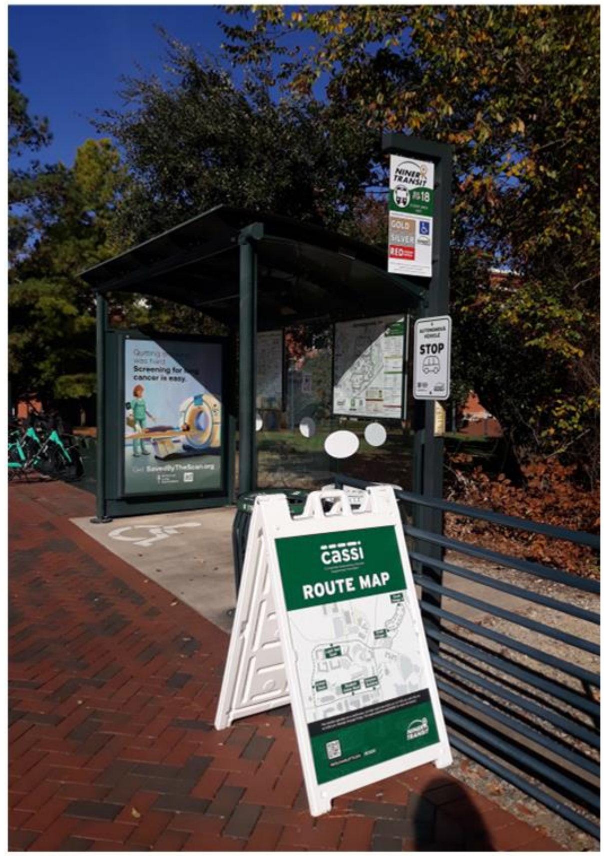

Connected Autonomous Shuttle Supporting Innovation (CASSI) at UNC Charlotte

Final Report

July 2024

UNIVERSITY OF NORTH CAROLINA CHARLOTTE

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Integrated Mobility Division
N.C. DEPARTMENT OF TRANSPORTATION

Disclaimer

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

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[1] 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

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Executive Summary

The North Carolina Department of Transportation (NCDOT) partnered with the University of North Carolina at Charlotte (UNC Charlotte) and Beep, Inc. (Beep) to bring a novel-design, all-electric, low-speed automated shuttle to UNC Charlotte's campus for a 23-week pilot through the Connected Autonomous Shuttle Supporting Innovation (CASSI) program. Beep operated a Navya Autonom shuttle on a 2.2-mile, six-stop route that connected the main campus LYNX Blue Line light rail station; Greek Village; dormitories, parking, and academic buildings; and the student union. The shuttle was free and open to the public on weekdays from 8:30 to 11:30 a.m. and 1:30 to 4:30 p.m. during the pilot period (July 12 through December 21, 2023). The shuttle was not in service from 11:30 a.m. to 1:30 p.m. due to scheduled midday charging. The pilot provided a first and last mile option in a fixed-route, circulator service. The shuttle shared its route and stops with existing Niner Transit bus services, including the Green, Silver, Gold, Red, and Greek Village routes. The automated shuttle supplemented the conventional shuttles already operating on the Greek Village route. UNC Charlotte also provides scooter share and bikeshare with supporting infrastructure such as shared use paths, bike lanes, and sidewalks alongside their Niner Transit bus, shuttle, and paratransit services, so faculty, staff, students, and visitors have multiple transportation options to reach their destinations on campus.

NCDOT advanced their exploration of shared autonomous vehicles by piloting the low-speed automated shuttle at UNC Charlotte. The pilot increased the complexity of the Vehicle-to-Infrastructure (V2I) communications from a single temporary traffic signal in the preceding CASSI in Cary's Bond Park project to four naturalistic traffic signals and featured the longest route and most complex operating environment to date—a dynamic campus shared with pedestrians, bicyclists, scooter riders, sidewalk delivery robots, and transit. Unique to the pilot at UNC Charlotte compared to past efforts under the CASSI program, the shuttle was offered as an additional option amongst other options in a robust multimodal transportation system. UNC Charlotte designed their transportation system to meet the travel needs of their community with multimodal routes linking key destinations on campus and offering off-campus connections. The shuttle provided redundancy on an existing route with established service.

Findings from the data and analyses indicate that, while some community members appreciated being able to experience and support new technology through the automated shuttle and service, most were choosing other options to reach their destinations on campus, whether due to comfort, convenience, reliability, or some other factor. The shuttle's slow speed, delay from when the attendant needed to troubleshoot problems or manually operate the shuttle, and route constraints that resulted in a less direct path between destinations contributed to the lower performance of the shuttle compared to conventional transit options. The most common cause of the shuttle's disengagement from autonomous mode into manual mode was lost connection or miscommunication between the shuttle's Onboard Unit (OBU) and the Roadside Units (RSUs) at the signalized intersections on the route. In addition, the shuttle was out of service for a considerable amount of time due to technology issues, notably due to Global Navigation Satellite System (GNSS) signal loss and battery insufficiency. These findings suggest that there was no time or connectivity benefit to using the shuttle over other options on campus. Overall, the shuttle's technology needs to advance further to usefully meet the demands of a university campus and the expectations of its community members. Additional key findings are summarized in the following.

Findings from complementary research supported by NCDOT and conducted by Pulugurtha et al. are published in a separate technical report.

Comparison with CASSI in Cary's Bond Park Pilot

The automated shuttle pilot at UNC Charlotte followed on a pilot that was completed by NCDOT in partnership with the Town of Cary (Cary) in the Fred G. Bond Metro Park (Bond Park) using the same vehicle and operator.

The pilot in Cary's Bond Park was the first under NCDOT's CASSI program to demonstrate Vehicle-to-Infrastructure (V2I) communications between a traffic signal and the shuttle. NCDOT and Cary installed a temporary two-phase traffic signal at one intersection on the shuttle's route and equipped it with a Roadside Unit (RSU) that transmitted Signal Phasing and Timing (SPaT) messages from the signal controller. The messages were received by the shuttle's Onboard Unit (OBU). The shuttle used the phasing and timing information to operate autonomously through the intersection. For the pilot at UNC Charlotte, NCDOT partnered with the university and the Charlotte Department of Transportation (CDOT) to increase the complexity of the V2I communications by equipping four existing permanent traffic signals on the shuttle's route with RSUs.

The pilot at UNC Charlotte featured a longer duration, longer route, and more complex operating environment compared to the pilot in Cary's Bond Park. The pilot also featured the most traffic signals using V2I technology for a route operated by Beep to date. While the shuttle was the only transit option available within Cary's Bond Park during the three-month pilot period, it was offered as an additional transportation option at UNC Charlotte alongside existing transit, paratransit, shuttle, and shared mobility options like scooter share and bikeshare. UNC Charlotte intentionally designed the automated shuttle's route and stops to align with an established route on campus called the Greek Village route that is served by conventional shuttles.

Both pilots concluded that the automated shuttle technology is not mature and is not ready to be mainstreamed or scaled as a conventional transit service. The shuttle is not designed to be fully autonomous. An onboard human attendant is necessary for the automated shuttle to operate since the shuttle and its system is inherently dependent on human intervention and confirmation to perform autonomous actions correctly and safely. The shuttle is not universally designed and does not include automated accessibility features like an automatic wheelchair ramp, securement system, or audible stop announcements and instructions.

