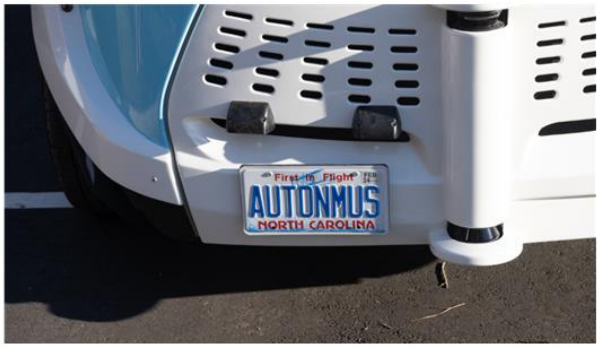

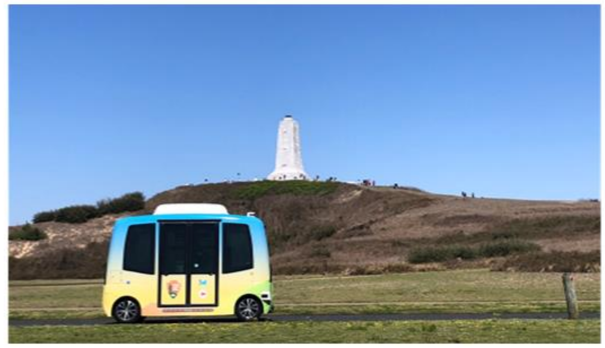

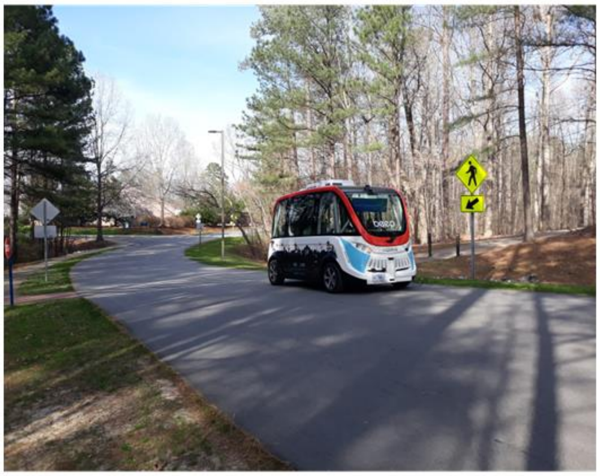

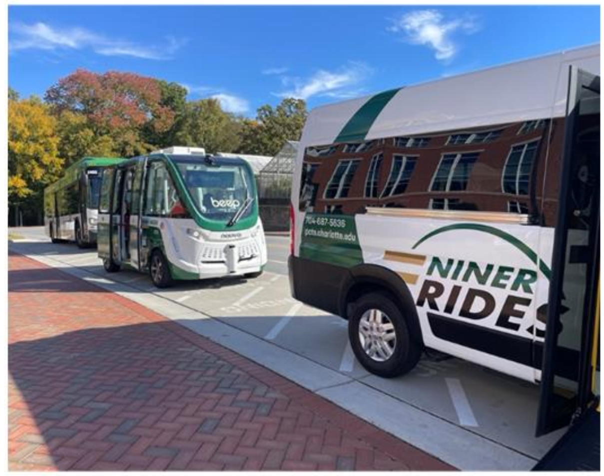

Connected Autonomous Shuttle Supporting Innovation (CASSI) Program Development

Final Report

January 2025

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Integrated Mobility Division
N.C. DEPARTMENT OF TRANSPORTATION

Disclaimer

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Contacts

North Carolina Department of Transportation

Brennon Fuqua – Director, Integrated Mobility Division

✉ bfuqua1@ncdot.gov

For more information about the Connected Autonomous Shuttle Supporting Innovation (CASSI) program, please visit: ncdot.gov/CASSI.

Authors

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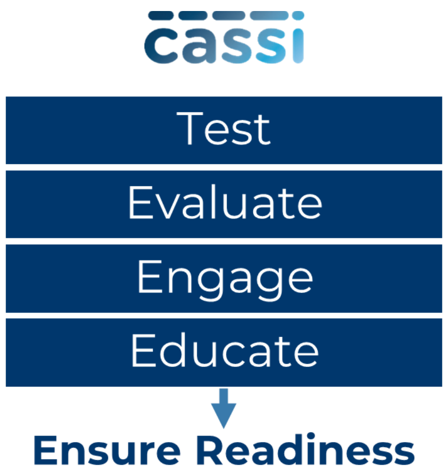
Executive Summary

Led by the Integrated Mobility Division (IMD), the North Carolina Department of Transportation (NCDOT)'s Connected Autonomous Shuttle Supporting Innovation (CASSI) is the state's flagship automated shuttle pilot program. CASSI introduces the public to automated vehicle technology through free shared rides and showcases how the technology works for public transportation now and its potential as an innovative mobility option as the technology matures. Through partnerships and feedback from surveys and engagement events, CASSI has developed analyses and findings that help guide how current generation automated shuttle technology can best be used now and further developed to meet the needs of all riders. CASSI provides a successful model for researching, testing, and evaluating new and emerging technologies, engaging and educating the public, and ensuring readiness.



The Connected Autonomous Shuttle Supporting Innovation (CASSI) program ***tests and evaluates automated vehicles with connected vehicle features in public transportation services.***

The CASSI program has tested two models of all-electric, low-speed automated shuttles in multi-week projects at two university campuses, a recreational public lands site, and a municipal park in fixed-route, circulator services on short routes that offered first and last mile connections.[1] Two of the pilots also tested connected vehicle features and infrastructure. The automated shuttles operated in mixed traffic environments.

Multi-week automated shuttle projects were completed at:

- N.C. State University's Centennial Campus,
- Wright Brothers National Memorial in partnership with the National Park Service (NPS),
- Cary, NC (Cary)'s Fred G. Bond Metro Park (Bond Park), and the
- University of North Carolina at Charlotte (UNC Charlotte)'s main campus.

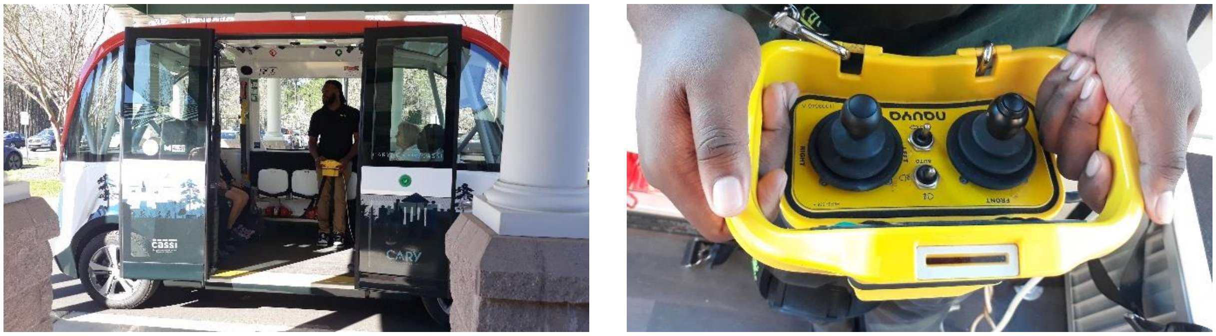
[1] NCDOT. (n.d.). Completed Projects. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Pages/completed-projects.aspx

Automated shuttles tested under the CASSI program (top: EasyMile EZ10 Gen 3 operated by EasyMile at N.C. State University's Centennial Campus (left) and the Wright Brothers National Memorial (right); bottom: Navya Autonom operated by Beep in Cary's Bond Park (left) and at UNC Charlotte (right)). (Images courtesy of NCDOT)

The automated shuttles tested under the CASSI program do not conform to Federal Motor Vehicle Safety Standards (FMVSS). Their design assumes high to full driving automation with minimal to no intervention by a human driver, so these vehicles often do not feature a driver's cockpit. The Automated Driving System (ADS) hardware and software are integrated into the vehicles' systems from design through production. These vehicles require an exemption from FMVSS and permission from the National Highway Traffic Safety Administration (NHTSA) to operate for research and demonstration purposes on a specific, pre-determined route according to approved operating conditions including a maximum speed of 12 mph.

These vehicles require an onboard human attendant (also called a "safety operator" or "safety driver") as a safety fallback and to provide customer service, including assisting riders using mobility devices. An onboard human attendant is needed since the vehicles operate at "conditional driving automation," where the shuttle's ADS or computer driver can drive the vehicle under limited conditions and the onboard attendant must take over driving using an industrial controller when the system requests.[2] The onboard attendant is responsible for monitoring the automated shuttle's operation and must be ready to take over control when required.

[2] SAE International. (2021, May 3). SAE Levels of Driving Automation Refined for Clarity and International Audience. https://www.sae.org/blog/sae-j3016-update



Attendant onboard the Navya Autonom operated by Beep in Cary's Bond Park (left); industrial controller used by the attendant onboard the Navya Autonom operated by Beep in Cary's Bond Park and at UNC Charlotte (right). (Images courtesy of NCDOT)

Overall findings from NCDOT's automated shuttle projects indicate:

Technology Readiness

- The automated shuttle technology is not mature and is not ready to be mainstreamed or scaled—the technology is still under development and full driving automation under all conditions is not here yet.
- The automated shuttles are not designed to be fully autonomous and require an onboard attendant to ensure correct and safe movement of the vehicles and interaction with the environment.

Operational Performance and Accessibility

- While the automated shuttles have advertised maximum speeds ranging from 15 to 25 mph, their practical operating speed is 12 mph since the shuttles are programmed to stop suddenly when they detect a safety risk such as an obstacle that is too close or in its path.
- The automated shuttles are unable to autonomously navigate around obstacles in its path—the attendant must manually operate the shuttle until the path is clear and conditions are appropriate to proceed in autonomous mode.
- The automated shuttles' slow speed, delay from when the attendant needed to troubleshoot problems or manually operate the shuttles, and route constraints that sometimes resulted in a less direct path between destinations contributed to the lower performance of the shuttles compared to conventional transit options.
- Based on the automated shuttles' slow speed and conservative driving approach, operating the shuttles in a dedicated lane may have reduced disengagements from conflicts with other roadway users and increased operational performance compared to mixed traffic conditions.
- Service interruptions occurred often and commonly resulted from technology issues, battery insufficiency, and inclement weather.

- The automated shuttles are not universally designed, and some do not include automated accessibility features like an automatic wheelchair ramp, securement system, or audible stop announcements and instructions.

Access to Existing Mobility Options

- Ridership was generally higher at locations with no existing transit or shared mobility options.
- Existing transit and shared mobility options were available along the same route as the automated shuttle for one project—UNC Charlotte—and the project's findings suggest that there was no time or connectivity benefit to using the automated shuttle over other options on campus.
- Where existing transit and shared mobility options were not available along the same route as the automated shuttle—Wright Brothers National Memorial and Cary's Bond Park—new trips appeared to result from the introduction of the shuttle and some personal vehicle trips were replaced by the shuttle during the pilot periods.

Public Engagement

- Making sure the public is involved in the decision-making process about automated vehicles in their communities is important to success.
- Engaging the public and including their feedback in evaluations is important to inform the future development of emerging technologies to better meet transportation needs.

Several organizations across the United States have tested automated shuttles and published their findings. To date, the shuttles have been tested in time-limited research and demonstration programs but not implemented in sustained transit services.

NCDOT has incrementally increased the complexity of its projects under the CASSI program since its start in 2020 to build on successes and lessons learned. CASSI will continue to explore the latest technological advancements to determine their near- and long-term benefits for public transportation. Future investigations are expected to include connectivity and automation in conventional vehicles, including full-size buses and vans, with a focus on meeting the needs of transportation disadvantaged and rural populations.

