sensors).
- Onboard logging capabilities.
- Integration and control with onboard turn signals.
- Visual and audible alerts for autonomous mode warnings.
- Addition of cooling technology for warm weather operations.
- Addition of active equipment cooling technology for warm weather operations.
- Mounting of solar panels and fast charging equipment.
- Protective and cosmetic covering of sensors.

Testing Process

At the time of the pilot there were no universally accepted or standard test procedures for AVs. Different organizations typically define their own procedures. Some procedures are high level, focused around on-road autonomy for passenger vehicles. Some are aimed at Level 2 and 3 automated functions vs Level 4 and 5 autonomy testing. PRI’s Founder/CEO worked with the Society of Automotive Engineers (SAE) to develop a verification and validation task force for autonomous vehicles but these standards have not yet emerged.

However, with over 16 years of deep experience in the AV space, PRI has developed best practices for testing. Such practices are informed by PRI’s own experience and activities and also from other organizations. PRI’s testing practices are tailored for the levels of autonomy and types of operational design domains in which PRI’s AVs operate.

A general workflow for AV testing is illustrated below.



HIL Simulation

Prior to testing on a test track or public roads, new software configurations are typically tested in a simulation tool by the engineering team at PRI. This simulation tool provides a hardware in the loop (HIL) simulation of the actual outfitted vehicle and controls and sensors for the vehicle. In this case, PRI used a simulated Polaris GEM vehicle model with the same sensor and controls configuration as the actual vehicle. PRI also created a model of its test track. PRI then tested specific autonomous capabilities using this simulation model before deploying on the physical track.

Developer Testing - Test Track

Engineers then take the software to be tested to the test track at PRI. PRI has an approximately 1 mile long test track in Crozet, Virginia complete with stop signs, intersections, higher speed stretches of roads, curves, traffic signals, GPS outage tunnels, and other real-world scenarios. Engineers test their configurations and updates in the vehicle on the test track. The same configurations tested in the simulator are tested in a controlled test track environment.

QA Testing - Test Track

Next, Quality Assurance (QA) test engineers with the company are given releases that run on the target hardware in the vehicle so they can test behavior independent from development engineers. QA staff test for specific conditions and scenarios based on what functions are being released to the vehicle.

Incremental On Road Testing

When ready for testing on the public roads, QA test engineers take the vehicle out acting as safety operators in the driver's seat and ready to take manual control of the vehicle at any time. Typically, simpler tests are performed first at slower speeds. Speed and complexity of tests are then incrementally increased to mitigate risk associated with testing on public roads.

To prepare for public deployment of any new release or update or on any new route, PRI engages in volume testing of features specific to a release. Beyond simply meeting functional requirements of the system, PRI tests to ensure that the system operates continuously and safely in a public environment for extended periods of time. To validate new releases, PRI operates the AV on a route a defined number of times (e.g. 100 or more times) as a function of the release change level on the intended operating routes and operational design domain. If the vehicle is able to complete the required number of runs without a critical event occurring, then that version of the system is deemed ready for public demonstration. However, if a critical event occurs during this test period, testing halts, and PRI engineers are tasked with resolving the source of the issue. Testing resumes after the issue has been resolved, but the count of successful consecutive runs is reset to zero as a result of the critical event. Subsequent system updates must be tested at a similar volume before being released for operation on public roads.

Pre-Operation Checks

Prior to beginning any testing in the vehicle, the test operator performs an inspection of the vehicle itself, verifies E-stop functionality, and verifies that sensors and auxiliary hardware are operational. Any necessary repairs or adjustments (sensor alignment, etc.) are made prior to testing. Once this is complete, the test operator then proceeds with the following checks:

- Verify that the navigation system is functioning properly
- Verify that the system has connectivity to all sensors
- Verify that the system has connectivity to all actuators
- Verify that the vehicle reports no faults or warning messages on its display
- Verify that the vehicle and peripheral batteries are adequately charged
- Verify that all passengers (including the operator) are wearing their seatbelts

Live Operations

Once a quality-assured and tested release is deployed to the AV, it is ready for live operations. For the pilot, a safety operator sits in the driver's seat with the ability to take control of the vehicle at any time. The safety operator can take control by pressing the brake pedal, grabbing the steering wheel, or pressing a manual override button. The ability to turn off the vehicle and apply the mechanical brakes is a final option.