Key Findings from the CASSI at UNC Charlotte Pilot	
Ridership and Operations*	• 565 Total Riders Served • 825 Total Trips • 85% Uptime (625 actual hours operated out of 736 scheduled hours of service) • 91.0% Time Spent in Autonomous Mode • 6.2 mph Average Vehicle Speed on Route • 12.6 mph Maximum Vehicle Speed on Route
Rider Feedback**	• 22% Visited UNC Charlotte to ride the shuttle • 59% Rode the shuttle to get to a specific destination • 83% Had a good experience using the shuttle • 92% Had a good experience with the attendant • 56% Thought the shuttle arrived at their stop within a reasonable amount of time • 61% Thought they were able to get to their destination in a reasonable amount of time • 69% Would ride the shuttle again • 69% Support seeing more driverless shuttles on UNC Charlotte's campus
Community Engagement*** ***What works well for you in the shuttle?***	• Open space and head room • Convenient stops • Provides another option for traversing a hilly campus that is full of stairs • Recognizes traffic lights and obstacles in the path • Safety features such as the hard braking and manual override • Seating and space are nice for non-wheelchair users
Community Engagement*** ***How could the shuttle work better for you?***	• Automatic ramp that is wider, more stable, and better accommodates bariatric wheelchair users, scooter users, and some larger motorized wheelchairs • Foldable seats to allow more room for wheelchair placement • Audible stop announcements and instructions (e.g., wear seat belts, no standing, etc.) • Increased seating capacity, bigger space, and larger seats • Automated features so ADA passengers are not entirely dependent on the attendant for assistance • Smoother movement • Determine practices for accessibility for when the vehicle becomes fully autonomous
Lessons Learned ***State of the Technology*** ***Traffic Signal Integration*** ***Accessibility***	• Automated shuttle technology needs to advance further to usefully meet the demands of a university campus and the expectations of its community members – 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. • The most common cause of the shuttle's disengagement from autonomous mode into manual mode was the signalized intersections – greater structure, predictability, and coordination around the testing and validation of the V2I equipment and more resources from the vendor towards troubleshooting would have been beneficial. • Most low-speed automated shuttles do not include the full set of accessibility-related features needed to serve people with disabilities – recommended improvements include an automatic wheelchair ramp, more room for wheelchair placement, and audible stop announcements and instructions.

**Ridership and operations data were provided by Beep in weekly reports. **Rider survey data were collected by NCDOT and UNC Charlotte using an online survey. Results are for the respondents that rode the shuttle (59 respondents total). ***Community engagement data were collected by NCDOT and UNC Charlotte during two engagement events with community members with disabilities and their caregivers, disability services professionals, and paratransit professionals (11 respondents total).*

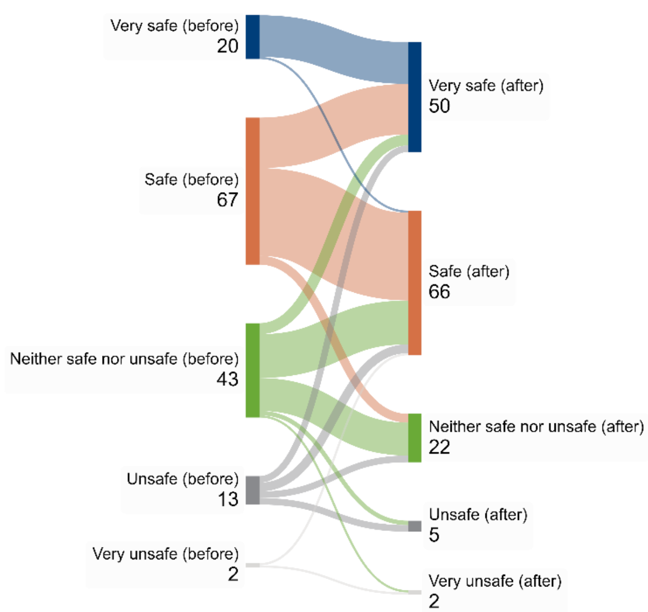
Common Successes

For the pilots in Cary's Bond Park and at UNC Charlotte, common successes were:

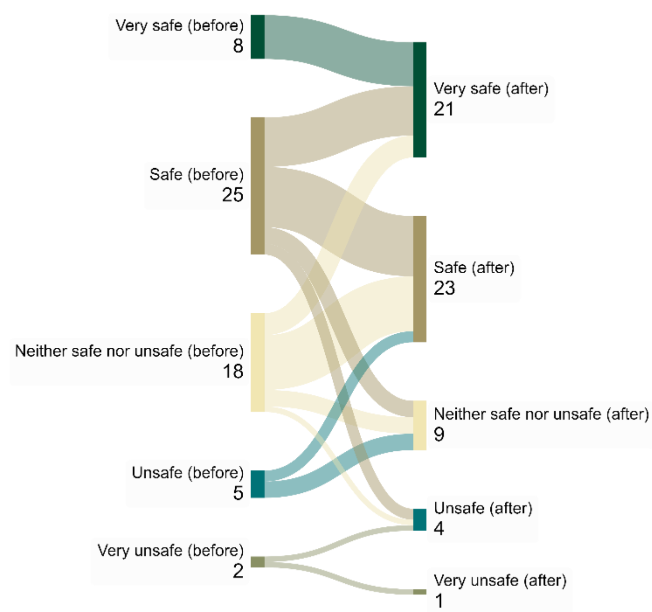
- **Riders generally had a good experience with the shuttle and the attendant on the shuttle.** Feedback from rider surveys indicated that most riders had a good experience with the shuttle (92% and 83% of survey respondents respectively) and a good experience with the attendant on the shuttle (97% and 92% of survey respondents respectively).
- **Riders generally felt that driverless vehicles are safe before and after riding the shuttle.** Feedback from rider surveys indicated that most riders felt that driverless vehicles are very safe, safe, or had no opinion before riding the shuttle. Many riders maintained or improved their perception of the safety of driverless vehicles after riding the shuttle, including some riders that had no opinion before riding the shuttle but felt that driverless vehicles are safe or very safe after riding the shuttle. These results are summarized in the following Sankey diagrams that show the matched pairs of responses to the two questions from the rider survey that captured riders' perceptions of the safety of driverless vehicles before and after riding the shuttle.

BEFORE and AFTER riding the shuttle, I felt that driverless vehicles are:

CASSI in Cary's Bond Park



CASSI at UNC Charlotte



- **Strong partnerships and trusting relationships between NCDOT and the project partners contributed to each pilot's successful planning and delivery.** Both pilots were interdepartmental and interdisciplinary efforts that relied on experience and expertise across multiple domains such as business services; contracting and legal; disability services; engineering and operations; facilities management; finance; information technology; intelligent transportation systems; marketing and communications; parking, transportation, and transit services; parks, recreation, and cultural resources; police, fire, emergency medical services, and public safety; program and project management; and public works. Staff from UNC Charlotte visited Bond Park, rode the shuttle while it was in operation, and met with Cary staff to learn more about their experiences prior to launching their pilot. Lessons learned from the pilot in Cary's Bond Park were carried forward by UNC Charlotte and NCDOT staff in the planning and delivery of the pilot on campus. Both teams were able to experience how well the automated shuttle technology works now in real-world settings and reflect on how automated vehicle technology needs to advance to usefully meet the needs of all riders in all environments.

Common Challenges

For the pilots in Cary's Bond Park and at UNC Charlotte, common challenges were:

- **Unreliable performance of enabling technology**, including GNSS signal loss, connection loss or miscommunication at the signalized intersections, and software malfunctions requiring hard system resets.
- **Battery insufficiency** due to demand on the shuttle's air conditioning system on hot days and amplified by the shuttle's age and subsequent lower battery capacity.
- **Operational inconsistency** due to technology issues, inclement weather, and other factors that resulted in service suspensions.
- **Missing features to make the shuttle fully accessible**, including an automatic wheelchair ramp and audible stop announcements.

Key Differences

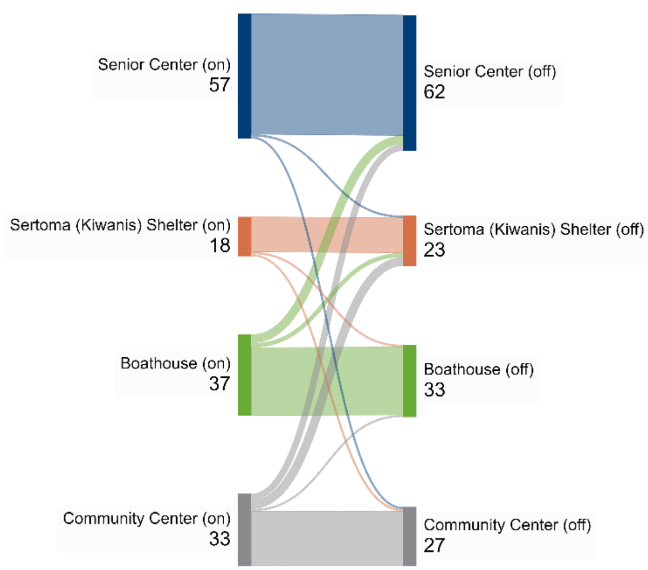
Key differences between the pilots in Cary's Bond Park and at UNC Charlotte include:

- **The shuttle was the only transit option within Cary's Bond Park during the pilot period while the shuttle was one option out of many at UNC Charlotte** and provided redundancy on an existing route with established transit service during the pilot period.
- **Ridership for the pilot at UNC Charlotte was considerably lower than for the pilot in Cary's Bond Park.** Ridership was lower per trip, daily, and overall across the pilot period at UNC Charlotte compared to the pilot in Cary's Bond Park when controlling for the varying pilot durations and downtime.
- **Most riders visited Cary's Bond Park to ride the shuttle and would ride the shuttle again, while most riders did not visit UNC Charlotte to ride the shuttle and fewer would ride the shuttle again.** Feedback from the rider survey for the pilot in Cary's Bond Park indicated that most riders visited Bond Park to ride the shuttle (79% of survey respondents) and would ride the shuttle again (81% of survey respondents). Feedback from the rider survey for the pilot at UNC Charlotte indicated that most riders did not visit UNC Charlotte to ride the shuttle (78% of survey respondents) and a smaller proportion would ride the shuttle again (69% of survey respondents) compared to the results from the pilot in Cary's Bond Park. A greater proportion of riders in Bond Park support seeing more driverless shuttles in their community (88% of survey respondents) compared to the results from the pilot at UNC Charlotte (69% of survey respondents).
- **Most riders rode the shuttle in Cary's Bond Park for a fun experience while most riders rode the shuttle at UNC Charlotte to get to a specific destination.** 96% of survey respondents for the

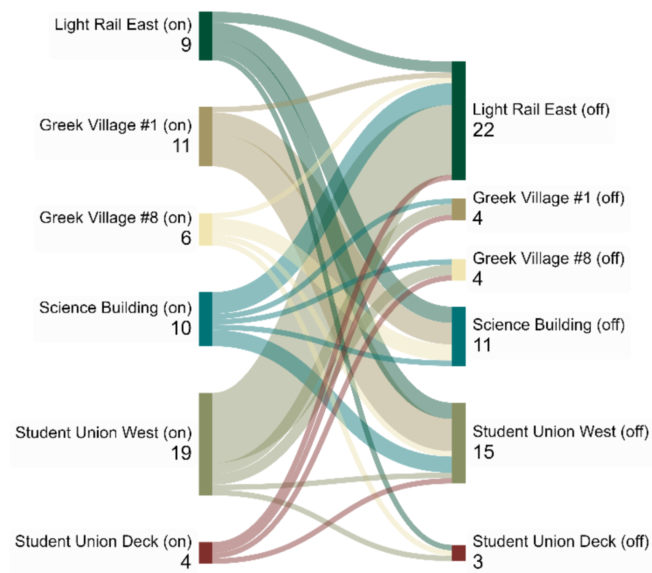
pilot in Cary's Bond Park rode the shuttle for a fun experience or both a fun experience and to get to a specific destination, compared to 74% of survey respondents for the pilot at UNC Charlotte. 59% of survey respondents for the pilot at UNC Charlotte rode the shuttle to get to a specific destination or for both a fun experience and to get to a specific destination, compared to 9% of survey respondents for the pilot in Cary's Bond Park. The survey responses further show that most riders rode the shuttle for a complete loop in Cary's Bond Park while most riders rode the shuttle to a different destination than their starting point at UNC Charlotte. These patterns are demonstrated in the following Sankey diagrams that show the matched pairs of responses to the two questions from the rider survey that captured where riders got on and off the shuttle. The stops in each diagram are listed in the order that they were served on each route.

Where did you get on and where did you get off the shuttle?

CASSI in Cary's Bond Park



CASSI at UNC Charlotte



- **Survey results for both pilots showed the lowest level of agreement for the question that asked about wait time, but for different reasons.** The results from the rider survey for the pilot in Cary's Bond Park showed the lowest level of agreement for the question that asked about wait time. 78% of survey respondents thought the shuttle arrived at their stop within a reasonable amount of time. Feedback from the rider survey for the pilot at UNC Charlotte showed a lower level of agreement. 56% of survey respondents thought the shuttle arrived at their stop within a reasonable amount of time. NCDOT and Cary did not include real-time tracking in their pilot since the shuttle could not be tracked against GoCary's other transit options using Beep's platform and the time and resources needed to establish a new solution were too great relative to the short duration of the pilot. The lack of Automatic Vehicle Location (AVL) technology coupled with inconsistency in the shuttle's timing due to frequent service interruptions and the shuttle's disengagements from autonomous mode into manual mode led to long wait times at the stop locations for riders and confusion about whether the shuttle was coming or going. UNC Charlotte used AVL technology to provide real-time tracking of the shuttle by integrating the shuttle into their existing Passio service. UNC Charlotte uses Passio to provide the campus community with information on Niner Transit routes, schedules, and real-time tracking. However, real-time tracking does not guarantee service reliability. Factors such as delay from the shuttle yielding priority to existing transit services at stops, long stop times due to the attendant idling at a stop or resolving issues with the shuttle's technology, and delay resulting from the attendant intervening during the shuttle's disengagements from autonomous mode into manual mode may have impacted service reliability during the pilot at UNC Charlotte.

- **Overall, results from the pilot at UNC Charlotte indicate that, while some community members appreciated being able to experience and support new technology through the automated shuttle and service, most were choosing other options to reach their destinations on campus, whether due to comfort, convenience, reliability, or some other factor.** Feedback from the rider survey indicated that most riders would have taken the bus or other transit (44% of survey respondents) or walked (39% of survey respondents) if they had not taken the shuttle.
- **Overall, results from the pilot in Cary's Bond Park indicate that, while the pilot was not able to achieve the same level of service as established and standardized transit options, new trips within the park resulted from the introduction of the shuttle and some personal vehicle trips were replaced by the shuttle during the pilot period.** Feedback from the rider survey indicated that most riders would have traveled in a personal vehicle (41% of survey respondents), walked (35% of survey respondents), or would not have taken the trip (19% of survey respondents) if they had not taken the shuttle. The shuttle was the only transit option within the park during the pilot period.

Next Steps for the CASSI Program

The data and analyses from the pilot at UNC Charlotte show that the campus' complex operating environment exceeded the automated shuttle and service's capabilities. NCDOT returned the Navya Autonom shuttle to Beep's headquarters in Lake Nona, Florida when the pilot was completed. NCDOT determined that it would not be reasonable to continue testing the vehicle in North Carolina given the limitations that were identified across the pilots in Cary's Bond Park and at UNC Charlotte.

NCDOT is exploring new options for the next set of pilots under the CASSI program through a Request for Information (RFI) on automated transit vehicles. The RFI covers 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. The RFI is focused on higher levels of automation and asks respondents to clearly describe the presence, role, and responsibility of a human attendant or operator as needed for safety or passenger assistance. NCDOT anticipates using the findings from the RFI to inform their selection of new vehicles, locations, use cases, and vendors for future projects through CASSI and beyond.

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 our 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. NCDOT seeks to honor the promise of a better world for all people by carefully and systematically evaluating new and developing solutions to see how well they work now and how they can better serve us in the future.

Comparison Between the CASSI in Cary's Bond Park & CASSI at UNC Charlotte Pilots		
Category	**Fred G. Bond Metro Park**	**UNC Charlotte**
Operator	Beep	Beep
Vehicle	Navya Autonom	Navya Autonom
Pilot Period	March 6-June 2, 2023 (13 weeks)	July 12-December 21, 2023 (23 weeks)
Number of Shuttles	One shuttle	One shuttle
Operating Days	Five days, Monday-Friday	Five days, Monday-Friday
Hours of Service	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	6 hours	6 hours (additional evening hours added in November and December)
Number of Unique Routes	One route	One route
Route Miles	1.6 miles	2.2 miles
Number of Stops	Four stops	Six stops
Number of Days in Operation	61	112
Number of Days with Complete Service	28	56
Number of Days with Partial Service	33	56
Number of Days with Complete Suspension of Service	3	2
Number of Days with No Scheduled Service	1	3
Scheduled Hours of Operation	384.0	735.5
Actual Hours of Operation	331.3	625.4
Percentage Uptime	86.3%	85.0%
Number of Disengagements	179	267
Average Number of Disengagements per Day	2.9	2.4
Percentage Time in Autonomous Mode	98.3%	91.0%
Average Vehicle Speed	5.4 mph	6.2 mph
Maximum Vehicle Speed	11.4 mph	12.6 mph
Number of Trips	494	825
Number of Passengers	1,718	565
Average Passengers per Trip	3.5	Less than 1
Average Passengers per Vehicle per Day	28.2	5.0
Average Trips per Vehicle per Day	8.1	7.4
Number of Ramp Deployments	7	0
Average Number of Ramp Deployments per Day	Less than 1	0

Introduction

The North Carolina Department of Transportation (NCDOT) envisions a transportation system in the state where shared mobility options are convenient, reliable, affordable, clean, and safe, and everyone has equal access to opportunities and services. NCDOT is exploring how shared autonomous vehicles can help achieve that vision through the Connected Autonomous Shuttle Supporting Innovation program, or CASSI. CASSI shows the public what autonomous vehicle technology can do in safe, real-world settings. CASSI evaluates how autonomous vehicles can best be used by riders with different needs and in different environments. NCDOT and communities statewide are partnering to test and evaluate autonomous vehicles in pilots that provide free shared rides to the public. Pilots focus on transit applications such as first mile/last mile solutions and demonstrating connected vehicle infrastructure.