NCDOT is committed to advancing emerging technologies for the benefit of the public through infrastructure investments, pilots and demonstrations, and defined pathways to scale successes with its partners. NCDOT recognizes the promise of connected and automated vehicles to make our roadways safer, produce economic and social benefits, and improve efficiency, convenience, and mobility. Connected and automated vehicles are still under development. Through programs like the IMD-led CASSI, NCDOT carefully and systematically evaluates new and developing solutions to see how well they work now and how they can better serve the public in the future.

Introduction

This report summarizes the history of the North Carolina Department of Transportation (NCDOT)'s Connected Autonomous Shuttle Supporting Innovation (CASSI) program. The Integrated Mobility Division (IMD) leads the CASSI program with support from teams across the department. This report provides background on the motivations for establishing the program, summarizes the program development process, details the automated shuttle projects that were completed under the program, and shares the program's vision and next steps to advance activities related to testing and evaluation, public engagement and education, and ensuring the state's readiness for automated vehicle technology.

Background

NCDOT envisions a transportation system in the state where shared mobility options are convenient, reliable, affordable, clean, safe, and accessible to all. A core part of NCDOT's mission is to prepare North Carolina for the future of transportation by researching, piloting, and evaluating emerging mobility options that help eliminate transportation barriers, ensure equal access to opportunities for all, and make the state a trailblazer in transportation. NCDOT is exploring how the use of automated vehicles can help achieve its vision through the IMD-led Connected Autonomous Shuttle Supporting Innovation (CASSI) program.[3] The CASSI program demonstrates what automated vehicle technology can do in safe, real-world settings and evaluates how automated vehicles can best be used by riders with different needs and in different environments.

The CASSI program has historically partnered with communities across the state to test and evaluate automated vehicles in pilots that provide free shared rides to the public.[4] Pilots have been focused on the usefulness of automated vehicle technology in transit applications, including as a first and last mile solution and by demonstrating connected vehicle features (e.g., Vehicle-to-Infrastructure (V2I) communications). The pilots that were completed under the CASSI program from 2020 through 2023 have demonstrated all-electric, low-speed automated shuttles that are not Buy America or Americans with Disabilities Act (ADA) compliant, need an exemption from Federal Motor Vehicle Safety Standards (FMVSS) to operate on public roads and accept passengers, and require an onboard attendant. Through partnerships and feedback from surveys and engagement events, the CASSI program has developed analyses and findings that help guide how current generation automated shuttle technology can best be used now and further developed to meet the needs of all riders.

[3] NCDOT. (n.d.). CASSI. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Pages/default.aspx
[4] NCDOT. (n.d.). Completed Projects. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Pages/completed-projects.aspx

Program Development Process

Why was the program created?

NCDOT created the CASSI program in 2019 as a new initiative arising from the creation of the Integrated Mobility Division (IMD) that merged its Bicycle and Pedestrian Division and Public Transportation Division. Through the CASSI program, NCDOT and IMD established a process to assess emerging technologies and innovations to serve and benefit the public. NCDOT's vision as advanced through IMD is for everyone to have equal access to opportunities and services through transportation systems that make traveling across shared modes and to any destination as easy and convenient as driving. To achieve this vision, the agency seeks to maximize the benefits of current mobility options while layering in emerging technologies and innovations as they are tested and proven to be useful.

NCDOT identified transit as an area best suited for early adoption of automated vehicle technology and established the CASSI program as a means to advance activities related to testing and evaluation, public engagement and education, and ensuring the state's readiness for automated vehicle technology. The CASSI program is led by IMD with support from teams across the department.

What are the goals of the program?

The primary goals of the CASSI program are to:

- Research, test, and evaluate automated vehicles (AVs) for reliable and safe use in public transportation in partnership with communities, university partners, technology vendors, and consultant support;
- Advance the testing of connected vehicle features in AV projects;
- Identify future infrastructure needs for AVs;
- Support public engagement and education around the current capabilities and limitations of AV technology;
- Enable the public to experience and share their feedback on AV technology;
- Ensure AVs are accessible to and meet the needs of people with disabilities and transportation disadvantaged populations;
- Evaluate the performance of AVs as compared to conventional vehicles for use in public transportation;
- Document and share best practices and lessons learned for AV planning and deployment; and
- Ensure the state's readiness as AV technology matures.

What were the funding and partnership pathways for the first projects?

NCDOT investigated various funding and partnership pathways for the first set of automated vehicle pilots in North Carolina as summarized in the following sections.

Local Motors Olli Fleet Challenge

As an initial pathway to launch its first automated shuttle pilot, NCDOT identified potential partnering communities and use cases towards a partnership with Local Motors to test its Olli automated shuttles in North Carolina. Local Motors launched its first Olli Fleet Challenge in September 2018. The challenge was open to submissions from the Phoenix, Arizona and Sacramento, California areas.[5] The company launched additional challenges within the Greater Washington, D.C. area in December 2018[6] and in the Pacific Northwest in July 2019.[7] The Olli Fleet Challenges had a formal advertisement and application process. Local Motors used the challenges to identify locations and support for successful deployment of its shuttles. Winning locations received at least two Olli automated shuttles to use for up to three months. Separate from the challenges, Local Motors had a webpage for its "Bring Olli to Your Area" initiative where potential partners could submit their interest to be the next challenge area. Local Motors also coordinated with potential partners informally.

NCDOT received an informal commitment from Local Motors for two Olli automated shuttles. NCDOT reached out to Metropolitan Planning Organizations (MPOs), Rural Planning Organizations (RPOs), transit systems, municipalities, and other potential partners to identify locations and use cases towards a partnership with Local Motors to pilot the shuttles. NCDOT prioritized outreach to transit systems and services in the state since the agency recognized transit as an area well-suited for early adoption of automated vehicle technology. NCDOT received 11 Requests of Interest (ROI) from across the state. NCDOT reviewed the applications and narrowed the list to eight locations, including rural and urban university campuses, a coastal town and its tourist area, and an urban downtown, as summarized in Figure 1.

[5] Local Motors. (2018, September 27). LM Industries Announces Launch of Olli Fleet Challenge. https://web.archive.org/web/20190417143512/https://localmotors.com/press-release/lm-industries-announces-launch-of-olli-fleet-challenge/

[6] PR Newswire. (2018, December 12). Local Motors Opens Autonomous Fleet Challenge For Greater Washington, D.C. https://www.prnewswire.com/news-releases/local-motors-opens-autonomous-vehicle-fleet-challenge-for-greater-washington-dc-300763996.html

[7] PR Newswire. (2019, July 1). Local Motors Brings Autonomous Vehicle Fleet Challenge To The Pacific Northwest. https://www.prnewswire.com/news-releases/local-motors-brings-autonomous-vehicle-fleet-challenge-to-the-pacific-northwest-300878186.html

Potential Partner	Description of Proposed Route
University of North Carolina at Wilmington (UNC Wilmington)	Four-mile route that loops through main campus and connects student housing, academic buildings, athletic fields, and parking areas.
Wilmington Urban Area Metropolitan Planning Organization (WMPO)/Town of Carolina Beach	Six-mile route that connects the central business district, Carolina Beach Boardwalk, Snow's Cut Crossing Shopping Center, Carolina Beach State Park, Mike Chappell Park, Carolina Beach Fishing Pier, and multiple public beach accesses.
City of Greenville/East Carolina University (ECU)/Uptown Greenville	Five-mile route that connects ECU's main campus, medical campus, and uptown area.
City of Fayetteville/Fayetteville Area System of Transit (FAST)/The Cool Springs Downtown District	1.2-mile route that connects the city's main street and key downtown destinations, including the ballpark, City Hall, Visitor's Bureau, and County Office Complex.
North Carolina State University (NCSU)	One-mile route on the university's Centennial Campus that connects office and academic buildings, student housing, the Alumni Center, and James B. Hunt Jr. Library.
North Carolina Central University (NCCU)/City of Durham Transportation Department	1.4-mile route that loops through main campus and connects student housing, academic buildings, athletic fields, and parking areas.
Village of Misenheimer/Pfeiffer University (PFU)	Three-mile route that connects main campus to the village activity center with restaurants, grocery stores, medical services, a post office, Town Hall, and retail.
Southwestern Commission/Western Carolina University (WCU)/Jackson County Transit	Six-mile route that connects commuter parking lots, the Health and Human Sciences Building, and on-campus housing.

Figure 1. Potential partners and proposed routes used for grant applications. (Image courtesy of NCDOT)

NCDOT used the shortlist of locations and use cases in multiple grant applications towards securing funding to pilot the Olli automated shuttles. These applications are summarized in the following sections.

Automated Driving System (ADS) Demonstration Grants

In December 2018, the United States Department of Transportation (USDOT) released a Notice of Funding Opportunity (NOFO) for its Automated Driving System (ADS) Demonstration Grants.[8] USDOT sought to award $60 million in funding to test the safe integration of automated vehicles into America's transportation system. Applications were due in March 2019.[9] NCDOT proposed to deploy the two Olli automated shuttles

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[8] Eno Center for Transportation. (2018, December 22). USDOT Makes $60 Million Available for Automated Driving System Demonstration Projects. https://enotrans.org/article/usdot-makes-60-million-available-for-automated-driving-system-demonstration-projects/

[9] United States Department of Transportation. (2018, December 21). Automated Driving System (ADS) Demonstration Grants. https://www.highergov.com/grant-opportunity/automated-driving-system-ads-demonstration-grants-310839/

committed by Local Motors across six use cases and three locations.[10] In September 2019, USDOT announced eight award recipients in seven states out of 73 total applications to the grant program.[11] USDOT did not select North Carolina for an award.

Transit Bus Automation Strategic Partnerships

In January 2019, the University of South Florida (USF)'s Center for Urban Transportation Research (CUTR) announced the Transit Bus Automation Strategic Partnerships solicitation on behalf of the Federal Transit Administration (FTA).[12] The solicitation called for organizations to apply to become an FTA strategic partner. FTA expected to support strategic partners' ongoing transit bus automation research and help disseminate research findings to the broader transit community. NCDOT responded to the solicitation but was not selected.

Integrated Mobility Innovation (IMI) Demonstration Program

In May 2019, FTA announced a competitive funding opportunity through its Integrated Mobility Innovation (IMI) Demonstration Program.[13] The NOFO enabled applicants to apply for multiple areas of mobility research administered by FTA, including Mobility on Demand (MOD) Sandbox demonstrations, Strategic Transit Automation Research (STAR), and Mobility Payment Integration (MPI). NCDOT submitted a proposal towards demonstrations of the two Olli automated shuttles committed by Local Motors and in alignment with FTA's STAR Plan but was not awarded.

Informational Meetings and Visits

In 2019, in parallel with developing and submitting its grant applications, NCDOT completed informational meetings with agencies with active or completed automated shuttle projects to better understand regulatory processes, available technology, appropriate use cases and operating conditions, project outcomes, lessons learned, and best practices. Figure 2 summarizes the agencies that shared their experiences with NCDOT.

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[10] United States Department of Transportation. (2019, September 18). 33 - North Carolina Department of Transportation. https://www.transportation.gov/policy-initiatives/automated-vehicles/33-north-carolina-department-transportation

[11] United States Department of Transportation. (2019, September 18). U.S. Secretary of Transportation Announces Automated Driving System Demonstration Grant Winners. https://www.transportation.gov/briefing-room/us-secretary-transportation-announces-automated-driving-system-demonstration-grant

[12] Federal Transit Administration. (2020, April 30). FTA Annual Report on Public Transportation Innovation Research Projects for FY 2019 (Report 0159). https://www.transit.dot.gov/research-innovation/fta-annual-report-public-transportation-innovation-research-projects-fy-2019

[13] Federal Transit Administration. (2019, May 8). Competitive Funding Opportunity: Integrated Mobility Innovation (IMI) Demonstration Program. https://www.transit.dot.gov/regulations/federal-register-documents/2019-09269

State	Project Lead	Route Location	Automated Shuttle Make and Model
Maryland	Maryland Department of Transportation (MDOT)	National Harbor[14]	Local Motors Olli
Rhode Island	Rhode Island Department of Transportation (RIDOT)	Providence[15]	May Mobility Polaris GEM e6
Utah	Utah Department of Transportation (UDOT); Utah Transit Authority (UTA)	West Valley; Park City[16]	EasyMile EZ10
Virginia	U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL)*	Joint Base Myer-Henderson Hall, Arlington[17]	Local Motors Olli
Virginia	Virginia Tech Transportation Institute (VTTI)	Virginia Tech University[18]	EasyMile EZ10

*Local Motors' second Olli Fleet Challenge winner.