SMI intended to operate the shuttle during the course of the pilot, but delays in the formation of the subsidiary and procurement of insurance for operations led to PRI, through its subsidiary PARTS, becoming the vehicle operator during the course of the pilot. PRI obtained insurance on an event basis for the pilot period.

Hierarchical Test Classification & Operations

Prior to launch, testing was performed to confirm that the AV performed to the levels required by the operational scope for the pilot, i.e., the pilot operational design domain. The AV's performance was verified by a variety of tests at different levels; component tests, integration tests, and systems tests. The core tests and implied domain of operation were described and presented in a document entitled “Autonomous Vehicle Safety Testing”. The structure of these tests are organized in a hierarchical fashion with a broad class of tests defined first. Then more specific tests within that class of tests are defined. Depending on the operational design domain, the appropriate selection of tests to apply for the scope of operations are made. In this way, testing can focus on the relevant tests for a particular operational design domain.

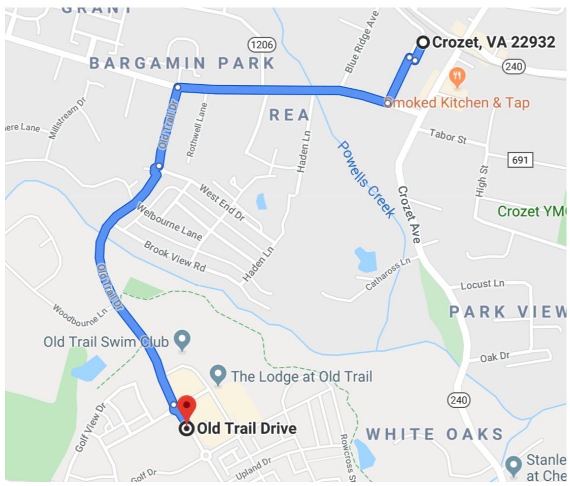
For example, the route selected for the launch reflected a subset of the total operational design domain for the pilot period. Thus, a subset of tests specific to that scope of operations could be applied, allowing more focus on repetition over that course of operation versus testing for scenarios that were outside of the scope of that launch route (e.g., climbing and descending hills).

Routes

A number of route configurations were selected for the pilot to demonstrate different types of practical transit for this class of neighborhood/community application. The following routes were selected and operated during the course of the pilot.

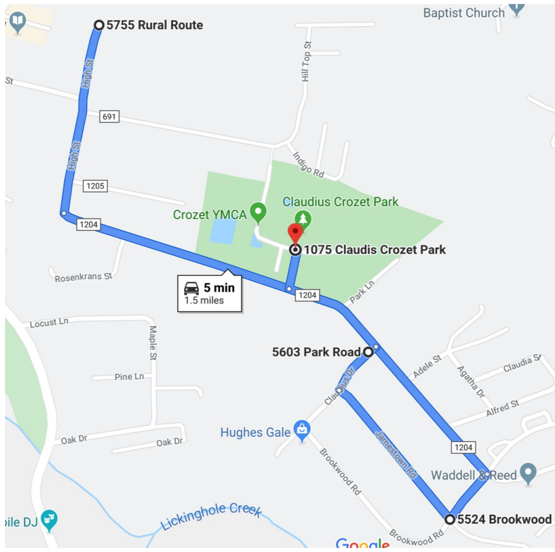
Community to Downtown

A route demonstrating operation between a residential community (i.e. Old Trail community) and a downtown business district (i.e. Downtown Crozet), connecting residents from a residential community to downtown services.