NCDOT partnered with the University of North Carolina at Charlotte (UNC Charlotte) and Beep, Inc. (Beep) to bring a novel-design, all-electric, low-speed automated shuttle to UNC Charlotte's campus for a 23-week pilot through the CASSI program. Beep operated a Navya Autonom shuttle on a 2.2-mile, six-stop route that connected the main campus LYNX Blue Line light rail station; Greek Village; dormitories, parking, and academic buildings; and the student union. The shuttle was free and open to the public on weekdays from 8:30 to 11:30 a.m. and 1:30 to 4:30 p.m. during the pilot period (July 12 through December 21, 2023). The shuttle was not in service from 11:30 a.m. to 1:30 p.m. due to scheduled midday charging. The pilot provided a first and last mile option in a fixed-route, circulator service. The shuttle shared its route and stops with existing Niner Transit bus services, including the Green, Silver, Gold, Red, and Greek Village routes. The automated shuttle supplemented the conventional shuttles already operating on the Greek Village route. UNC Charlotte also provides scooter share and bikeshare with supporting infrastructure such as shared use paths, bike lanes, and sidewalks alongside their Niner Transit bus, shuttle, and paratransit services, so faculty, staff, students, and visitors have multiple transportation options to reach their destinations on campus.

Through their partnership, NCDOT and UNC Charlotte sought to:

- Learn more about how shared autonomous vehicles can be safely and effectively used in the future,
- Allow the campus community to experience up close what autonomous vehicle technology can do in a safe, real-world setting,[2,3]

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[2] NCDOT. (n.d.). CASSI. https://www.ncdot.gov/divisions/integrated-mobility/innovation/cassi/Pages/default.aspx

[3] Beep. (2023, September 7). North Carolina Department of Transportation and Beep Launch Autonomous Shuttle Pilot Project at UNC Charlotte. https://ridebeep.com/press-releases/north-carolina-department-of-transportation-and-beep-launch-autonomous-shuttle-pilot-project-at-unc-charlotte

- Determine where the technology fits on campus now and where it might fit in the future, and
- Provide a live learning lab for university researchers.[4]

The pilot advanced NCDOT's goal of incrementally increasing the complexity of projects while learning from past challenges and building on successes. The pilot increased the complexity of the Vehicle-to-Infrastructure (V2I) communications from a single temporary traffic signal in the preceding CASSI in Cary's Bond Park project to four naturalistic traffic signals and featured the longest route and most complex operating environment to date—a dynamic campus shared with pedestrians, bicyclists, scooter riders, sidewalk delivery robots, and transit.

Overview

Partners

NCDOT, UNC Charlotte, Charlotte Department of Transportation (CDOT), and Beep collaborated to plan and launch the pilot. The project teams included:

- North Carolina Department of Transportation
  - Integrated Mobility Division (program and project management)
  - Contract Unit and Purchasing Section (contracting and legal)
  - Communications Office (marketing and communications)
  - Transportation Mobility and Safety Division – Intelligent Transportation Systems (ITS) and Signals Management Section (traffic signal integration)
- Kimley-Horn
  - Consultant support to NCDOT
- UNC Charlotte
  - Parking and Transportation Services
  - Division of Business Affairs
    - Auxiliary Services
    - Business Services
    - Facilities Management
    - Police and Public Safety
    - University Leadership
    - Chancellor's Office
  - Division of Academic Affairs
    - Office of Disability Services
  - Division of University Advancement
    - University Communications
  - William States Lee College of Engineering
    - Civil and Environmental Engineering
- Charlotte Department of Transportation
  - Engineering and Operations
- Beep
  - Shuttle operator
- Navya
  - Shuttle manufacturer

[4] The Charlotte Ledger. (2023, June 22). UNC Charlotte is testing a self-driving shuttle. https://charlotteledger.substack.com/p/unc-charlotte-is-testing-a-self-driving

Timeline

NCDOT and UNC Charlotte began discussions towards an automated shuttle pilot in April 2022 after UNC Charlotte staff attended a presentation about the CASSI program at the North Carolina Public Transportation Association (NCPTA)'s annual conference. At the time, NCDOT and Cary, NC (Cary) were determining how to transition their automated shuttle pilot in Cary's Fred G. Bond Metro Park (Bond Park) to a new vehicle and operator. Their first attempt to launch was unsuccessful due to technical issues with the vehicle—an EZ10 Gen 3 shuttle manufactured and operated by EasyMile Inc. (EasyMile)—and extensive project delays. NCDOT decided not to pursue additional projects with EasyMile and cancelled their contract effective October 1, 2022. NCDOT then began exploring alternate vendors to complete the project in Bond Park and future pilots under the CASSI program.

UNC Charlotte leadership greenlit their proposed pilot in September 2022. NCDOT established a new contract with Beep in November 2022 to complete the automated shuttle pilots in Bond Park and at UNC Charlotte using a shuttle manufactured by Navya S.A. (Navya) called an Autonom. NCDOT and UNC Charlotte worked with Beep to identify a suitable route on campus. Beep planned to visit the campus in November 2022 to review a preliminary route identified by NCDOT and UNC Charlotte, but the visit was postponed to December 2022 due to Hurricane Ian.

Lead time from the start of route discussions to start of operations for the CASSI at UNC Charlotte project was approximately ten months. The timeline from the start of route discussions to start of operations is summarized in Figure 1.

September 2022	Route discussions begin
November 2022	NCDOT executes contract with Beep
December 2022	Site visit completed and route confirmed
February 2023	Kickoff meeting completed
April and May 2023	NCDOT, UNC Charlotte, and Beep execute agreements
June 2023	Letter received from the National Highway Traffic Safety Administration (NHTSA) granting permission to Beep to operate the shuttle on its route on UNC Charlotte's main campus
	Shuttle transported to UNC Charlotte and wrapped
	Route preparations completed including installation of Vehicle-to-Infrastructure (V2I) equipment at the four traffic signals on the shuttle's route
	First Responder Workshop completed
	Transit Operator Training completed
July 2023	Beep completes commissioning activities including mapping and testing
	Shuttle opens to the public

Figure 1. Timeline from the start of route discussions to start of operations. (Image courtesy of NCDOT)

Funding

The pilot was funded as a 50/50 cost share between NCDOT and UNC Charlotte. The cost share covered the lease and operating expenses related to the commissioning of the shuttle, attendant training, and public operations associated with the pilot. UNC Charlotte was responsible for costs associated with on-site work for the project.

Setting

UNC Charlotte is known as North Carolina's urban research university and Niner Nation, the home of the Charlotte 49ers. Founded in 1946, UNC Charlotte is the third largest university in the University of North Carolina system of 16 universities and located in Charlotte, the state's largest city, approximately nine miles northeast of the city center. The university has nearly 170 undergraduate, graduate, and doctoral programs; 3,000 faculty and staff; and an enrollment of over 30,000 students—35% of which are first-generation college students.[5] The university has three campuses: Charlotte Research Institute Campus, Center City Campus, and the main campus located in University City. Main campus features 1,000 acres, 85 buildings, and nearly 7,000 students residing in on-campus housing.