Figure 2. States with active automated shuttle projects in 2019 that shared information with NCDOT. (Image courtesy of NCDOT)

NCDOT attended the Maryland Department of Transportation (MDOT)'s Connected and Automated Vehicle (CAV) Working Group meeting in April 2019 that included a visit to the Local Motors Global Sales and Demonstration Facility in National Harbor and a demonstration ride on an Olli automated shuttle.

NCDOT also investigated active and completed automated shuttle projects using the National Highway Traffic Safety Administration (NHTSA)'s Automated Vehicle Test Tracking Tool provided through its Automated Vehicle Transparency and Engagement for Safe

[14] Pascale, Jordan. (2019, February 13). Toaster-Shaped Autonomous Shuttle Is First To Test On Public Roads In Maryland. https://wamu.org/story/19/02/13/toaster-shaped-autonomous-shuttle-is-first-to-test-on-public-roads-in-maryland/

[15] Marini, Megan, et al. (2022, April). A Rhode Trip: Lessons for the Future of Mobility from the Little Roady Autonomous Microtransit Pilot. https://rosap.ntl.bts.gov/view/dot/64116

[16] Utah Department of Transportation. (2021, April). Utah Autonomous Shuttle Pilot Final Report. https://transportationtechnology.utah.gov/wp-content/uploads/2023/01/UtahAutomatedShuttle_FinalReport-2021-S-1.pdf

[17] Allen, James P., et al. (2020, September). Autonomous Vehicle Pilot at Joint Base Myer-Henderson Hall: Project Report Summary and Recommendations. http://dx.doi.org/10.21079/11681/38088

[18] Grove, Kevin, et al. (2022, December). Automated Last Mile Connectivity for Vulnerable Road Users – Real-World Low Speed Autonomous Vehicle Deployment Final Report. https://www.ncat.edu/cobe/transportation-institute/_files/catm-lastmiledeploymentfinalreport-pt2ada.pdf

Testing (AV TEST) initiative.[19] States can upload information about their automated vehicle deployments to enable users to map and analyze projects across the country.

NCDOT summarized its research into national, state, and local automated vehicle projects, legislation, and other activities into an executive summary that was used as a reference for internal discussions and to initiate conversations with external stakeholders.

Partnership with EasyMile

While NCDOT initially pursued using Local Motors Olli shuttles, regulatory challenges prevented NCDOT from continuing its partnership. By late 2019, when NCDOT desired to launch its first automated shuttle pilot, Local Motors had not yet manufactured the shuttles committed to North Carolina and had limited experience operating its shuttles on public roadways in the United States. NCDOT ultimately decided to partner with EasyMile Inc. (EasyMile) for the first projects under the CASSI program since the company had successfully navigated NHTSA's regulatory requirements to operate automated shuttles on public roadways in the United States.

NCDOT visited one of EasyMile's active projects at the National Renewable Energy Laboratory (NREL)'s campus in Denver, CO[20] in September 2019 to ride its automated shuttles and to learn the process for planning and delivering an automated shuttle pilot. The visit also enabled representatives from the North Carolina Division of Motor Vehicles (NC DMV) to evaluate the shuttles for compliance with North Carolina's state statutory requirements for motor vehicles. Prior to the visit, NCDOT surveyed representatives from NCDOT and NC DMV to determine additional areas of interest to explore while onsite and in conversation with the project team.

Topics of interest included:

- How to gain the support of and communicate with the public;
- Realistic timeline to plan and launch an automated shuttle project, including a reasonable estimate of the time needed for regulatory approval from NHTSA;
- Cost and effort required for site modifications to enable the shuttle to operate;
- Practicality of the shuttle's speed limitation;
- Weather limitations relative to the shuttle's sensors and technology;
- Realistic headway between route loops;
- How to plan for safety operator breaks relative to service hours;
- Impact of hot weather and the shuttle's air conditioning on the shuttle's battery life;

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[19] National Highway Traffic Safety Administration. (2024, July 22). AV TEST Initiative Test Tracking Tool. https://www.nhtsa.gov/automated-vehicle-test-tracking-tool

[20] National Renewable Energy Laboratory. (2019, September 10). Automated Electric Shuttle Makes its Debut on NREL Campus. https://www.nrel.gov/news/program/2019/automated-electric-shuttle-makes-its-debut-on-nrel-campus.html

- Appropriate operating conditions as permitted by NHTSA;
- Change in ridership and level of interest across a deployment period; and
- Data access.

NCDOT opted to use state funds in a 50/50 cost share model with partnering communities to launch its automated shuttle pilot program using EasyMile's EZ10 third generation (Gen 3) shuttle. The cost share covered the lease and operating expenses related to the commissioning of the shuttle, attendant training, and public operations associated with each pilot. Each partnering community was responsible for costs associated with on-site work such as storage, electrical charging, and route preparations like trimming vegetation along the roadside or installing temporary ramps at stops with insufficient curb to deploy the shuttle's wheelchair ramp.

The CASSI name was finalized in December 2019 ahead of the program's first demonstration that took place over two days in January 2020 during the N.C. Transportation Summit. The first pilot opened to the public in February 2020 on N.C. State University's Centennial Campus.

How were projects selected?

NCDOT leveraged its list of potential partners and proposed routes that was compiled for its grant applications towards the selection of the location for its first automated shuttle pilot. From the potential partners and proposed routes summarized previously in Figure 2, N.C. State University was selected since it was willing to provide cost share funding, its route aligned with EasyMile's suggested route for the campus, and its use case aligned with using a single automated shuttle as offered through NCDOT's contract with EasyMile. For subsequent projects, NCDOT created and advertised a web-based form where potential partnering communities could submit ideas.

Completed Projects

What projects were completed?

The CASSI program has tested automated shuttles in multi-week projects at two university campuses, a recreational public lands site, and a municipal park in fixed-route, circulator services on short routes that offered first and last mile connections.[21] Two of the pilots also tested connected vehicle features and infrastructure. The automated shuttles operated in mixed traffic environments.

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[21] NCDOT. (n.d.). Completed Projects. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Pages/completed-projects.aspx

Multi-week automated shuttle projects were completed at:

- N.C. State University's Centennial Campus,
- Wright Brothers National Memorial in partnership with the National Park Service (NPS),
- Cary, NC (Cary)'s Fred G. Bond Metro Park (Bond Park), and the
- University of North Carolina at Charlotte (UNC Charlotte)'s main campus.

An automated shuttle was also demonstrated at the Raleigh Convention Center during the 2020 N.C. Transportation Summit for the initial launch of the CASSI program. Attendees were able to ride the shuttle on a short loop within the Raleigh Convention Center's grounds. NCDOT displayed an automated shuttle at the same convention center in an exhibition of emerging transportation technologies during the 2023 N.C. Transportation Summit and at the Colorado Convention Center during the 2023 AUVSI Xponential conference.

Figure 3 summarizes the basic details of the displays, demonstrations, and pilots. Figure 4 provides images of the automated shuttles that NCDOT piloted under the CASSI program from 2020 through 2023.

Project Type	Year	Dates Active	Location	Automated Shuttle Make and Model	Passenger Service Operator	Connected Vehicle Features	Final Report Available
Demonstration	2020	Jan. 8-9	Raleigh Convention Center	EasyMile EZ10 Gen 3	EasyMile	No	No
Pilot	2020	Feb. 7-25	N.C. State University's Centennial Campus	EasyMile EZ10 Gen 3	EasyMile; Free2Move	No	No
Pilot	2021	April 20-July 16	Wright Brothers National Memorial	EasyMile EZ10 Gen 3	EasyMile; Transdev	No	Yes
Display	2023	Jan. 18-19	Raleigh Convention Center	Navya Autonom	Beep	No	No
Pilot	2023	March 6-June 2	Cary's Bond Park	Navya Autonom	Beep	Yes	Yes
Display	2023	May 8-11	Colorado Convention Center	Navya Autonom	Beep	No	No
Pilot	2023	July 12-Dec. 21	UNC Charlotte's main campus	Navya Autonom	Beep	Yes	Yes

Figure 3. Projects completed under the CASSI program through calendar year 2023. (Image courtesy of NCDOT)

Figure 4. Automated shuttles tested under the CASSI program (top: EasyMile EZ10 Gen 3 operated by EasyMile at N.C. State University's Centennial Campus (left) and the Wright Brothers National Memorial (right); bottom: Navya Autonom operated by Beep in Cary's Bond Park (left) and at UNC Charlotte (right)). (Images courtesy of NCDOT and UNC Charlotte)

What automation approaches were tested?

The CASSI program has tested two models of all-electric, low-speed automated shuttles across five different projects to date—three in partnership with EasyMile using an EasyMile EZ10 Gen 3 shuttle and two in partnership with Beep, Inc. (Beep) using a Navya S.A. (Navya) Autonom shuttle.

Automated vehicles like the shuttles tested under the CASSI program are sometimes described as "purpose-built," "novel-design," or "bespoke" because the vehicles do not conform to Federal Motor Vehicle Safety Standards (FMVSS). Their design assumes high to full driving automation with minimal to no intervention by a human driver, so these vehicles often do not feature a driver's cockpit. The Automated Driving System (ADS) hardware and software are integrated into the vehicles' systems from design through production.

The current generation purpose-built automated vehicles piloted under the CASSI program in North Carolina require:

- An exemption from FMVSS,
- Permission from the National Highway Traffic Safety Administration (NHTSA) to operate on public roadways in the United States and accept passengers, and

- An onboard human attendant (also called a “safety operator” or “safety driver”) as a safety fallback and to provide customer service, including assisting riders using mobility devices.

Because the shuttles do not comply with FMVSS, they are temporarily imported into the United States under the Box 7 provision on NHTSA’s HS-7 declaration form.[22] In conformance with the Box 7 requirements, each automated shuttle operator submits a request to NHTSA for an exemption from FMVSS and permission to operate its shuttle for research and demonstration purposes on a specific, pre-determined route according to approved operating conditions including a maximum speed of 12 mph. The shuttles operate at “conditional driving automation,” where the shuttle’s ADS or computer driver can drive the vehicle under limited conditions and an onboard human attendant must take over driving using an industrial controller when the system requests.[23]

Technology

The automated shuttles tested under the CASSI program were programmed to operate on pre-determined, pre-mapped routes. Figure 5 describes the technologies that each model of automated shuttle used to navigate the roadway.