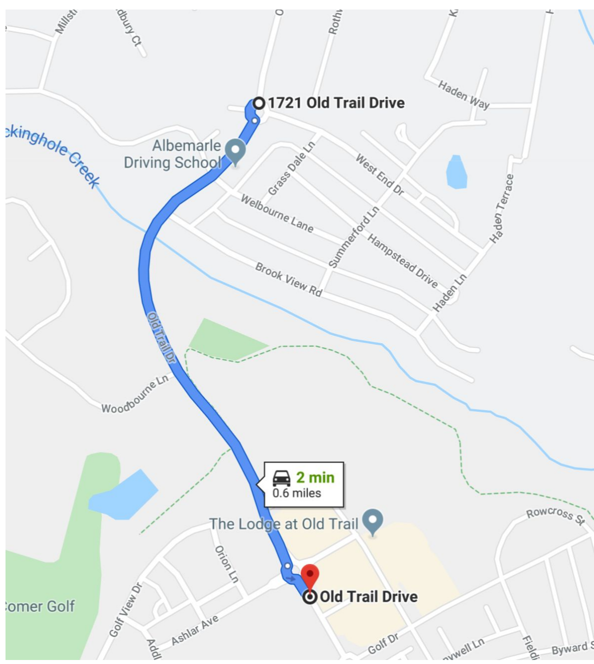
Neighborhood to Downtown

A route demonstrating operation between a residential neighborhood (i.e. Jamestown Road and Crozet Claudius Park) a downtown business district (i.e. Downtown Crozet) connecting residents from a neighborhood to downtown services and recreational park activities.



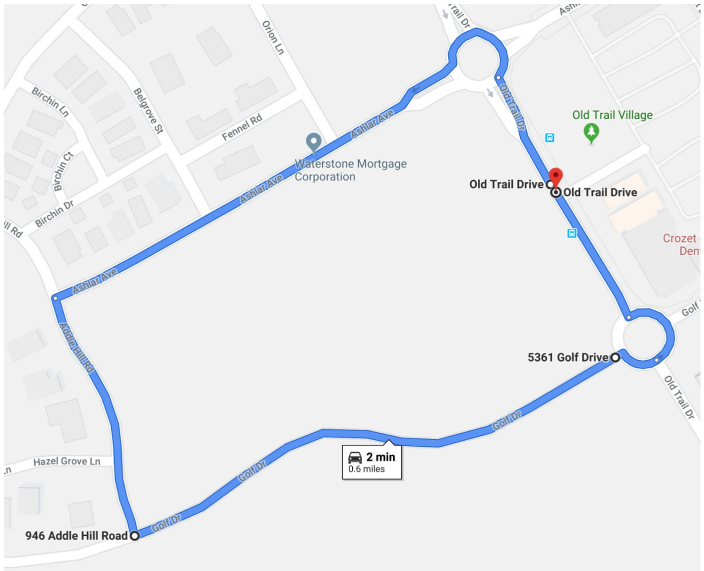
Intra-Community

A route demonstrating operation within a residential community (i.e. Old Trail) connecting residents within a community to services within the community (e.g. community swimming pool, coffee shop).



Demo Circulator

A route demonstrating a circulator transit service around a specified region of operation. This route was also used for the launch event and for high volume demonstrations for community members to experience autonomy without long waits given the single vehicle pilot.