Organized campus transportation at UNC Charlotte began in 2007 with trolley buses then evolved to transit buses when the Charlotte Area Transit System (CATS) added three on-campus routes. UNC Charlotte's existing transit service is called Niner Transit. UNC Charlotte contracts with Academy Bus to operate a fleet of twelve 40-foot buses—ten buses operate on four primary routes during peak hours while two secondary routes are operated in-house. Niner Transit serves 1.4 million rides annually. In addition to Niner Transit, UNC Charlotte operates a paratransit service (Niner Rides Paratransit); offers bikeshare and scooter share with designated parking areas, bike lockers, and racks; and provides a CATS All-Access Transit Pass to every student for unlimited rides on all CATS buses, streetcars, the airport sprinter, and LYNX light rail.

UNC Charlotte's campus also features supporting infrastructure for travel across modes, including shared use paths, bike lanes, and sidewalks as well as designated transit pull offs and stops. UNC Charlotte's future transportation focus is on enabling first mile/last mile connections and seamless transfer between modes; supporting efficient, safe, and attractive options; implementing a Transportation Demand Management (TDM) program; and exploring autonomous transportation.

Route

NCDOT and UNC Charlotte selected a 2.2-mile, six-stop route on the university's main campus that complemented existing transportation options and connected to the main campus LYNX Blue Line light rail station; Greek Village; dormitories, parking (e.g., North

[5] The University of North Carolina System. (n.d.). UNC Charlotte. https://www.northcarolina.edu/institution/unc-charlotte/

Deck and Student Union Deck), and academic buildings (e.g., Science Building and Burson Hall); and the student union (Popp Martin Student Union). The posted speed limit throughout the campus was 20 mph. UNC Charlotte intentionally designed the route and stops to align with an established route on campus called the Greek Village route that is served by conventional shuttles. UNC Charlotte's goal was to offer the automated shuttle as a transportation option amongst others during the pilot period.

Beep visited UNC Charlotte in December 2022 to video the route, take pictures of the storage location and charging equipment, and identify a suitable location to install their Global Navigation Satellite System (GNSS) antenna used as a Real-Time Kinematic (RTK) base station. Beep used the information gathered during the visit for their exemption application to the National Highway Traffic Safety Administration (NHTSA) for permission to operate the shuttle on the route and accept passengers. Beep worked with Navya to validate the slope of the route at certain points on Craver Road and confirm that it was within the shuttle's appropriate operating conditions since it appeared to exceed the maximum allowable slope of 12%. In February 2023, Navya approved the route's slope, and Beep confirmed that the route chosen by UNC Charlotte met the appropriate operating conditions for the Navya Autonom shuttle as described in Appendix A. Beep indicated that they would evaluate the shuttle's performance throughout the deployment to ensure safe operation.

Beep hired a new quality assurance and deployment team director in April 2023. The director reviewed the proposed route at UNC Charlotte and recommended modifications to further improve safety towards approval by NHTSA by eliminating an unprotected left turn. Beep summarized their review of the route in Route Analysis documentation. Beep shared the Route Analysis documentation with NCDOT and UNC Charlotte to be included as an appendix to the general agreement between NCDOT and UNC Charlotte. A map of the route and stops is provided in Figure 2.

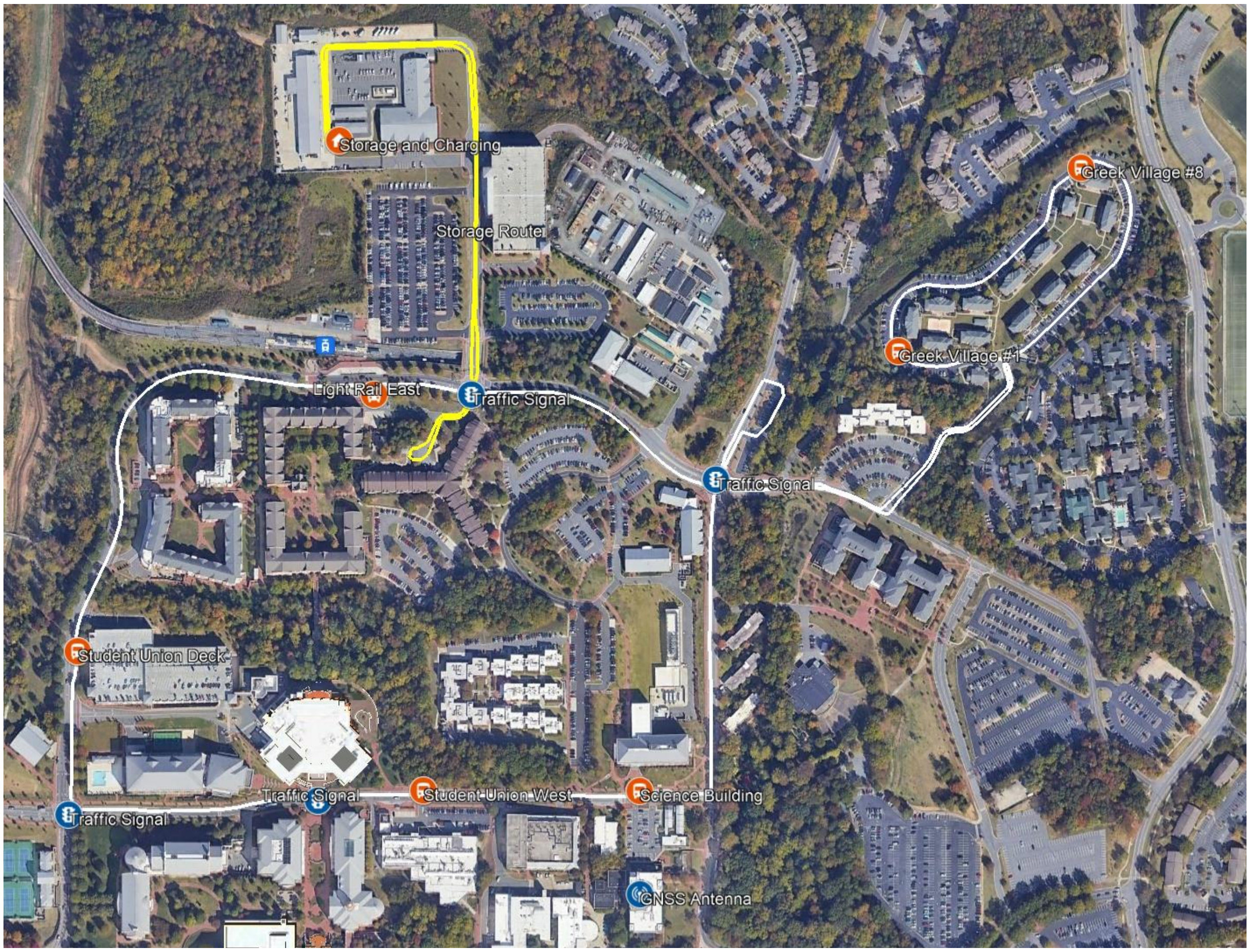

Figure 2. Map of the shuttle's route and stops on UNC Charlotte's main campus. The shuttle's path from the storage area to the first stop on the route at Light Rail East is indicated in yellow. (Image courtesy of NCDOT)

Vehicle

Form Factor

France-based Navya manufactured the Autonom shuttle and Florida-based Beep operated the shuttle. Beep provided a trained attendant to take manual control of the shuttle if needed. The attendant also provided customer service, including answering riders' questions about the technology and assisting riders using mobility devices.

The Navya Autonom shuttle has four wheels and is approximately 15.6 feet long, 8.7 feet high, and 6.9 feet wide with a 9.4-foot wheelbase, 6.7-inch ground clearance, and 14.7-foot turning radius. The shuttle's curb weight is 5,291 lb and its gross vehicle weight is 7,605 lb. The Navya Autonom shuttle does not feature a traditional driver's cockpit, mirrors, steering wheel, accelerator, or brake pedals and has an unconventional seating configuration. The shuttle has an advertised maximum operating speed of 15.5 mph but operates on its route at speeds up to 12 mph per the operating conditions approved by NHTSA.

The Navya Autonom shuttle has 11 seats. The seated capacity is ten passengers or one wheelchair plus up to eight passengers. Like the passengers, the attendant must be seated with their seatbelt fastened, including while operating the shuttle. The shuttle includes a manual ramp to ensure access for riders using mobility devices. The attendant can also kneel the shuttle (i.e., lower the suspension of the vehicle to decrease the height of the vehicle floor) to enable easier access for riders stepping up into or out of the shuttle. The shuttle has an air conditioning and heating system to regulate the interior temperature. The shuttle is fully electric with up to seven hours operating time on a four-hour charge, dependent on factors such as weather, slope of the route, passenger load, and idling time at the stops. The shuttle can operate in temperatures ranging from 14 °F to 104 °F and stored in temperatures ranging from 32 °F to 86 °F.