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[22] National Highway Traffic Safety Administration. (2022, September 30). Temporary Importation of a Motor Vehicle Under Box 7 on the HS-7 Form. https://www.nhtsa.gov/document/temporary-importation-motor-vehicle-under-box-7-hs-7-form

[23] SAE International. (2021, May 3). SAE Levels of Driving Automation Refined for Clarity and International Audience. https://www.sae.org/blog/sae-j3016-update

Technology	Description	EasyMile EZ10	Navya Autonom
Light Detection and Ranging (LiDAR) sensors	Remote sensing technology that uses lasers to measure distances and create precise, two-dimensional (2D) and three-dimensional (3D) maps of the shuttle's surroundings; collects real-time point cloud data to create a 3D map while the shuttle operates on its route that is compared to a stored 3D map; used for vehicle positioning and obstacle detection.	✓	✓
Global Navigation Satellite System (GNSS) antenna	Used as a Real-Time Kinematic (RTK) base station that provides additional known location information to improve the accuracy of the positioning information received by the GPS sensor on the shuttle to enable it to maintain its pre-mapped route to centimeter-level accuracy.	✗ Uses LiDAR and vertical reference panels for improved positioning.	✓ Uses GNSS antenna installed on site for improved positioning.
Global Positioning System (GPS) unit	Receiver with an antenna that uses a satellite-based radio navigation system to provide position, velocity, and timing information; used for vehicle positioning.	✓	✓
Inertial Measurement Unit (IMU)	An electronic device that measures acceleration, orientation, angular rates, and other gravitational forces; used for vehicle positioning.	✓	✓
Odometry	Measurement of the shuttle's velocity and change in position relative to a specific starting location using motion sensors in the shuttle's wheels called wheel encoders that count the number of times the wheel has rotated; used for vehicle positioning.	✓	✓
Cameras	Front, interior, and rear cameras; used for supervision purposes only (not for obstacle detection).	✓	✓
Radio Detection and Ranging (radar) sensors	Remote sensing technology that uses radio waves to measure distances and velocities of objects around the shuttle; transmits radio waves in the direction of interest that strike objects within range and return to the sensor; used for obstacle detection.	✓	✗
Vehicle-to-Everything (V2X) Onboard Unit (OBU)	An electronic device installed on the shuttle and integrated with its Automated Driving System (ADS) software; receives Signal Phasing and Timing (SPaT) messages transmitted from a traffic signal controller by a Roadside Unit (RSU); used to enable the shuttle to operate autonomously through signalized intersections.	✓ V2X capable but not tested in NC.	✓ V2X capable and tested in NC.

Figure 5. Technologies used by the two models of automated shuttles tested under the CASSI program. (Image courtesy of NCDOT)

Regulations

State Fully Autonomous Vehicle (FAV) Legislation

The definition of a fully autonomous vehicle (FAV) included in North Carolina's 2017 law that defines and regulates FAV does not apply to automated vehicles that operate at lower levels of driving automation. However, automated vehicles that operate at "conditional driving automation" requiring human driver fallback are subject to the provisions of North Carolina's 2017 legislation.[24]

NCDOT ultimately determined that NHTSA's regulatory requirements under the Box 7 provision and resulting exemption from FMVSS superseded the state's 2017 legislation for the automated shuttles that were tested under the CASSI program.[25]

State Statutory Requirements for Motor Vehicles

Because the automated shuttles were operated on public vehicular areas (PVA) as defined by state statute,[26] they were required to comply with state statutory requirements for motor vehicles as listed in Figure 6.[27] The Integrated Mobility Division (IMD) and the North Carolina Division of Motor Vehicles (NC DMV) worked closely together to identify and confirm the correct approach to inspect, title, and register the automated shuttles tested under the CASSI program prior to their operation on roadways in the state.

IMD and NC DMV determined that each automated shuttle would require a vehicle examination completed by an agent from NC DMV License and Theft that included Vehicle Identification Number (VIN) verification and a safety inspection completed by a certified mechanic to ensure that the shuttle's equipment met state statutory requirements. Since the shuttles did not have mirrors, each automated shuttle vendor installed two cameras (backup camera to substitute for the rearview mirror and side camera to substitute for the side driver mirror) and an interior video display to meet the statutory requirements.

As the vehicle owner, each automated shuttle vendor was the registrant and title holder for its respective shuttle. To title and register its shuttle in North Carolina, each vendor was required to provide standardized documentation to NC DMV as listed in Figure 7, including the safety inspection report and an approval document from NHTSA that grants

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[24] North Carolina General Assembly. (n.d.). North Carolina General Statutes, Chapter 20, Article 18 – Regulation of Fully Autonomous Vehicles. https://www.ncleg.gov/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_20/Article_18.pdf

[25] National Highway Traffic Safety Administration. (2022, September 30). Temporary Importation of a Motor Vehicle Under Box 7 on the HS-7 Form. https://www.nhtsa.gov/document/temporary-importation-motor-vehicle-under-box-7-hs-7-form

[26] North Carolina General Assembly. (n.d.). North Carolina General Statute § 20-4.01(32). https://www.ncleg.gov/EnactedLegislation/Statutes/PDF/BySection/Chapter_20/GS_20-4.01.pdf

[27] North Carolina General Assembly. (n.d.). North Carolina General Statutes, Chapter 20 – Motor Vehicles. https://www.ncleg.gov/Laws/GeneralStatuteSections/Chapter20

permission to each vendor to operate its shuttle on a specific route under certain defined conditions in a research and demonstration program involving interaction with members of the public. If the vendor was an out-of-state business, it was also required to register with the NC Secretary of State to certify that it can transact business in the state and provide the certification as a requirement for titling and registration. The NC DMV added the make of each automated shuttle tested in the state into its computer system to facilitate registration and titling.

- Tires – §20-122.1 (19A NCAC 03D .0538)
- Steering mechanism – §20-123.1 (19A NCAC 03D .0535)
- Speedometer – §20-123.2
- Brakes – §20-124 (19A NCAC 03D .0532)
- Horns and warning devices – §20-125 (19A NCAC 03D .0533)
- Directional signals – §20-125.1 (19A NCAC 03D .0537)
- Mirrors – §20-126 (19A NCAC 03D .0540)
- Windshield and windshield wiper – §20-127 (19A NCAC 03D .0536)
- Exhaust system and emissions control devices – §20-128 (19A NCAC 03D .0541)
- Required lighting equipment of vehicles – §20-129 (19A NCAC 03D .0533)
- Requirements as to headlamps and auxiliary driving lamps – §20-131
- Safety belts and anchorages – §20-135.2
- Vehicle Identification Number (VIN) – §49 CFR 565

Figure 6. North Carolina statutory requirements for motor vehicles. (Image courtesy of NCDOT)

- MVR-1 – Title Application
- Manufacturer's Certificate of Origin (MCO)
- Certificate of Liability Insurance with the covered VIN added
- MVR-180 – Odometer Disclosure Statement
- Bill of Sale with the covered VIN added
- Department of Homeland Security, U.S. Customs and Border Protection – Entry Summary
- NC Department of Secretary of State registration
- NHTSA approval document (permission letter) to operate the vehicle according to the research and demonstration program
- Safety inspection report

Figure 7. North Carolina titling and registration documentation requirements for the automated shuttles tested under the CASSI program. (Image courtesy of NCDOT)

For the initial projects completed under the CASSI program, the automated shuttle vendor as owner of the vehicle was required to pay fees associated with a certificate of title or registration. For projects completed in calendar year 2023, NCDOT applied the fee exemption under NC General Statute § 105-187.6 as enacted in Session Law 2022-68

(Senate Bill 201) (exemption from fees associated with a certificate of title or registration for vehicles to be used by a state agency in a research pilot or demonstration project).[28,29]

How were contracts and agreements established for the projects?

NCDOT began its partnership with EasyMile in December 2019 by contracting for the lease and operations of one EasyMile EZ10 Gen 3 shuttle for a two-year term with the intention of completing multiple projects over the timeframe. A demonstration at the Raleigh Convention Center for the 2020 N.C. Transportation Summit, a pilot at N.C. State University, and a second pilot that was ultimately completed at the Wright Brothers National Memorial were included in the initial contract. NCDOT chose to lease rather than buy the shuttle since the vehicle would be used to research and evaluate autonomous vehicle technology and not as an NCDOT vehicle fleet.

Under its initial contract with NCDOT, EasyMile partnered with PSA Group North America (PSA). PSA purchased an EZ10 Gen 3 shuttle from EasyMile and provided the vehicle to NCDOT through EasyMile's leasing agreement with NCDOT. PSA held a separate contract with a third-party vendor for training the safety operators that were required onboard the automated shuttle. Before the launch of the first project in North Carolina with EasyMile, PSA ended its partnership with the company and relinquished ownership of the shuttle back to EasyMile. At this time, the shuttle was registered in North Carolina to PSA, so the records were updated to reflect EasyMile's ownership. EasyMile maintained its relationship with the third-party vendor to complete the training with the safety operators.

When the pilot at the Wright Brothers National Memorial concluded, NCDOT amended its contract with EasyMile to extend the term and add two more projects. EasyMile at this time had moved the automated shuttle that was originally leased to NCDOT from North Carolina to Texas, so the company was required under the contract amendment to provide another EZ10 Gen 3 vehicle. NCDOT expected to complete its next pilot under the contract amendment in partnership with Cary, NC (Cary) in Fred G. Bond Metro Park (Bond Park). NCDOT and Cary ultimately cancelled the project with EasyMile due to technical issues with the vehicle and extensive project delays. NCDOT decided not to pursue additional projects with the vendor. NCDOT cancelled its contract with EasyMile effective October 1, 2022. NCDOT established a new contract with Beep in November 2022 to complete automated shuttle pilots in Bond Park and at the University of North Carolina at Charlotte (UNC Charlotte) using a Navya Autonom shuttle. Cary was able to apply the assets that they invested in for the EasyMile project (e.g., storage, charging equipment, signs, route and stops, and marketing materials) to the project with Beep.

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[28] North Carolina General Assembly. (n.d.). North Carolina General Statute § 105-187.6. https://www.ncleg.gov/EnactedLegislation/Statutes/PDF/BySection/Chapter_105/GS_105-187.6.pdf

[29] S. 201, 2021 Gen. Assem. (N.C. 2021). https://www.ncleg.gov/Sessions/2021/Bills/Senate/PDF/S201v6.pdf

NCDOT executed contracts with the vendors with respect to NC General Statute § 136-28.1(h).[30] NC General Statute § 136-28.1(h) allows NCDOT to enter into contracts for applied research and experimental work without soliciting bids or proposals. The use of the automated shuttles met the definition of applied research or experimental work. Any shuttle supplied by a vendor would be deployed to research and evaluate autonomous vehicle technology and not as an NCDOT vehicle fleet.

NCDOT executed a general agreement with each partnering community that documented the funding arrangement, responsibilities, and expectations for each demonstration or pilot. Each general agreement detailed the project timeline, key activities, dates, and responsible parties; the total cost for the lease and operating expenses; the expected cost share amount; joint and individual responsibilities of NCDOT and each partnering community; and additional provisions. NCDOT maintained an updated certificate of coverage through the NC Department of Insurance for each project. NCDOT and each partnering community were named as additional insured on all of the respective automated shuttle operator's insurance policies (except worker's compensation and professional liability).

What were the key activities to plan and deliver the projects?

NCDOT, community partners, automated shuttle operators, technology vendors, and consultant support collaborated to plan and deliver the pilots. Each project included a formal kickoff meeting to discuss and confirm roles and responsibilities for each contributing team and its members, establish a timeline with key activities towards opening the shuttle to the public, and review the shuttle operator's commissioning process for preparing the shuttle for operations on the route. NCDOT used standardized agenda and meeting summary templates that organized key activities by category, including administrative, operations, infrastructure, marketing and promotion, incident response plan and first responder workshop, data collection, commissioning by the shuttle operator, and start of service. Updates with action items by category were communicated through bi-weekly check in meetings between the contributing teams. Additional meetings were scheduled as needed to discuss specific topics, such as the traffic signals and other enabling technology, data collection, marketing and promotion, safety and security, and logistics for special events.

NCDOT, community partners, automated shuttle operators, technology vendors, and consultant support planned and delivered their automated shuttle pilots by completing the following key tasks:

[30] North Carolina General Assembly. (n.d.). North Carolina General Statute § 136-28.1(h). https://www.ncleg.gov/EnactedLegislation/Statutes/PDF/BySection/Chapter_136/GS_136-28.1.pdf

- **Site selection** including identifying stakeholders, establishing buy-in, confirming the cost share, establishing goals, verifying the use case, and confirming the location;
- **Route assessment** through computer-based tools and site visits;
- **Administrative** including contracts, agreements, regulatory applications, insurance, and shuttle delivery and transport between locations;
- **Operations** including confirming the operations period, hours of operation, and stops and creating a service interruption plan;
- **Infrastructure** including preparing the shuttle's storage location, installing charging equipment, ensuring Wi-Fi and cellular connectivity, installing signs along the route and at stops, and trimming vegetation along the route;
- **Marketing and promotion** including the shuttle's wrap design and a communications plan;
- **Incident response plan and first responder workshop** developed in collaboration with police, fire, and Emergency Medical Services (EMS);
- **Transit operator training** where routes are shared with existing transit services;
- **Commissioning** including installing and verifying enabling technology, route mapping and validation, and training the onboard attendant on the route;
- **Start of service** including ribbon cutting and special events, daily operations, and weekly check ins;
- **Data collection** including ridership, operations, and rider surveys; and
- **Evaluation** of the shuttle and service.