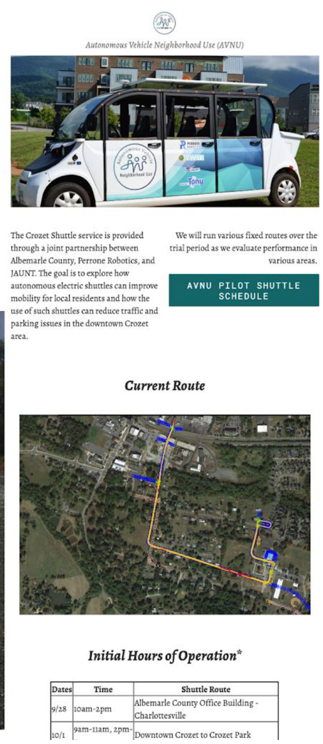
Automated Vehicles Symposium 2019

Shortly after the launch of the shuttle in Crozet, a team from PRI, the County, and SMI attended the Automated Vehicles Symposium in Orlando, Florida (July 15-18, 2019). There, a number of demo rides were given to attendees on a complex course around a large Marriott resort that included intersections, busy pedestrian crosswalks, and speeds up to 25 mph (course map shown to the left). While there, rides were given to industry representatives more versed in AV technology than the average consumer. The feedback given was positive with many riders commenting that it was the smoothest and most realistic autonomous shuttle ride they had ever experienced.

Pilot Operations

As noted above, PRI in conjunction with its subsidiary PARTS operated the shuttle for the public with SMI generously reimbursing PRI for many of the at cost expenses incurred for these operations. Operations conducted throughout the pilot period included:

- Weekly internal operation meetings to discuss and reinforce safety policies, rules, protocol, routes, and action items.
- Daily morning “touch base” meetings to discuss and reinforce the above before each day of operations and any testing.
- Coordination of personnel to operate the shuttles on weekends and weekdays as planned throughout the pilot.
- Extensive testing of any new routes charted for operation.
- Update and maintenances of the avnushuttle.com Web site where information was posted for the public regarding operations.
- Coordination and securing of insurance for days of operation.
- Design and placement of signage for shuttle start locations.
- Design and placement of advertisements notifying the public of operation dates and the Web site.
- Charging of the vehicle’s batteries when out of service.
- Maintenance of the vehicle and onboard hardware.
- Housing and securing the vehicle.
- Arrangement of transport for the vehicle to events (e.g. launch, A275).



Autonomous Vehicle Neighborhood Use (AVNU)

The Crozet Shuttle service is provided through a joint partnership between Albemarle County, Perrone Robotics, and JAUNT. The goal is to explore how autonomous electric shuttles can improve mobility for local residents and how the use of such shuttles can reduce traffic and parking issues in the downtown Crozet area.

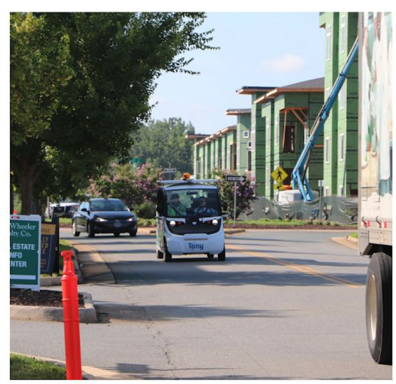
We will run various fixed routes over the trial period as we evaluate performance in various areas.

AVNU PILOT SHUTTLE SCHEDULE

Current Route

Initial Hours of Operation*

Dates	Time	Shuttle Route
9/28	10am-2pm	Albemarle County Office Building - Charlottesville
10/1	9am-11am, 2pm-	Downtown Crozet to Crozet Park



Key Pilot Evaluation Parameters

There were six criteria used to measure the success or value of this autonomy pilot. They are as follows:

Safety of Operations

The safety of operations was of paramount importance during the pilot. Safety not only for onboard passengers but for pedestrians, cyclists, and passengers in other vehicles. The target was zero accidents or near-misses of any kind.

Disengagements

As there is a safety operator onboard, the safety operator can assume manual control of the vehicle at any time. Two classes of disengagement are relevant to autonomous operations:

1. **Required.** These disengagements are required to remain safe:
    a. **Safety Disengagement**: A safety operator disengages the vehicle from autonomous operation because not doing so would result in an accident or hazardous event. For example, if an AV cannot support traversal through busy intersections, the operator has to disengage the vehicle because not doing so would result in an accident with other vehicles present.