Level of Automation

The shuttle operates at Society of Automotive Engineers (SAE) Level 3 automation (known as "conditional automation").[6] This means that the shuttle's Automated Driving System (ADS) can drive the vehicle under limited conditions and that the human in the driver's seat, meaning an onboard attendant, must take over driving when the ADS requests. The conditions under which an ADS is designed to function is known as the Operational Design Domain (ODD).[7] The ODD includes, but is not limited to, environmental, geographic, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. The onboard attendant is responsible for monitoring the shuttle's operation and must be ready to take over control when required. The shuttle is programmed to automatically disengage from autonomous mode and come to a complete stop when an obstacle is too close or when all required conditions for operation are not met. The attendant can also manually disengage from autonomous mode when deemed necessary. The attendant uses an industrial controller connected to the shuttle to take over driving or to perform an emergency stop.

The shuttle is programmed to stop at all stop signs and permissive left turns. The attendant must prompt the shuttle to proceed through stop sign controlled intersections and uncontrolled left turns. The attendant looks to confirm 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 shuttle is also programmed to slow and stop at priority zones, such as crosswalks, when an obstacle is detected within the zone. If the zone is clear when the shuttle approaches, the shuttle will cross the zone without slowing or stopping.

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

[7] SAE International. (2021, July 15). J3259 (WIP) Taxonomy & Definitions for Operational Design Domain (ODD) for Driving Automation Systems. https://www.sae.org/standards/content/j3259

Technology

The Navya Autonom shuttle is programmed to operate on a pre-determined, pre-mapped route and navigates the roadway using the following technologies:

- 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; used for vehicle positioning and obstacle detection
- Cameras – front, interior, and rear cameras; used for supervision purposes only (not for obstacle detection)
- Global Positioning System (GPS) sensor – 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

The shuttle uses eight LiDAR sensors, three cameras, one GPS sensor/GNSS antenna, and one IMU in total. The sensor systems provide localization (knowing where the vehicle is), navigation (knowing where the vehicle is going), and obstacle detection (knowing what is happening around the vehicle).

The Navya Autonom shuttle's localization is supported by a GNSS antenna used as a 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. The shuttle's localization is also supported by the onboard LiDAR sensors that collect 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.

Beep required access to a rooftop location on campus to install the GNSS antenna. UNC Charlotte provided access to McEniry Hall's rooftop so Beep could securely mount the antenna with a 90° view of the sky at minimum (Figure 3). UNC Charlotte also provided a ladder, rope, and staff support to help Beep hoist the heavy equipment to the rooftop.

Figure 3. GNSS antenna installed on the roof of McEniry Hall on UNC Charlotte's main campus. (Image courtesy of Beep)

Storage and Charging

UNC Charlotte provided a secure location at the Facilities Operations and Parking Services (FOPS) complex (Figure 4) to store the shuttle that included the appropriate charging equipment to power the all-electric shuttle as listed in Appendix B.

Figure 4. Shuttle inside its storage and charging location at FOPS on UNC Charlotte's main campus. (Image courtesy of Beep)

Remote Monitoring

Beep monitored the operation of the Navya Autonom shuttle during the pilot through their "Beep Command Center" (BCC). Beep uses the BCC as their central hub for data collection and analysis. The BCC collects and analyzes operational data throughout the duration of a project and provides support for and monitors automated vehicle operations during the operational hours of Beep's deployments across the United States.

Regulations

Beep operates the Navya Autonom shuttle on public roadways in the United States for research and demonstration purposes through importation under Box 7 on the HS-7 declaration form[8] in accordance with 49 U.S.C. § 30114(a)[9] and 49 CFR Part 591.[10] Vehicles that do not conform with all applicable Federal Motor Vehicle Safety Standards (FMVSS) may be imported under Box 7 for the purpose of research, investigations, demonstrations, training, or competitive racing events. Under their contract with NCDOT, Beep submitted a request to NHTSA for an exemption from FMVSS for the Navya Autonom shuttle and permission to operate the shuttle in a pilot on the route at UNC Charlotte in compliance with Box 7 requirements.

Planning

NCDOT, UNC Charlotte, and Beep held a formal project kickoff meeting to discuss and confirm roles and responsibilities for each team and its members, establish a timeline with key activities towards opening the shuttle to the public, and review Beep's commissioning process for preparing the shuttle for operations on the route. NCDOT and UNC Charlotte used standardized agenda and meeting summary templates that organized key activities by category: administrative, operations, infrastructure including the traffic signals, marketing and promotion, incident response plan and first responder workshop, data collection, commissioning by Beep, and start of service (Appendix C). Updates with action items by category were communicated through bi-weekly check in meetings between NCDOT, UNC Charlotte, and Beep. 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.

[8] National Highway Traffic Safety Administration. (2023). Information for Importing a Vehicle. https://www.nhtsa.gov/importing-vehicle

[9] Special exemptions, 49 U.S.C. § 30114. (2021). https://www.govinfo.gov/app/details/USCODE-2021-title49/USCODE-2021-title49-subtitleVI-partA-chap301-subchapII-sec30114

[10] Importation of Vehicles and Equipment Subject to Federal Safety, Bumper and Theft Prevention Standards, 49 CFR Part 591. (2023). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-591

Administrative

Contract

NCDOT executed a contract with Beep in November 2022 with respect to NC General Statute § 136-28.1(h).[11] The contract covered multiple projects in North Carolina under the CASSI program, including the pilots in Cary's Bond Park and at UNC Charlotte. 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 Beep's automated shuttle meets the definition of applied research or experimental work. Any shuttle supplied by Beep would be deployed to research and evaluate autonomous vehicle technology and not as an NCDOT vehicle fleet.

Vehicle Delivery to North Carolina and Inspection, Titling, and Registration

Beep contracted with Eagle Express to deliver the shuttle from Navya's facility in Michigan to North Carolina in December 2022 for the pilot in Cary's Bond Park. NCDOT coordinated with Beep and the North Carolina Division of Motor Vehicles (NC DMV) to ensure that the shuttle was inspected, titled, and registered prior to operating on roadways in North Carolina. As the owner of the shuttle, Beep was the registrant and title holder for the vehicle. A representative from Beep was on site for the inspection, titling, and registration activities. Additional details on the vehicle delivery and inspection, titling, and registration activities are provided in the final report for the CASSI in Cary's Bond Park project.[12]

Vehicle Transport to and from UNC Charlotte

Upon the completion of the pilot in Cary's Bond Park, Beep transported the shuttle to UNC Charlotte on a flatbed truck. Beep transported the shuttle from UNC Charlotte to their headquarters in Lake Nona, Florida on a flatbed truck when the pilot concluded (Figure 5).

Figure 5. Transport of the shuttle from UNC Charlotte to Lake Nona, Florida. (Image courtesy of Beep)

[11] 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
[12] Ibid.

General Agreement

NCDOT and UNC Charlotte executed a general agreement that documented the funding arrangement, responsibilities, and expectations for the pilot. The 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 UNC Charlotte; and additional provisions. Joint and individual responsibilities per the agreement are summarized in Appendix D. The basic project timeline as included in the general agreement is provided in Appendix E.

Permission to Operate the Vehicle on Public Roadways

An approval document from NHTSA grants permission to Beep to operate the shuttle on its route at UNC Charlotte under certain defined conditions (Appendix F) in a research and demonstration program involving interaction with members of the public. This document is required to register and title the shuttle in North Carolina and for Beep to operate the shuttle on an approved route and accept passengers.

Permission to Enter Agreement

UNC Charlotte executed a permission to enter agreement with Beep prior to Beep conducting any on-site work on campus. The agreement detailed insurance requirements, including minimum limits for general liability, commercial automobile liability, commercial excess liability (umbrella policy), worker's compensation, and employer's liability, with UNC Charlotte named as additional insured on all insurance policies (except worker's compensation and professional liability).

Insurance

NCDOT maintained an updated certificate of coverage through the NC Department of Insurance for the pilot and, like UNC Charlotte, were named as additional insured on all of Beep's insurance policies (except worker's compensation and professional liability).