Detailed documentation of the planning and delivery of NCDOT's automated shuttle pilots are provided in each project's final report, where available, including responsible parties and timelines for each task. Final reports are available for the pilots completed at the Wright Brothers National Memorial,[31] in Cary's Bond Park,[32] and at UNC Charlotte.[33] NCDOT collaborated with the National Park Service (NPS) and the United States Department of Transportation (USDOT) Volpe Center on the report for the project completed at the Wright Brothers National Memorial.

NCDOT's automated shuttle pilot at N.C. State University's Centennial Campus was suspended after only three weeks of public operations and ultimately cancelled due to the COVID-19 pandemic and associated State of Emergency declarations. Limited data and reporting are available for the project. Available findings are summarized in Appendix A.

[31] Cregger, Joshua, et al. (2022, May). First in Flight, First in Automation: NCDOT and NPS Pilot an Automated Shuttle at the Wright Brothers National Memorial. (DOT-VNTSC-NPS-22-02). United States Department of Transportation. https://rosap.ntl.bts.gov/view/dot/62313
[32] NCDOT. (2023, October). CASSI in Cary's Bond Park – Final Report. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Documents/cassi-ncdot-cary-final-report.pdf
[33] NCDOT. (2024, July). CASSI at UNC Charlotte – Final Report. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Documents/cassi-ncdot-unc-charlotte-final-report.pdf

What data were collected during the projects?

NCDOT and its partners used several data sources to conduct evaluations for the pilots completed at the Wright Brothers National Memorial, in Cary's Bond Park, and at UNC Charlotte.

These data include:

- **Ridership and operations data** provided by each automated shuttle operator in weekly or monthly data reports (all projects)
  - Ridership as number of passengers, number of trips or loops operated, ramp deployments and wheelchair securements, scheduled hours and hours operated, uptime percentage (hours operated divided by scheduled hours), battery percentage, service suspensions, vehicle speed, and time in autonomous mode
  - Locations of the shuttle's disengagements from autonomous mode into manual mode and the reported cause for each event
- **Feedback from riders** captured through online surveys administered by NCDOT (all projects)
  - Travel patterns and trip purpose, experience with the shuttle and attendant, and basic demographics
- **Feedback from community members with disabilities and their caregivers, disability services professionals, and paratransit professionals** captured by NCDOT through engagement events and exit surveys (Cary's Bond Park and UNC Charlotte)
  - Typical trips, what works well in the shuttle, and how the shuttle could work better
- **Visitation numbers** collected by park staff (Wright Brothers National Memorial)
- **Observational data** collected by NCDOT and its partners when on site or riding the automated shuttle for service audits (all projects)

Detailed documentation on data collection, cleaning, and analysis are provided in each project's final report, where available, and in separate data documentation for the projects completed in Cary's Bond Park[34] and at UNC Charlotte.[35]

What were the findings of the projects?

Findings from NCDOT's automated shuttle pilots are summarized in Appendix A. Findings from the projects at the Wright Brothers National Memorial, in Cary's Bond Park, and at UNC Charlotte were sourced from their final reports. Lessons learned from NCDOT's automated shuttle pilots in the areas of technology; route design; infrastructure;

[34] NCDOT. (2023, October). CASSI in Cary's Bond Park – Data Documentation Report. https://data.townofcary.org/api/datasets/1.0/cassi-in-cary-s-bond-park-usage/attachments/cassi_ncdot_cary_open_data_portal_data_documentation_report_20240612_pdf/

[35] NCDOT. (2024, July). CASSI at UNC Charlotte – Data Documentation Report. https://data.townofcary.org/api/datasets/1.0/cassi-at-unc-charlotte-usage/attachments/cassi_ncdot_unc_charlotte_open_data_portal_documentation_20240712_pdf/

marketing, promotion, and engagement; operations; data; regulations; and accessibility are provided in Appendix A.

For the automation approach tested across the three projects—i.e., current generation purpose-built automated shuttles operated in fixed-route, circulator services on short routes that served as first and last mile connections—overall findings indicate:

Technology Readiness

- The automated shuttle technology is not mature and is not ready to be mainstreamed or scaled—the technology is still under development and full driving automation under all conditions is not here yet.
- The automated shuttles are not designed to be fully autonomous and require an onboard attendant to ensure correct and safe movement of the vehicles and interaction with the environment.

Operational Performance and Accessibility

- While the automated shuttles have advertised maximum speeds ranging from 15 to 25 mph, their practical operating speed is 12 mph since the shuttles are programmed to stop suddenly when they detect a safety risk such as an obstacle that is too close or in its path.
- The automated shuttles are unable to autonomously navigate around obstacles in its path—the attendant must manually operate the shuttle until the path is clear and conditions are appropriate to proceed in autonomous mode.
- The automated shuttles' slow speed, delay from when the attendant needed to troubleshoot problems or manually operate the shuttles, and route constraints that sometimes resulted in a less direct path between destinations contributed to the lower performance of the shuttles compared to conventional transit options.
- Based on the automated shuttles' slow speed and conservative driving approach, operating the shuttles in a dedicated lane may have reduced disengagements from conflicts with other roadway users and increased operational performance compared to mixed traffic conditions.
- Service interruptions occurred often and commonly resulted from technology issues, battery insufficiency, and inclement weather.
- The automated shuttles are not universally designed, and some do not include automated accessibility features like an automatic wheelchair ramp, securement system, or audible stop announcements and instructions.

Access to Existing Mobility Options

- Ridership was generally higher at locations with no existing transit or shared mobility options.
- Existing transit and shared mobility options were available along the same route as the automated shuttle for one project—UNC Charlotte—and the project's findings suggest

that there was no time or connectivity benefit to using the automated shuttle over other options on campus.
- Where existing transit and shared mobility options were not available along the same route as the automated shuttle—Wright Brothers National Memorial and Cary's Bond Park—new trips appeared to result from the introduction of the shuttle and some personal vehicle trips were replaced by the shuttle during the pilot periods.

Public Engagement

- Making sure the public is involved in the decision-making process about automated vehicles in their communities is important to success.
- Engaging the public and including their feedback in evaluations is important to inform the future development of emerging technologies to better meet transportation needs.

Several organizations across the United States have tested EasyMile EZ10 and Navya Autonom automated shuttles and published their findings. Appendix B provides a sample of these projects and their corresponding final reports and key findings.

What is next for the CASSI program?

NCDOT is committed to advancing emerging technologies for the benefit of the public through infrastructure investments, pilots and demonstrations, and defined pathways to scale successes with its partners. NCDOT has intentionally framed its projects under the IMD-led CASSI program as pilots—time-limited, small-scale investigations to test out emerging technologies and evaluate their capabilities, limitations, and how well they work compared to existing solutions. NCDOT has incrementally increased the complexity of its pilots under the CASSI program since its start in 2020 to build on successes and lessons learned. NCDOT openly shares results so others can learn from North Carolina's experiences. NCDOT includes the public in the evaluation process and gathers their feedback through surveys and engagement events to inform the evolution of the technology to better meet transportation needs.

NCDOT has sufficiently tested and evaluated current generation purpose-built automated shuttles through its pilots at N.C. State University, the Wright Brothers National Memorial, Cary's Bond Park, and UNC Charlotte. Led by IMD, NCDOT expects to shift the CASSI program's focus from current generation purpose-built automated vehicles to Automated Driving System (ADS)-equipped conventional vehicles, including full-size buses, cutaways, and passenger vans. NCDOT anticipates that these vehicles will integrate more effectively into existing transit services and better complement traditional public transportation options. Next generation purpose-built automated vehicles are expected to have improved accessibility features, operate safely at higher speeds, and serve a greater range of routes under expanded operating conditions. Certain models may be available by 2026, but their actual capabilities and limitations are not yet fully known.

NCDOT is exploring how ADS-equipped conventional vehicles can be tested and integrated into high quality, on-demand transit services that address transportation challenges, including through grant applications[36] to the USDOT Advanced Transportation Technology and Innovation (ATTAIN) program. NCDOT is also supporting N.C. A&T State University[37] to develop shared autonomous vehicles, an innovative rural test track, automated shuttle pilots between the university and downtown Greensboro, and a teleoperations platform for remote control of its automated shuttles.

NCDOT completed a Request for Information (RFI) on automated transit vehicles in summer 2024.[38] The RFI covered the full range of transit vehicle form factors, from pods to small shuttles and vans to full-size buses, as well as automated accessibility features, such as automated wheelchair ramps and securement systems. NCDOT anticipates using the findings from the RFI to inform its selection of new vehicles, locations, use cases, and vendors for future projects through CASSI and beyond.

NCDOT's RFI was a part of a larger effort to identify and explore new ground and air vehicle technologies under its ongoing Advance Mobility NC campaign. Advance Mobility NC is a collaboration between the Integrated Mobility Division, Division of Aviation and Uncrewed Aircraft Systems (UAS) Program, and Rail Division that seeks to identify and invest in new technologies to better connect people, goods, and places and meet public needs. An early outcome from this initiative is a three-year Advanced Transportation Mobility Strategic Plan that was adopted in April 2024.[39]

NCDOT recognizes the promise of connected and automated vehicles to make our roadways safer, produce economic and social benefits, and improve efficiency, convenience, and mobility. Connected and automated vehicles are still under development. Through programs like the IMD-led CASSI, NCDOT carefully and systematically evaluates new and developing solutions to see how well they work now and how they can better serve the public in the future.

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[36] NCDOT. (n.d.). Connected, Rural, Equitable, and Autonomous Transportation for Everyone (CREATE). https://connect.ncdot.gov/resources/ATTAIN2024-CREATE/Pages/default.aspx

[37] N.C. A&T State University. (n.d.). Aggie Autonomous Shuttles. https://www.aggieauto.com/

[38] NCDOT. (2024, January 26). NCDOT Seeks Information about New Vehicle Technologies. https://www.ncdot.gov/news/press-releases/Pages/2024/2024-01-26-ncdot-seeks-automated-vehicle-technology.aspx

[39] NCDOT. (2024, April). Advance Mobility NC Strategic Plan. https://www.ncdot.gov/divisions/aviation/advance-mobility/Pages/advanced-transportation-mobility-plan.aspx

Appendices

Appendix A. Findings and Lessons Learned from the CASSI Program's Automated Shuttle Pilots

Table 1. Findings from the automated shuttle pilots completed under the CASSI program.