2. **Desired.** These disengagements are optional to improve performance of the shuttling service:
    a. **Precautionary Disengagement**: A safety operator disengages the vehicle from autonomous operation as a precaution due to a potentially environmentally hazardous situation, even if the AV is designed to handle the situation and would avoid an accident. For example, if there is a reckless driver barreling through an intersection and the AV would otherwise stop, but, out of an abundance of caution, the operator takes manual control.

    b. **Convenience Disengagement**: A safety operator disengages the vehicle from autonomous operation as a matter of convenience or comfort for moving a ride along, even if the AV is designed to properly handle the situation. For example, if there is a bus driver at an intersection waving an AV on, and the AV is stopped and should yield, the operator of the AV may decide to take manual control to move the ride forward and not wait for the bus driver. The disengagement was not necessary for safety or even as a precaution, but in this case the operator disengaged at his own discretion for convenience.

Autonomous Capability Level

At the time of this pilot's first conception in the summer of 2018, autonomous shuttle pilots were infrequent. As of this report's date just over a year later, there are nearly a dozen different companies piloting or proposing to pilot autonomous shuttles throughout the U.S. and abroad. However, while the term "autonomous" is used broadly, the actual autonomous capability level of these pilots varies significantly. For distinction and clarity, we define a number of autonomous capability levels to support a more refined evaluation of capabilities. Each successive level includes the capabilities of all the prior levels. The autonomous capability levels are:

- **Basic:** Basic autonomous capabilities required for forward motion operation with other vehicles and pedestrians in the environment.
  - **Blind Self-Navigation**: Able to autonomously navigate based on a defined route.
  - **Forward Obstacle Detection**: Able to detect and avoid collisions with obstacles in the vehicle's path.
  - **Pacing and Following**: Able to pace and follow behind a lead vehicle in stop and go traffic.
- **Enhanced:** Enhanced autonomous capabilities required for operation in poor weather and reverse and lateral maneuvers.
  - **Parking & Rear Obstacle Detection**: Able to react to obstacles behind the vehicle when backing up and also to engage in parking maneuvers.
  - **Poor Weather**: Able to operate in poor weather (i.e. light to moderate rain, sleet, and snow).
  - **Passing & Lane Changes**: Able to detect and react to vehicles alongside the AV during passing and lane change maneuvers.
- **Advanced:** Advanced autonomous capabilities required for through intersecting roads and paths of travel.
  - **Intersections**: Able to traverse intersections. Inclusive of multiple lanes, multiple ways of travel (3-way, 4-way, N-way), stop signs, yield signs, and following rules of precedence order.
  - **Roundabouts**: Able to traverse through, enter, and exit roundabouts.
  - **Traffic Signals**: Able to obey traffic signals at intersections.
- **Full Autonomy:** Capabilities required of any human driver with a driver's license following rules of the road and traffic signs, where the vehicle may stop if encountering anomalous conditions.
  - **Traffic Signs**: Able to obey rules implied by traffic signs.
  - **Path Crossings**: Able to detect objects off of the road crossing into the vehicle travel lane.
- **Complete:** Complete autonomy to handle all anomalous conditions and extreme weather that may be difficult for most human drivers.
  - **Anomalous Conditions**: Able to handle anomalous conditions that arise (e.g. construction, emergency vehicles).
  - **Extreme Weather**: Able to handle extreme weather conditions such as heavy rain, high winds, and other conditions that would cause normal autonomous operations to be halted.

Rider Comfort, Enjoyment, & Utility

Almost everyone riding in the vehicle during the pilot in Crozet, Virginia, will have taken their first ride ever in an AV. An important part of the user experience is for the ride to be comfortable, with “human-like” actions. This means the smoothness of operational speeds and turns are important evaluation considerations. It must feel like a human driver is driving. Unnecessary or abrupt stops must be mitigated.

Beyond comfort is enjoyment. Is the ride an enjoyable experience because the riders are getting from point A to point B in an autonomous vehicle that feels safe? Can they open the windows and enjoy the experience without concerns with, and anxiety about, the autonomous vehicle?