Operations

Service Schedule

NCDOT, UNC Charlotte, and Beep worked together to set a service schedule for the pilot. They agreed that the shuttle would operate up to forty (40) hours per week only during weekdays, excluding public holidays unless otherwise specified. Service was scheduled for eight (8) hours each weekday, and the shuttle accepted riders during six (6) of those hours (8:30 to 11:30 a.m. and 1:30 to 4:30 p.m.). The shuttle was not expected to be in service from 11:30 a.m. to 1:30 p.m. due to scheduled midday charging.

Additional evening service hours were added to the schedule in November and December to compensate for lost hours of service due to connectivity issues with the GNSS antenna.

The evening service hours also supported research on the shuttle and service being conducted by UNC Charlotte faculty and students. The additional service hours were from 5:30 to 8:30 p.m. on the following 18 dates:

- November 9-10; 13-17; 27; 29-30
- December 4; 6-7; 11; 13-14; 18; 20

Service Interruption Plan

NCDOT, UNC Charlotte, and Beep designed a service interruption plan that outlined the actions to be taken in the event of a service interruption due to attendant absence, inclement weather, battery insufficiency, special events, or construction impacts on campus, including how the change in service would be communicated to the public. The plan also included mutually agreed upon service hours for a defined list of special events and holidays—Friday home football games, Fall Break, Labor Day, and Thanksgiving. The service interruption plan is provided in Appendix G.

Infrastructure

Site Modifications

UNC Charlotte invested significant funding and staff resources to meet requirements for the shuttle's route, storage location, and charging equipment. UNC Charlotte equipped a secure, covered parking area at FOPS with charging equipment. UNC Charlotte assisted Beep with access to McEniry Hall's rooftop to install the GNSS antenna and provided repeated access to the rooftop over the course of the pilot along with a computer monitor, mouse, and power strip so the shuttle's attendant could troubleshoot the GNSS antenna's connectivity issues. UNC Charlotte designed, fabricated, and installed aluminum stop signs at four stops and plastic A-frame informational signs that included a route map at all six stops (Figure 6). UNC Charlotte trimmed back vegetation along the route to ensure that branches and foliage did not intrude into the shuttle's route or be detected as obstacles.

Figure 6. Signs along the shuttle's route and at the stops on UNC Charlotte's main campus. The Science Building (upper left), Light Rail East (upper right), Student Union West (lower left), and Student Union Deck (bottom right) stops are shown. (Images courtesy of NCDOT)

Real-Time Tracking

NCDOT, UNC Charlotte, and Beep desired real-time tracking of the shuttle on the route using Automatic Vehicle Location (AVL) technology. The preferred option for real-time tracking was integrating the shuttle into UNC Charlotte's existing service for their Niner Transit fleet provided by Passio Technologies, Inc. (Passio). UNC Charlotte uses Passio to provide the campus community with information on Niner Transit routes, schedules, and real-time tracking.[13] UNC Charlotte added the shuttle to their Passio system and loaned a tablet to the shuttle's attendant to enable real-time tracking using the tablet's cellular GPS capabilities.

Traffic Signals

NCDOT, UNC Charlotte, CDOT, Beep, and additional technology vendors collaborated to accomplish the V2I integration that enabled the shuttle to autonomously navigate the four signalized intersections on its route. UNC Charlotte owns and maintains the traffic signals and roads on the shuttle's route. The university partners with CDOT for signal operations.

The Roadside Units (RSUs) used for the pilot were Kapsch RIS-9160 – V2X Roadside ITS Station.[14] The RSUs had antennas already attached from their previous project. The antennas were replaced with Mobile Mark 6 dB 5.9 Ghz since the original ones were not optimized for use in the pilot. The controllers at each location were 2070 form factor, installed in the 2000s and 2010s, and retrofitted in June 2023 with 2070-1C CPU modules capable of operating EOS software.

NCDOT purchased the Onboard Unit (OBU) through their contract with Beep. The OBU is an Unex OBU-201U[15] that is fully integrated with the shuttle's ADS software. Navya provides support to Beep for the OBU's operation.

Details about each team's contributions to the V2I integration, the V2I equipment, and the tasks that were completed to set up the V2I equipment are documented in Appendix H.

Marketing and Promotion

NCDOT, UNC Charlotte, and Beep worked together to communicate information about the pilot to the community leading up to and during public operations.

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[13] UNC Charlotte. (n.d.). Transportation. https://pats.charlotte.edu/transportation

[14] Kapsch TrafficCom. (n.d.). Technical Manual Roadside ITS Station RIS-9160-xx0x. https://fccid.io/XZU9160/User-Manual/User-and-Installers-manual-3874195

[15] Federal Communications Commission. (2017, March 6). OBU-201U Specification. https://apps.fcc.gov/els/GetAtt.html?id=201591

Media Assets

NCDOT, UNC Charlotte, and Beep collaborated on and delivered numerous marketing and promotion efforts through various channels (e.g., webpages, media advisories, news releases, and social media). UNC Charlotte's media advisory is provided in Appendix I. Beep's news release is provided in Appendix J.

UNC Charlotte created a visual strategy that guided the creation of assets for external media, including photos and b-roll for local news media; an informational video for web and YouTube; a social media video for Instagram, TikTok, and YouTube Shorts; a design for the shuttle's wrap; designs for the stop and route signs; t-shirts to hand out to the campus community; and stories for campus publications including Niner Insider and Inside UNC Charlotte. The strategy assigned roles to key UNC Charlotte staff and set a schedule to guide content development. NCDOT provided review and feedback as needed.

The UNC Charlotte marketing team visited the CASSI in Cary's Bond Park project in May 2023 to capture exterior and interior photos and b-roll of the shuttle and staff riding the shuttle. The team was also able to meet with Cary staff to learn more about their experiences with the pilot in Bond Park. UNC Charlotte used the photos and videos in their marketing materials to announce the launch of the pilot at UNC Charlotte. UNC Charlotte spliced the footage from Bond Park including drone footage taken above the route with footage of the shuttle testing on its route at UNC Charlotte to create an announcement video.[16] UNC Charlotte also created a video that showed the shuttle "meeting" an automated sidewalk delivery robot from the Starship Technologies (Starship) fleet.[17] The Starship robots deliver food from campus vendors to locations on campus.[18]

Public Engagement

Thirteen documented engagement activities were completed at UNC Charlotte during the pilot period (Figure 7), including a media day and visits from professionals from local and regional organizations such as the Airbus U.S. Manufacturing Facility, Charlotte Douglas International Airport, Atlanta International Airport, River District, and Georgia Institute of Technology. These activities furthered NCDOT's goal of building public awareness and acceptance of emerging shared mobility options by enabling the community to experience new technologies firsthand.

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[16] UNC Charlotte Auxiliary Services. (2023, July 18). Say Hello to CASSI at UNC Charlotte. https://www.youtube.com/watch?v=fgTsJsTkp8g

[17] UNC Charlotte Auxiliary Services. (2023, August 24). CASSI meets Starship #cltauxservices. https://www.youtube.com/watch?v=SpL2w6cZ43U

[18] Inside UNC Charlotte. (2023, March 8). Meet the Food Delivery Robots. https://inside.charlotte.edu/news-features/2023-03-08/meet-food-delivery-robots

September 2023	Media Meet and Greet Day
	Airbus U.S. Manufacturing Facility Visit
	Charlotte Douglas International Airport (CLT) Visit
	Hartsfield-Jackson Atlanta International Airport (ATL) Visit
October 2023	NCDOT ITS & Signals Management Section Visit
	Engagement Event with Community Members with Disabilities
	River District Visit
	Georgia Institute of Technology Visit
November 2023	Centralina Regional Council's CAV Task Force Meeting
	Engagement Event with Community Members with Disabilities
December 2023	Cary Team Visit
	Centralina Regional Council's Mobility Management Meeting
	CRTPO Transportation Staff Meeting

Figure 7. List of documented engagement activities during the pilot on UNC Charlotte's main campus. (Image courtesy of NCDOT)

NCDOT, UNC Charlotte, and Beep collaborated to plan and complete a ribbon-cutting event to officially launch the pilot in August 2023 when students returned to campus for the fall semester. The teams expected to hold the event outside the Popp Martin Student Union and to include remarks from the Chancellor, NCDOT Transportation Secretary, Charlotte Mayor, and the Beep CEO. The event was expected to include an "inaugural ride" on the shuttle with the speakers and the UNC Charlotte Student Body President and photos with the shuttle. Due to the threat of adverse weather from Hurricane Idalia and an active shooter incident at a neighboring UNC system university just days prior to the scheduled event, the ribbon-cutting event was cancelled and replaced by a media day with invited local and regional media outlets.[19,20,21]

Wrap Design

UNC Charlotte created the design for the shuttle's wrap (Figure 8). Beep was contracted to print and install the wrap. Beep contracted with a local company for the printing and installation of the wrap—the same company used for the CASSI in Cary's Bond Park project.