Category	N.C. State University's Centennial Campus	Wright Brothers National Memorial	Fred G. Bond Metro Park	UNC Charlotte
Operator	EasyMile/Free2Move	EasyMile/Transdev	Beep	Beep
Vehicle Make and Model	EasyMile EZ10 Gen 3	EasyMile EZ10 Gen 3	Navya Autonom	Navya Autonom
Use Case	University campus with existing transit	Recreational public lands site with no transit	Municipal park with no transit	University campus with existing transit
	No traffic signals on route	No traffic signals on route	Signalized intersection	Signalized intersections
	First and last mile	First and last mile	First and last mile	First and last mile
	Fixed-route circulator	Fixed-route circulator	Fixed-route circulator	Fixed-route circulator
	Mixed traffic	Mixed traffic	Mixed traffic	Mixed traffic
Pilot Period	Feb. 7-25, 2020 (19 days)	April 20-July 16, 2021 (13 weeks)	March 6-June 2, 2023 (13 weeks)	July 12-Dec. 21, 2023 (23 weeks)
Number of Shuttles	One shuttle	One shuttle	One shuttle	One shuttle
Operating Days	Five days, Monday-Friday	Five days, Monday-Friday	Five days, Monday-Friday	Five days, Monday-Friday
Hours of Service	8:00 a.m.-4:00 p.m. (with two breaks)	10:00 a.m.-4:30 p.m. (with one break)	10:00 a.m.-4:00 p.m. (with one break)	8:30-11:30 a.m. and 1:30-4:30 p.m. (with one break from 11:30 a.m.-1:30 p.m.)
Planned Hours per Day	8 hours	6 hours	6 hours	6 hours (additional evening hours added in November and December)
Number of Unique Routes	One route	One route	One route	One route

Category	N.C. State University's Centennial Campus	Wright Brothers National Memorial	Fred G. Bond Metro Park	UNC Charlotte
Route Miles	0.8 miles	1.5 miles	1.6 miles	2.2 miles
Number of Stops	Three stops	Two stops	Four stops	Six stops
Number of Days in Operation	19	54	61	112
Number of Days with Complete Service	3	46	28	56
Number of Days with Partial Service	16	8	33	56
Number of Days with Complete Suspension of Service	Service indefinitely suspended due to COVID-19 pandemic	10	3	2
Number of Days with No Scheduled Service	N/A	N/A	1	3
Scheduled Hours of Operation	152.0	384.0	384.0	735.5
Actual Hours of Operation	79.0	279.0	331.3	625.4
Percentage Uptime	52.0%	72.7%	86.3%	85.0%
Number of Disengagements	Not available	620	179	267
Average Number of Disengagements per Day	Not available	11.5	2.9	2.4
Percentage Time in Autonomous Mode	Not available	87.0%	98.3%	91.0%
Average Vehicle Speed	Not available	5.2 mph	5.4 mph	6.2 mph
Maximum Vehicle Speed	Not available	9.5 mph	11.4 mph	12.6 mph
Number of Trips	Not available	809	494	825
Number of Passengers	Not available	3,380	1,718	565
Average Passengers per Trip	Not available	4.2	3.5	Less than 1
Average Passengers per Vehicle per Day	Not available	62.6	28.2	5.0
Average Trips per Vehicle per Day	Not available	15.0	8.1	7.4
Number of Ramp Deployments	Not available	193	7	0
Average Number of Ramp Deployments per Day	Not available	4	Less than 1	0
Project Planning and Delivery – Key Similarities	Shuttles were operated on public roadways for research and demonstration purposes through temporary importation into the United States under the Box 7 provision on NHTSA's HS-7 declaration form.			

Category	N.C. State University's Centennial Campus	Wright Brothers National Memorial	Fred G. Bond Metro Park	UNC Charlotte
Project Planning and Delivery – Key Similarities	Shuttles were operated on pre-determined, pre-mapped routes according to approved, appropriate operating conditions in conformance with NHTSA's Box 7 requirements.			
	Shuttles were operated under comparable approved, appropriate operating conditions including a maximum speed of 12 mph.			
	NCDOT, partnering communities, and vendors completed comparable key activities to plan and deliver the projects.			
	Many people across multiple departments and disciplines contributed their time, experience, and expertise to plan and deliver the projects.			
	Service interruptions occurred often, with some projects experiencing more issues than others.			
	Service interruptions frequently resulted from technology issues, battery insufficiency, and inclement weather.			
	Ridership, operations, and rider survey data were collected to evaluate the shuttle and service.			
	Lead time from the start of route discussions to start of operations was six months or more.			
Project Planning and Delivery – Key Differences	Adequate curbs at stops for wheelchair ramp deployment.	Used temporary modular ramp at one stop.	Used temporary modular ramps at three stops.	Adequate curbs at stops for wheelchair ramp deployment.
	Route was mapped using the shuttle and its onboard technology.		Route was mapped using a mobile scanning unit installed on a conventional vehicle.	
	Vertical reference panels were installed along the route to enable the shuttle's localization.		A GNSS antenna used as a RTK base station was installed on site to enable the shuttle's localization.	
Vehicle and Service Performance	Damage to the shuttle's storage location and service suspension due to inclement weather during the first week of service.	Service suspensions due to inclement weather.	Initial attempt to launch the pilot was not successful due to technical issues with the shuttle prompting a change of vendor.*	Service suspensions due to GNSS signal loss and troubleshooting leading to substantial loss of scheduled hours of service.
	Battery fuse and charging issues resulted in service hour reductions.	Service suspension to evaluate and mitigate safety concerns at a pedestrian crossing.	Service suspensions due to inclement weather.	Service suspensions due to inclement weather.

Category	N.C. State University's Centennial Campus	Wright Brothers National Memorial	Fred G. Bond Metro Park	UNC Charlotte
Vehicle and Service Performance	Continued service suspensions due to inclement weather.	Battery issues requiring a cable replacement from the shuttle's manufacturer in France causing week-long service suspension.	Service suspensions due to battery insufficiency.	Service suspensions due to battery insufficiency.
	One crash caused by a human-driven vehicle backing into the shuttle.	Shuttle's speed was slower where grass was tall along the route prompting increased mowing.	Midday charging was implemented midway through the pilot to mitigate battery insufficiency resulting from demand on the shuttle's air conditioning system on hot days.	Vegetation trimming along the route required at the beginning of the pilot period.
	NHTSA suspended service in February 2020 due to incident in Ohio.**	Inconsistent messaging and script delivered by the onboard attendants.	Vegetation trimming along the route was required due to the change from winter to spring during the pilot period.	Disengagements were commonly caused by other roadway users and lost connection or miscommunication at the signalized intersections.
	State of Emergency due to the COVID-19 pandemic declared in March 2020.***	COVID-19 pandemic safety precautions were in place.****	Disengagements were commonly caused by lost connection or miscommunication at the signalized intersection and signal loss.	Route modification required to avoid unprotected left turn that resulted in a deviation from the most direct path between stops.
Rider Experience	Survey results not available.	Survey results showed that most riders had a good experience with the shuttle.		

Category	N.C. State University's Centennial Campus	Wright Brothers National Memorial	Fred G. Bond Metro Park	UNC Charlotte
Rider Experience	Survey results not available.	Survey results showed the lowest level of agreement for the question that asked about wait time as whether the shuttle arrived at the respondent's stop within a reasonable amount of time.		
		Received feedback from walkers in the area about their interaction with the shuttle.	Received feedback from community members with disabilities and their caregivers, disability services professionals, and paratransit professionals about the accessibility of the shuttle and service.	

*NCDOT and Cary initially expected to partner with EasyMile to complete the automated shuttle pilot in Bond Park, but ultimately cancelled the project due to technical issues with the vehicle and extensive project delays; NCDOT established a new contract with Beep to complete the project in Bond Park.
**An incident in Columbus, Ohio resulted in the suspension of 16 EasyMile shuttles across 10 cities in the United States; NHTSA required EasyMile to implement safety mitigations before services could resume, including a requirement for all passengers to be seated and using seatbelts.[40,41,42]
***The project at N.C. State University's Centennial Campus was indefinitely suspended at the onset of the COVID-19 pandemic and ultimately cancelled due to North Carolina's State of Emergency declaration and its requirements.[43,44,45]
****NCDOT and NPS implemented COVID-19 pandemic safety precautions, including limiting the number of passengers to five from the same household plus the attendant or three from different households plus the attendant at one time.

[40] Reuters. (2020, February 25). U.S. agency slams brakes on self-driving EasyMile shuttles after passenger injury. https://www.reuters.com/article/us-autos-selfdriving/us-agency-slams-brakes-on-self-driving-easymile-shuttles-after-passenger-injury-idUSKBN20J2N6/
[41] EasyMile. (2020, February 26). Low speed emergency stop for safety triggers partial US suspension. http://web.archive.org/web/20200227113740/https://easymile.com/low-speed-stop-triggers-temporary-suspension/
[42] EasyMile. (2020, May 15). EasyMile given green light to resume passenger operations in US. http://web.archive.org/web/20200525095928/https://easymile.com/green-light-resumed-passenger-operations-us/
[43] N.C. State University. (2020, February 5). Driverless Shuttle a Smart Move for Centennial Campus. https://news.ncsu.edu/2020/02/driverless-shuttle-a-smart-move-for-centennial-campus/
[44] The News & Observer. (2020, February 7). You will be able to ride in a driverless shuttle at NC State University starting Friday. https://www.newsobserver.com/news/local/article240036238.html
[45] North Carolina Criminal Law: A UNC School of Government Blog. (2020, February 17). Meet CASSI: North Carolina's First Fully Autonomous Vehicle. https://nccriminallaw.sog.unc.edu/meet-cassi-north-carolinas-first-fully-autonomous-vehicle/

Table 2. Lessons learned from the automated shuttle pilots completed under the CASSI program.

Focus Area	Lessons Learned
Technology	Purpose-built automated shuttles are still under development. The technology is not mature and is not ready to be mainstreamed or scaled as a conventional transit service. Expectations need to be appropriately managed, and the capabilities and limitations of the technology need to be communicated up front when planning and delivering projects.
Technology	Current generation purpose-built automated shuttles require an exemption from FMVSS, permission from NHTSA to operate on public roadways in the United States and accept passengers, and an onboard human attendant as a safety fallback and to provide customer service, including assisting riders using mobility devices. To date in the United States, the shuttles have been tested in time-limited research and demonstration programs but not implemented in sustained transit services.
Technology	Current generation purpose-built automated shuttles are not fully autonomous. An onboard human attendant is necessary for the automated shuttle to operate.
Technology	While the automated shuttles have advertised maximum speeds ranging from 15 to 25 mph, their practical operating speed is 12 mph since the shuttles are programmed to stop suddenly when they detect a safety risk such as an obstacle that is too close or in its path. The automated shuttles are programmed to stop at all stop signs and permissive left turns. The onboard human attendant confirms that the roadway is clear then presses a button on a touchscreen inside the shuttle to authorize the shuttle to move forward on the route. The automated shuttles are also programmed to slow and stop at priority zones, such as crosswalks, when an obstacle is detected within the zone.
Technology	The automated shuttles that were tested at sites with no existing transit experienced higher ridership than those tested at sites with existing transit and shared mobility options. At UNC Charlotte, an urban university campus with a robust multimodal transportation system, no time or connectivity benefit was found when comparing the automated shuttle to other options on campus and a substantial number of service hours were lost due to issues with the shuttle's technology.
Technology	An automated shuttle's sensors can be disrupted by conditions such as light rain, vegetation growing alongside the roadway, parked vehicles in or encroaching on the travel lane, standing water, and small insects causing slowdowns, sudden hard stops, and disengagements from autonomous mode into manual mode.
Technology	Vertical reference panels may need to be installed along the route to support an automated shuttle's LiDAR-based localization if poles, walls, buildings, or other fixed elements are limited or absent. A GNSS antenna used as a RTK base station may also be needed to support an automated shuttle's localization by enabling the shuttle to maintain its pre-mapped route to a high degree of accuracy.
Technology	Common challenges with the technology were signal loss, connection loss or miscommunication at the signalized intersections, and software updates or malfunctions requiring hard system resets. Considerable time may be needed to troubleshoot and resolve issues when the technology fails, resulting in operational inconsistency including service suspensions and reduced service hours.
Route Design	Route design influences how much time an automated shuttle is in autonomous mode compared to manual mode and is guided by the capabilities and limitations of the technology. Routes should be kept stable and unchanging to the extent possible since an automated shuttle's localization is dependent on validating real-time data against a historic high-definition map of the route and environment. Vertical reference panels or a GNSS antenna installed on site may be needed to support localization.