Finally, the utility of the experience is important. Although a pilot with one vehicle has limited serviceability, are the routes and destinations places where riders would like to go? Are the riders going to places they could not otherwise go to easily because of limited or no existing means of transportation to the destination?

Clean Energy Consumption

An important consideration for autonomy pilots is how much energy is consumed and what is the clean carbon footprint of the AV. As more AVs are deployed and become part of shared or centrally management mobility fleets, the economics and ability to field such fleets as “greener” forms of transportation becomes more viable. This also complements the County’s Comprehensive Plan and natural resource preservation interests.

Economic Development

An important motive behind some AV shuttles pilots is to explore the extraordinary economic opportunities offered by these vehicles. PRI and many AV industry experts sees the autonomy market as an inevitable wave of the future and a trillion dollar market opportunity where stakes are high. To establish one’s community as an early adopter helps embed this technology into the community where AV technologists, businesses, agencies, operations, and maintenance personnel all get an early start on transitioning toward high-value, higher-paying jobs. One of the outcomes for this pilot was to foster PRI’s continued growth in the space and to bring more high value jobs to the community. Further, businesses that cater to the AV industry, such as operations, maintenance and other service providers, stand to benefit economically from wide scale deployments of AVs, creating the potential for more jobs in the County.

Direct Rider Feedback

Throughout the course of the pilot, PRI personnel received feedback from riders. A sampling of feedback received included:

- A grandfather experienced a ride in the shuttle and said that he was going to text his grandson stating; "I've done something you've never done -- ride in a driverless vehicle. You've got some catching up to do."
- A gentleman wrote that he read an article about the TONY project in Crozet, Virginia and stated that “it is truly amazing what your company continues to accomplish and innovate. As a person with a physical disability (Quadriplegia) autonomously operated vehicles will open many doors for independence for many individuals living with physical hurdles that limit their ability to drive. I was encouraged by the article and wanted to reach out and share my perspective. What your company does everyday gives hope and potentially greater quality of life to many and I wanted to say thank you. I look forward to the future of wheeling my chair into a vehicle and be able to travel to a desired location without having to rely on others. Thank you for your time and all you do. Keep innovating and sharing your brilliant minds with the world and especially the state of Virginia.”
- From our operator’s reports, TONY dropped off a couple at the post office in Downtown Crozet, and after enjoying breakfast and shopping, they boarded the shuttle back to Old Trail. They communicated that they found this shuttle very useful and would like to see it a regular service.
- Request to transport students from Western Albemarle High School (at the edge of Old Trail) to downtown for ballet class since students would not have enough time to get to their ballet class on time, and also “depending on weather conditions that walk may not be ideal”. PRI conducted a demonstration run to verify viability of this service and also ran as one of its demonstration routes, a route from Old Trail to Downtown Crozet.
- “My 91 year-old mother and I had a great ride in TONY today.”
- From our operator’s reports, numerous elderly residents at the Lodge at Old Trail took rides, mentioned their interest in being able to get to Downtown Crozet on such a vehicle, and offered their gratitude and satisfaction after the ride.
- A local AAA member took a ride to/from a Downtown barbershop stating that it was a “great experience”, however that it was “random” and “of no real use to anyone until and unless it is regular, every day. Make it so. Need more than one vehicle.”
- A mother of a young child with a disability expressed her interest in seeing such transit give more mobility for her child in the future.

Media & Publicized Feedback

A number of print, radio, and TV news sources produced content covering the pilot's announcement, launch, and operations. During operations, some reports also captured direct and independent feedback from riders. Here is a sample of coverage:

- NPR (Radio) “Crozet Hosts First Public Autonomous Shuttle in Virginia”: https://www.wvtf.org/post/crozet-hosts-first-public-autonomous-shuttle-virginia#stream/0
- CBS 7 (TV) “Self-driving car offers public rides”: https://www.wdbj7.com/video/?vid=561908842
- CBS 19 (TV) “Crozet launches first driverless shuttle service in Virginia”: https://www.cbs19news.com/content/news/512482241.html
- NBC 29 (TV) “Autonomous Shuttle in Crozet Receives Rave Reviews”: https://www.nbc29.com/story/40928401/perrone-robotics-tony-shuttle-in-crozet-receives-rave-reviews
- CBS 19 (TV) “Community gives feedback for autonomous shuttle”: https://www.cbs19news.com/content/news/Autonomous_Shuttle_feedback-513298461.html
- Washington State DOT Representative feedback (Independent Video) “Take a ride in a Perrone Robotics Level 4 Automated Vehicle”: https://www.linkedin.com/feed/update/urn:li:activity:6559119130954469376/
- Crozet Gazette (Newspaper) “Don't Underestimate the Importance of This”: Driverless Vehicle Shuttles Passengers On Crozet Roads”: https://www.crozetgazette.com/2019/08/02/dont-underestimate-the-importance-of-this-driverless-vehicle-shuttles-passengers-on-crozet-roads/ (quotes from tech icon Nolan Bushnell)
- Daily Progress (Newspaper) “Perrone launches autonomous shuttle program in Crozet”: https://www.dailyprogress.com/news/local/perrone-launches-autonomous-shuttle-program-in-crozet/article_d043456c-86e5-56d5-a823-e05f2730344e.html (reprinted in Richmond Times newspaper as well)
- ABC 8 (TV) “Self-driving shuttles? The future of transportation could be coming to Richmond”: https://www.wric.com/news/local-news/self-driving-shuttles-the-future-of-transportation-could-be-coming-to-richmond/
- CBS 7 (TV) “Automated shuttle offers Virginia's first driverless rides on public roads”: https://www.wdbj7.com/content/news/Automated-shuttle-offers-Virginias-first-driverless-rides-on-public-roads-561806121.html
- AUVSI (Trade News) “Autonomous Shuttle Begins Pilot Phase in Crozet, Virginia”: https://www.auvsi.org/industry-news/autonomous-shuttle-begins-pilot-phase-crozet-virginia
- Press Release “Perrone Robotics Delivers AVNU, VA's First Autonomous Public Shuttle Pilot”: https://www.prnewswire.com/news-releases/perrone-robotics-delivers-avnu-vas-first-autonomous-public-shuttle-pilot-300881456.html
- Daily Progress (Newspaper) “Autonomous transit eyed for greater Charlottesville area”: https://www.dailyprogress.com/news/local/autonomous-transit-eyed-for-greater-charlottesville-area/article_e5c29cc6-7a98-11e9-b692-0f513899bdfd.html

Data Collection

Throughout the pilot, a variety of data files were captured and generated from the rides. Map data for the routes include lane waypoints and geometries, intersection geometries, lane and road connections, speed limits, and stop/yield sign locations. Desired route data is also stored and includes the map referenced, desired destination point, desired intermediate stop or pass through points. PRI also stores data collected from our AV autonomous operations, including interpreted and filtered sensor data, perceived objects by sensor and by fusion output, state of each autonomous maneuver and calculated maneuver outputs, desired path information, desired steering angle and calculated steering limits and rules, desired speed and calculated speed limits and rules, control values, miles traveled over the course of a mission/run, average speed traveled over the course of a mission/run and total time for mission/run.

The safety operator was also responsible for tracking any unique environmental conditions and situations, interventions, weather events, and ridership feedback given.

Pilot Results

A summary of results against key evaluation parameters is provided here:

- **Zero Incidents**
  - During the course of the pilot, safety of operations was paramount. There were no accidents or unsafe incidents throughout the pilot program.
- **Zero Safety Disengagements**
  - During the course of public pilot operations, there were no safety disengagements.
- **Miles Travelled**
  - During the course of public pilot operations, approximately 534 miles were traversed autonomously.
  - PRI’s underlying AV software platform, MAX, now has over 33,500 miles accumulated in autonomous vehicles where it is or has been deployed.
- **Full Autonomy**
  - The TONY retrofit kit fielded for this application supports a Full Autonomy Capability Level as defined earlier in this report. A Complete Autonomy Capability Level is forthcoming in 2020.
  - During the course of public pilot operations, routes demonstrating Full Autonomy Capabilities included complex intersections, roundabouts, operation in poor weather, and avoidance of obstacles (vehicles/cyclists/pedestrians).
- **Positive Rider Feedback**
  - Feedback provided from riders was positive.
  - The vast majority of riders commented on a comfortable and pleasant ride.
  - A handful of riders commented that the vehicle stopped once or twice more aggressively than they would’ve expected during their ride.