Focus Area	Lessons Learned
Route Design	Routes must be mapped in advance using a mobile scanning unit or the automated shuttle and its onboard technology. If the route or its environment changes significantly after initial mapping, remapping is required. Changes may include construction on the original route or using different roadways on a new route.
Route Design	Cellular coverage along the route is required. Tall buildings or dense foliage may disrupt an automated shuttle's GPS connectivity causing service interruptions.
Route Design	Vegetation should be routinely trimmed and maintained along the route, so branches and leaves are not detected as obstacles. The roadway should be kept clear of debris that may be detected as obstacles.
Route Design	The slope of the roadway may need to be assessed to determine impacts to the automated shuttle's performance including its battery sufficiency. Routes with low traffic density, without railroad crossings, without construction or work zones, and that require minimum switching or merging lanes with other traffic are preferred. Paved roadway surfaces are required.
Route Design	Unprotected left turns are typically avoided since the attendant would need to intervene to safely navigate the turn by visually confirming that the roadway is clear then authorizing the automated shuttle to proceed with the turn by touching a button on a touchscreen inside the shuttle. An automated shuttle may operate on a less efficient route or diversion to avoid unprotected left turns.
Route Design	Any changes to the route or operations are reviewed and confirmed by NHTSA prior to implementation. Changes could include running the automated shuttle in the opposite direction on the route, on an abbreviated version of the route, or at different times than those originally permitted by NHTSA. Changes require at least a seven-day lead time with notice by the automated shuttle operator to NHTSA and are expected to conform to the shuttle's appropriate operating conditions.
Infrastructure	A secure, climate-controlled building that is large enough to hold the automated shuttle is required along with appropriate charging equipment.
Infrastructure	The automated shuttles can only be operated by trained attendants on pre-determined, pre-mapped routes approved by NHTSA. An automated shuttle is moved between project locations on a human-driven flatbed truck with care given to the delicate sensors and technology.
Infrastructure	While the automated shuttles have wheelchair ramps, either automated or manual, adequate curbs are required at the stops to ensure safe use. Temporary modular ramps were used at stops without adequate curb to ensure access for riders using mobility devices.
Infrastructure	Vegetation along the route can be detected by the automated shuttle's sensors as an obstacle so should be trimmed and maintained routinely. The roadway should be kept clear of debris that may be detected as obstacles.
Marketing, Promotion, and Engagement	Marketing, promotion, and engagement activities, like webpages, social media campaigns, and meeting facilitation with media and visitors, are essential to ensure that the community can experience the automated shuttle and service firsthand, provide their feedback, and build awareness of the current capabilities of the technology and its promise as it continues to mature.
Marketing, Promotion, and Engagement	Engagement events with community members with disabilities and their caregivers, disability services professionals, and paratransit professionals are important to gather feedback about the accessibility of the automated shuttle and service, including what works well and what could work better.
Marketing, Promotion, and Engagement	First responder workshops with local fire, police, and EMS professionals are important to provide hands-on training on the automated shuttle, including how to tow and lift the vehicle, disable its power supplies, and access and extract its occupants.

Focus Area	Lessons Learned
Marketing, Promotion, and Engagement	Training with transit operators is important where the automated shuttle shares its route with existing transit options to set expectations for how the shuttle will coexist with other transit fleets during the pilot period.
Operations	Clear and consistent communication, honesty, and collaborative problem solving are essential to the successful planning and delivery of each project.
Operations	The pilots are interdepartmental and interdisciplinary efforts that rely on the time, experience, and expertise of many people across multiple domains.
Operations	Service suspensions and interruptions are expected since the technology is being tested and evaluated while providing passenger service to the public. Service interruption plans and protocols are necessary to ensure that riders are promptly informed when the automated shuttle is out of service.
Operations	Service interruptions due to inclement weather or issues with the automated shuttle's technology were frequent and disruptive enough to result in loss of scheduled service hours. Aligning the automated shuttle's route with an existing route during the pilot period can ensure that riders are able to reach their destinations using other options if the shuttle goes out of service.
Operations	Real-time tracking of the automated shuttle is recommended so riders can anticipate arrival and departure times and effectively plan their travel. Service reliability may be impacted by inconsistent times at stops and delays due to intervention by the attendant during disengagements or to address other issues.
Operations	An onboard human attendant is needed as a safety fallback. The attendant also provides essential customer service, including explaining how the technology works, answering riders' questions, ensuring riders' safety, and assisting riders using mobility devices. Expectations should be set early and reinforced around the attendant's responsibilities to provide consistent information to riders, monitoring and addressing issues with the automated shuttle and service, and documenting incidents. Project partners can develop a script for the attendant to ensure reliable messaging.
Data	Since the technology is still under development and being tested for research and demonstration purposes, key performance indicators or measures of success should be sensitive to limitations in comparison to conventional options.
Data	Automated data collection by the automated shuttle operator of ridership, operations, disengagement, and enabling technology-related data is preferred to manual approaches to ensure timeliness, accuracy, completeness, and consistency.
Regulations	Automated shuttles that are not FMVSS-compliant can be operated on public roadways for research and demonstration purposes through temporary importation into the United States under the Box 7 provision on NHTSA's HS-7 declaration form. The shuttles are operated on pre-determined, pre-mapped routes according to approved, appropriate operating conditions in conformance with NHTSA's Box 7 requirements.
Regulations	Automated shuttles must be inspected, titled, and registered in North Carolina to operate on roadways in the state.
Accessibility	Current generation purpose-built automated shuttles are not universally designed and do not include the full set of accessibility-related features needed to serve people with disabilities, including features to support people with cognitive and sensory disabilities. Universal design of automated vehicles will be important as the vehicles are tested and ultimately adopted across transit service types including on-demand and demand response applications. Attention should be paid to determining practices for accessibility for when automated vehicles become fully autonomous.

Appendix B. Findings and Lessons Learned from Other Automated Shuttle Pilots Completed in the United States from 2018-2023

Table 3. Summary of other automated shuttle pilots completed in the United States from 2018-2023.

State	Project Year	Project Lead	Route Location	Operator	Vehicle Make and Model	Project Identifier
California	2023	Treasure Island Mobility Management Agency	Treasure Island on public roadways	Beep	Navya Autonom	CA: Treasure Island (2023)[46,47,48]
Florida	2023	Lynx	Orlando on public roadways	Beep	Navya Autonom	FL: Orlando (2023)[49]
Michigan	2018, 2019	Mcity	University of Michigan (U-M) on public roadways	U-M employees	Navya Autonom	MI: University of Michigan (U-M) (2018, 2019)[50,51,52,53]

[46] Treasure Island Mobility Management Agency. (2024, June). The Loop Final Evaluation Report. https://www.sfcta.org/sites/default/files/2024-06/Loop_Final_Evaluation_Report_2024-06-25_0.pdf

[47] San Francisco County Transportation Authority. (n.d.). Treasure Island Autonomous Shuttle Pilot. https://www.sfcta.org/projects/treasure-island-autonomous-shuttle-pilot

[48] San Francisco County Transportation Authority. (2024, June 28). Treasure Island Mobility Management Agency Approves AV Shuttle Pilot Final Report. https://www.sfcta.org/blogs/treasure-island-mobility-management-agency-approves-av-shuttle-pilot-final-report

[49] Jamison, Doug. (2024, August 23). VI. C. Lynx Autonomous Shuttle Deployment. MetroPlan Orlando – TAC Meeting. https://www.youtube.com/watch?v=q5DXOPg8gCo

[50] Mcity. (2020, October 15). Mcity Driverless Shuttle reports research findings after safe project conclusion. https://mcity.umich.edu/mcity-driverless-shuttle-reports-research-findings-after-safe-project-conclusion/

[51] Mcity. (2020, October). Mcity Driverless Shuttle: What We Learned About Consumer Acceptance of Automated Vehicles. https://mcity.umich.edu/wp-content/uploads/2020/10/mcity-driverless-shuttle-whitepaper.pdf

[52] Mcity. (2018, September 19). How to launch a driverless shuttle: U-Michigan shares insights in new case study. https://mcity.umich.edu/how-to-launch-a-driverless-shuttle-u-michigan-shares-insights-in-new-case-study/

[53] Mcity. (n.d.). Mcity Driverless Shuttle: A Case Study. https://mcity.umich.edu/wp-content/uploads/2018/09/mcity-driverless-shuttle-case-study.pdf

State	Project Year	Project Lead	Route Location	Operator	Vehicle Make and Model	Project Identifier
Minnesota	2018	Minnesota DOT	MnROAD on closed course test track; Minneapolis on public roadways	First Transit	EasyMile EZ10	MN: MnROAD; Minneapolis (2018)[54,55]
New Jersey	2022, 2023	NJ Transit	Former Marlboro Airport on closed course test track	NJ Transit	Navya Autonom	NJ: Former Marlboro Airport (2022, 2023)[56,57,58]
Ohio	2020	City of Columbus	Linden on public roadways	EasyMile	EasyMile EZ10	OH: Linden, Columbus (2020)[59,60,61]

[54] Minnesota Department of Transportation. (n.d.). Automated Shuttle Bus Pilot Project. https://www.dot.state.mn.us/automated/bus/index.html
[55] Minnesota Department of Transportation. (2018, June 27). MnDOT Autonomous Bus Pilot Project Testing and Demonstration Summary. https://www.dot.state.mn.us/automated/bus/finalreport.pdf
[56] NJ Transit. (n.d.). Avatar. https://www.njtransit.com/Avatar
[57] NJ Transit. (2024, April 26). Evaluation of Low-Speed Automated Vehicles in Providing Effective Community Transit in New Jersey – Executive Summary. https://content.njtransit.com/sites/default/files/marketing/website/pdf/LSAV%20Executive%20Summary.pdf
[58] NJ Transit. (2024, April 26). Evaluation of Low-Speed Automated Vehicles in Providing Effective Community Transit in New Jersey – Volume I: Final Report. https://content.njtransit.com/sites/default/files/marketing/website/pdf/Volume%20I%20Final%20Report.pdf
[59] Shared-Use Mobility Center. (2020, September 23). Autonomous Vehicles for Equity: Linden LEAP Shuttle, Columbus, OH. https://learn.sharedusemobilitycenter.org/casestudy/autonomous-vehicles-for-equity-linden-leap-shuttle-columbus-oh/
[60] Smart Columbus. (2021, May 19). Smart Columbus Deployment Playbook. https://d2rfd3nxvhnf29.cloudfront.net/2021-05/SCC-B-CEAV-Deployment-Playbook-FINAL%2005-19-21.pdf
[61] Smart Columbus. (2021, June 15). Final Report for the Smart Columbus Demonstration Program. https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf

State	Project Year	Project Lead	Route Location	Operator	Vehicle Make and Model	Project Identifier
Utah	2019, 2020	Utah DOT	Eight locations: Utah Driver's License Test Track on closed course test track; Canyons Village, Station Park, 1950 West, University of Utah, Utah State Capitol, Mountain America Expo Center, and Dixie Convention Center on public and private roadways	EasyMile	EasyMile EZ10	UT: Eight locations (2019, 2020)[62,63]
Virginia	2019	Virginia Tech Transportation Institute (VTTI)	Virginia Tech University on public roadways	VTTI employees	EasyMile EZ10	VA: Virginia Tech University (2019)[64,65,66]

[62] Utah Department of Transportation. (n.d.). Automated Shuttle Pilot Project. https://transportationtechnology.utah.gov/automatedshuttlepilotproject/
[63] Utah Department of Transportation. (2021, April). Utah Autonomous Shuttle Pilot Final Report. https://transportationtechnology.utah.gov/wp-content/uploads/2023/01/UtahAutomatedShuttle_FinalReport-2021-S-1.pdf
[64] Fairfax County, Virginia. (n.d.). Autonomous Electric Shuttle Pilot Project. https://www.fairfaxcounty.gov/transportation/Autonomous-Shuttle-Pilot
[65] Fairfax County, Virginia. (2020, October 20). Connected and Autonomous Vehicle Demonstration Project. https://www.fairfaxcounty.gov/transportation/sites/transportation/files/assets/documents/pdf/tac/tac%20presentation%20cav%2010.20.20.pdf
[66] Klauer, Sheila, et al. (2023, May 5). Infrastructure-Based Performance Evaluation for Low-Speed Automated Vehicle (LSAV). https://doi.org/10.3390/safety9020030

Table 4. Key findings and lessons learned from other automated shuttle pilots completed in the United States from 2018-2023.

Project Identifier	Focus Area	Key Findings and Lessons Learned
CA: Treasure Island (2023)	Administrative	A well specified milestone-based contract is appropriate for future pilots.
CA: Treasure Island (2023)	Technology	Technology can be unreliable, and issues took time to fix causing the automated shuttles to be out of service for extended periods of time.
CA: Treasure Island (2023)	Route Design	Ongoing construction created a complex operating environment that presented risks to project delivery and was the reason that the pilot was ended early.
CA: Treasure Island (2023)	Marketing, Promotion, and Engagement	Public perception of automated vehicles was generally positive.
CA: Treasure Island (2023)	Operations	Incident response and management required significant resources and more than anticipated at the start of the project.
FL: Orlando (2023)	Technology	The automated shuttles' operation was impacted by inclement weather since the shuttles' sensors do not work well in rain, snow, and fog.
FL: Orlando (2023)	Technology	Heat and humidity affect the automated shuttles' battery range.
FL: Orlando (2023)	Operations	The automated shuttles were approved by NHTSA to operate in a dedicated bus lane, so service interruptions occurred when the lane was blocked for extended periods of time by parked vehicles or construction.
FL: Orlando (2023)	Operations	The automated shuttles moved more slowly through intersections than a conventional vehicle, so signal timing adjustments may be necessary to enable the shuttle to safely clear the intersection before the red phase.
FL: Orlando (2023)	Operations	Attendants are not transit employees and were not able to provide the level of customer service expected by riders, including giving directions to popular destinations, knowing changes in service hours due to holidays or special events, and signaling their presence to potential riders at the stops using their horn.
FL: Orlando (2023)	Operations	The attendant regularly stopped 30 feet away from the designated stops to avoid disengagements from autonomous mode into manual mode requiring a hard system reset.
FL: Orlando (2023)	Operations	The novelty of the technology caused delays when people stopped the automated shuttles while on route to take pictures and speak with the attendant and riders onboard.

Project Identifier	Focus Area	Key Findings and Lessons Learned
FL: Orlando (2023)	Operations	The automated shuttle is much smaller than a conventional bus with a different seating arrangement that may not be as comfortable or work as well based on riders' expectations.
FL: Orlando (2023)	Operations	Nearly one third of the automated shuttles' scheduled hours of service were lost due to inclement weather, battery insufficiency, lane blockages, construction, traffic signal issues, signal loss, crashes, or other issues.
MI: University of Michigan (U-M) (2018, 2019)	Marketing, Promotion, and Engagement	Outreach and education are key to engaging the community and promoting ridership.
MI: University of Michigan (U-M) (2018, 2019)	Marketing, Promotion, and Engagement	Riders were generally satisfied with their experience and trusted the automated shuttle.
MI: University of Michigan (U-M) (2018, 2019)	Operations	A successful automated shuttle service should provide a viable and practical transportation solution that uses automated technology, not the other way around.
MI: University of Michigan (U-M) (2018, 2019)	Operations	The automated shuttles were not a practical alternative to riders' daily transportation challenges due to slow speeds and limited on-route stops.
MI: University of Michigan (U-M) (2018, 2019)	Operations	Robust safety protocols, operator training, and communication should be established and are essential for oversight and to ensure safety.
MN: MnROAD; Minneapolis (2018)	Technology	The automated shuttle operated as expected under clear weather conditions, but performance was diminished in falling snow, blowing snow, or when loose snow was kicked up from the test track and detected by the shuttle's sensors as obstacles leading to slowdowns and emergency stops.
MN: MnROAD; Minneapolis (2018)	Technology	The automated shuttle lost its location when its tires slipped on snow or slush on the pavement.
MN: MnROAD; Minneapolis (2018)	Technology	Temperatures below 0 °F drained the automated shuttle's battery at a faster rate than temperatures above 0 °F and the interior heating system, internal lights, and cold weather drained the battery at a noticeably faster rate which reduced the shuttle's performance.
MN: MnROAD; Minneapolis (2018)	Technology	The automated shuttle performed well in detecting other vehicles, pedestrians, and bicycles and detected and reacted to static obstacles placed in its path.
MN: MnROAD; Minneapolis (2018)	Technology	The automated shuttle displayed more conservative braking behavior and increased stopping distances as speed increased or as pavement conditions worsened.

Project Identifier	Focus Area	Key Findings and Lessons Learned
NJ: Former Marlboro Airport (2022, 2023)	Technology	The automated shuttle performed within the manufacturer's stated specifications.
NJ: Former Marlboro Airport (2022, 2023)	Technology	The automated shuttle's operation was impacted by heavy rain or wet snow that was detected as momentary obstacles by the shuttle's sensors, roadside vegetation movements detected as momentary obstacles, certain blind spots of the LiDAR array at low and high elevations that may lead to strikes by objects like hanging tree branches or trash on the roadway, and the need for installation of V2X roadside hardware to communicate signal phasing and timing information to the shuttle to enable operation through signalized intersections in autonomous mode.
NJ: Former Marlboro Airport (2022, 2023)	Technology	The automated shuttle was not able to consistently operate without human attendant supervision.
NJ: Former Marlboro Airport (2022, 2023)	Route Design	Planning a safe and reliable automated shuttle service requires carefully matching the route characteristics with the vehicle and its capabilities.
NJ: Former Marlboro Airport (2022, 2023)	Operations	Well-trained and knowledgeable onboard human attendants are vital to ensure passenger safety and to provide customer service.
NJ: Former Marlboro Airport (2022, 2023)	Operations	The automated shuttle operated safely without injuries or damage during closed course testing.
NJ: Former Marlboro Airport (2022, 2023)	Regulations	Approval from NHTSA was required to test the automated shuttle on the closed course test track since the vehicle is not compliant with FMVSS.
OH: Linden, Columbus (2020)	Administrative	A fully developed list of criteria that the service aims to address will align partners in determining the ideal route for deployment and should be developed early in the project development timeline.
OH: Linden, Columbus (2020)	Administrative	A thorough procurement process and document is needed that outlines each requirement a vendor should meet to ensure that the desired automated shuttle and service is provided.
OH: Linden, Columbus (2020)	Administrative	Testing is critical to validate the system delivered by the vendor is the same as procured, and a thorough test plan should be developed that communicates the expectations of the testing and aligns the tests with the requirements.
OH: Linden, Columbus (2020)	Administrative	While not all agencies may have the opportunity to hire local to the deployment, doing so can provide new and advanced jobs for the community.
OH: Linden, Columbus (2020)	Technology	The automated shuttles do not perform well in inclement weather leading to downtime.

Project Identifier	Focus Area	Key Findings and Lessons Learned
OH: Linden, Columbus (2020)	Route Design	Being flexible in the route design relative to project needs like service time or headway is important since the route needs to maximize safety and minimize intervention from the onboard human attendant.
OH: Linden, Columbus (2020)	Route Design	Evaluation of grade differentials on the route is essential to ensure that the route is appropriate for the automated shuttle and its sensors and to avoid route changes.
OH: Linden, Columbus (2020)	Route Design	A fully developed list of criteria that the service aims to address will align partners in determining the ideal route for deployment and should be developed early in the project development timeline.
OH: Linden, Columbus (2020)	Infrastructure	Vegetation along the route needs to be maintained to ensure consistent operation in autonomous mode.
OH: Linden, Columbus (2020)	Operations	Standard operating procedures, operator training, a test plan, and a safety management plan are key to clearly define and communicate any actions or steps required during an incident and prior to placing the automated shuttles back into operation.
OH: Linden, Columbus (2020)	Data	With well-defined procurement requirements related to data, it is possible to request the data needed to evaluate the success of the project and work with the vendor for its use.
OH: Linden, Columbus (2020)	Regulations	Working closely with state motor vehicles services prior to procurement can alleviate delays prior to launch related to registering the vehicle and paying any related fees that could be associated with electric vehicles.
OH: Linden, Columbus (2020)	Regulations	Submitting a testing route to NHTSA prior to sending the full route for approval is recommended to ensure the project schedule is maintained since FMVSS exemption is required prior to importing the automated shuttle into the United States.
OH: Linden, Columbus (2020)	Regulations	Safety mitigations may be required by NHTSA prior to route approval and before operating the automated shuttle on the route for testing and passenger service.
UT: Eight locations (2019, 2020)	Administrative	Rotating the automated shuttle across eight different locations within a short period of time in coordination with two executive teams resulted in logistical challenges that would have been minimized with a less ambitious plan.
UT: Eight locations (2019, 2020)	Administrative	Where and how long to deploy an automated shuttle should be guided by project goals.

Project Identifier	Focus Area	Key Findings and Lessons Learned
UT: Eight locations (2019, 2020)	Administrative	Developing a clear timeline and approval criteria for projects helps inform decisions when requests for new projects are received from government officials, site owners, and conference planners.
UT: Eight locations (2019, 2020)	Administrative	Budgeting time for reflection and documentation of lessons learned between projects ensures feedback can be captured while still fresh.
UT: Eight locations (2019, 2020)	Technology	Automated shuttle technology is continually advancing but still has significant limitations including low speeds, inability to move around obstacles without human intervention, frequent disengagements for human control, battery life, programmed stop locations that may need to be adjusted after initial route setup to enhance rider comfort and ramp landing area, sensitivity to landscaping, need for signs or other objects to support localization, weather and slope limitations, challenges with interactions with other vehicles or pedestrians, and transition time from manual mode to autonomous mode.
UT: Eight locations (2019, 2020)	Technology	The automated shuttle needs a very simple environment to operate safely.
UT: Eight locations (2019, 2020)	Infrastructure	The automated shuttle needs to be stored on site very close to its route.
UT: Eight locations (2019, 2020)	Operations	Service availability was impacted due to maintenance needs, battery insufficiency, and inclement weather.
UT: Eight locations (2019, 2020)	Data	Accessing and sharing real-time data was challenging.
UT: Eight locations (2019, 2020)	Regulations	Because automated shuttles are an emerging technology, state and federal approvals may require extra coordination and time as existing regulations are adapted or new regulations are developed.
UT: Eight locations (2019, 2020)	Accessibility	The automated shuttle is accessible but not ADA-compliant.
UT: Eight locations (2019, 2020)	Accessibility	Improvements are recommended to the automated shuttle’s wheelchair ramp, securement system, and audible stop announcements.
VA: Virginia Tech University (2019)	Technology	Managing expectations around the actual versus hyped capabilities of automated vehicle technology is important.
VA: Virginia Tech University (2019)	Technology	An automated vehicle is a system that includes hardware, software, and human resources that require maintenance and have ongoing costs.
VA: Virginia Tech University (2019)	Technology	Automated vehicles are designed to function within a highly specific Operational Design Domain (ODD) and may become unreliable or dysfunctional if real world conditions fall outside the ODD.
VA: Virginia Tech University (2019)	Technology	For all-electric vehicles, the use of features like climate control may significantly impact vehicle range.

Project Identifier	Focus Area	Key Findings and Lessons Learned
VA: Virginia Tech University (2019)	Technology	The automated shuttle requires an onboard human attendant to operate and to assist and ensure the safety of passengers.
VA: Virginia Tech University (2019)	Technology	Remote operation platforms are under development and not mature enough to replace an onboard human attendant.
VA: Virginia Tech University (2019)	Technology	Objects and features on and along a route that are not accounted for in the automated shuttle's high-definition map will be interpreted as obstacles and may impact operation.
VA: Virginia Tech University (2019)	Route Design	Automated vehicles vary in their functionalities which may limit route choices.
VA: Virginia Tech University (2019)	Operations	Federal and state regulations impact where and how automated shuttles operate and influence funding eligibility.
VA: Virginia Tech University (2019)	Operations	The speed differential between an automated shuttle and human-driven vehicles in mixed traffic may create safety risks.
VA: Virginia Tech University (2019)	Data	Data needs should be identified and confirmed with the automated vehicle manufacturer or operator prior to purchase or lease.