  - More than a handful of users commented on the utility and interest in having such a service in the community operate on a regular and expanded basis.
- **100% Zero Emissions**
  - The NEV used for the pilot operated all-electric 100% of the time with zero emissions.
- **Economic Development**
  - PRI has over 200 person-years of development behind the technology, have navigated over 33,500 miles autonomously, have outfitted over 29 different vehicles to date, and have a patented and proven full-stack AV software platform called MAX that has been fielded in applications with Automotive OEMs, Tier 1 Auto Suppliers, Industrial Equipment OEMs, and Fortune 500 technology providers.
  - The launch of the autonomous shuttle represents PRI's first public launch of its autonomous transit retrofit kit package called "TONY" (TO Navigate You).
  - After launch of the shuttle, the feedback from demonstrations with potential customers has been extraordinary. The program has led to PRI's growth of a substantial sales pipeline and has accelerated progress toward securing a second round of venture capital (Intel Capital led PRI's first round of venture capital financing).
  - PRI has actively engaged with multiple organizations ranging from Fortune 500 firms to governmental transit agencies across the world for fielding of its TONY-based solution into stock vehicle platforms of choice (e.g. additional NEVs, transit vans, buses, trams, and legacy vehicles). PRI has also secured a contract with a Fortune 100 entertainment company for a confidential autonomous technology project, and is in the final stages of negotiating a contract involving autonomous vehicles with a Fortune 500 logistics services company.

Milestones

This pilot has also achieved a few milestones and represents a few historic firsts not only for Albemarle County and the State of Virginia, but, we believe, also in the U.S. and worldwide.

For one, to our knowledge, this pilot represents the **first autonomous shuttle operating on public roads for the public in the state of Virginia.**

Secondly, the level of autonomous capability of the shuttle technology inclusive of operation across complex intersections and roundabouts, without requiring safety disengagements and interventions during operations represents, to our knowledge, as defined above, **the first autonomous shuttle with Full Autonomous capabilities operating on public roads for the public in the U.S. and worldwide.**

As there were no safety disengagements or interventions during public operations, while there was a safety operator onboard, the vehicle can also be said to have **operated as a Level 5 autonomous vehicle** under the operational design domain.

Next Steps

The autonomous shuttle pilot conducted demonstrated (i) “zero incident” safe operation, (ii) driverless technology, (iii) retrofit of a stock vehicle platform that meets federal safety standards, (iv) a comfortable and safe rider experience. It also received positive rider feedback. Next steps for this program as it relates to further deployment within the County and the surrounding region will be discussed among PRI, the County, and SMI. Public feedback for the program received has been extremely positive. Continued public support and interest in such programs will warrant and drive these conversations. If the public seeks such solutions to be more widely deployed in the community, we welcome community feedback to be provided via feedback forms at www.avnushuttle.com or to PRI company representatives at contact@perronerobotics.com.

PRI’s next steps are to continue refining and improving upon our already mature technology, and to deploy pilots and demos not only in our own community, as desired, but in other locations throughout the state, country, and the world. The economic development component of this pilot has played a significant role in PRI’s pipeline and demand for similar solutions from other customers. That interest is large and investor interest in the company is high. Everyone knows of Uber and Lyft but soon they'll be hearing about "TONY", our self driving "drop-in any vehicle" kit that provides middle distance Full Autonomy transit of people and goods at a cost that is a fraction of the others.