[19] WBTV. (2023, September 7). Autonomous bus CASSI operates longest route yet at UNC Charlotte. https://www.wbtv.com/2023/09/07/autonomous-bus-cassi-operates-longest-route-yet-unc-charlotte/

[20] WCNC Charlotte. (2023, September 7). New self-driving shuttle being tested at UNC Charlotte. https://www.wcnc.com/article/news/local/unc-charlotte-self-driving-shuttle/275-ea0de37c-bb48-40ae-8ab3-a4255c4d914e

[21] Queen City News. (2023, September 7). UNC Charlotte students can now use autonomous vehicle to get around campus. https://www.qcnews.com/news/unc-charlotte/unc-charlotte-students-can-now-use-autonomous-vehicle-to-get-around-campus/

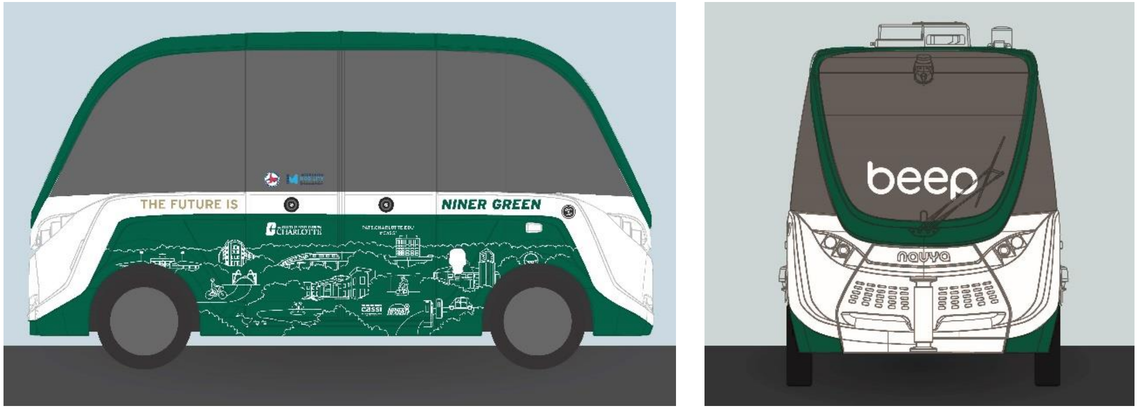

Figure 8. The shuttle's wrap design. (Images courtesy of UNC Charlotte)

Incident Response Plan

NCDOT, UNC Charlotte, and Beep created an incident response plan that defines the actions to be taken by NCDOT, UNC Charlotte, Beep, the attendant, and first responders in the event of a non-emergency or emergency incident. A non-emergency incident was defined as an incident whereby the vehicle has become immobilized for reasons that do not pertain to involvement with another vehicle, pedestrian, or object. An emergency incident was defined as an incident whereby the vehicle has struck or been struck by any object, car, or person, or a crash has occurred to jeopardize the safety of a person or inflicted damage to the vehicle. The incident categorization was aligned with Beep's internal safety protocol.

The incident response plan included phone numbers for all responsible parties and a list of towing companies with phone numbers as a reference in the event the shuttle was inoperable and needed to be removed from the roadway. The incident response plan with contact information redacted is provided in Appendix K.

First Responder Workshop

NCDOT, UNC Charlotte, and Beep held a first responder workshop with staff from the UNC Charlotte Police Department, Charlotte Fire Department, and Mecklenburg Emergency Medical Services (EMS) Agency (Medic). Beep shared a slide presentation that reviewed the project details and scope, incident categorization, and response flow then provided hands-on training on the shuttle, including how to tow and lift the vehicle, disable its power supplies, and access and extract its occupants. NCDOT then reviewed the incident response plan that was created with input from UNC Charlotte and Beep. Feedback from attendees was incorporated into the final version of the plan that was distributed to the first responders assigned to the project area.

Transit Operator Training

Beep organized and held a virtual training with UNC Charlotte transit operators and staff prior to opening the shuttle to the public. Beep's goal was to orient the Niner Transit team to the pilot and to share their expectations for how the automated shuttle would coexist with the Niner Transit fleet during the pilot. Beep shared a slide presentation that reviewed information about their company, how the shuttle would share the road with the Niner Transit fleet, best practices for sharing the road, the shuttle's technology and capabilities including its accessibility features, and the incident categorization with response flow that was shared during the first responder workshop. Key guidance from the presentation included:

- Where the shuttle and Niner Transit stops were on the same curb, Niner Transit would have priority and stop closest to the destination;
- If Niner Transit was behind the shuttle, the shuttle would wait at the stop and give Niner Transit the right of way; and
- Niner Transit was advised to maintain a proper distance behind the shuttle in case the shuttle stopped quickly, not to pass the shuttle between stops since the shuttle would wait for the transit buses to pass, and that the shuttle would have dynamic messaging boards on the front and back to indicate the shuttle's status or next action (Figure 9).

Figure 9. One of the shuttle's dynamic message boards indicates that the shuttle is "going left." Photo from the CASSI in Cary's Bond Park project. (Image courtesy of NCDOT)

Commissioning

Beep completed a standardized set of activities to commission the shuttle, i.e., prepare the shuttle to operate on the route and provide passenger service to the public.

Commissioning by Beep involved the following activities and time commitments. The actual time to completion for each activity is listed first followed by the best practice time to completion where different. Certain tasks deviated from best practice due to factors such as inclement weather and alignment with planned follow up activities.

- Installing the GNSS antenna – one day
- Completing route mapping (environment mapping) using a mobile scanning unit installed on a conventional vehicle – one day
- Processing the mapping data – fifteen days [five to seven days]
- Completing path creation (mapping data analyzed in office) – four days
- Completing path validation using the shuttle – twelve days [five to seven days]
- Validating the RSU/OBU – eighteen days [one to two days to configure the RSU/OBU and then validation is conducted in parallel with path validation]
- Training the on-site attendant on the route – two days [attendant transferred from the previous project in Cary's Bond Park so three to five days for new attendants]
- Handing off the shuttle and service to the on-site attendant – one day

Approval of Beep's exemption application and receipt of a permission letter from NHTSA was required before path validation on the shuttle's route could commence.

NCDOT and UNC Charlotte initially planned to open the shuttle to the public on June 26, 2023 based on Beep's commissioning schedule that anticipated approval from NHTSA in early June 2023. Due to unexpected new documentation needs and extended review time from NHTSA, Beep did not receive approval or the permission letter from NHTSA until June 15, 2023. Beep's commissioning activities could not commence until NHTSA approval was granted. Per the conditions of NHTSA's approval, Beep could not open the shuttle to the public and accept passengers until the RSU and OBU communications were working. The unexpected delay combined with the need for more time to complete the V2I integration shifted the commissioning schedule towards a mutually agreed upon revised launch date in July 2023.

Research

NCDOT funded a separate research project with UNC Charlotte faculty and students. The research team instrumented the shuttle with their own sensors and technology to evaluate its operational and safety performance on campus. The research team also conducted an expanded set of surveys to capture the perceptions of shuttle and non-shuttle riders. The research provides in-depth analysis of the effectiveness of an automated shuttle in a complex operating environment such as a university campus. The findings from this research conducted by Pulugurtha et al. are published in a separate report that complements this final report.

Evaluation

NCDOT and UNC Charlotte used multiple data sources to evaluate the shuttle and its service, including:

- Ridership and operations data provided by Beep in weekly data reports
- Feedback from riders captured by NCDOT and UNC Charlotte through an online survey
- Feedback from community members with disabilities and their caregivers, staff from UNC Charlotte's Office of Disability Services, and paratransit professionals from the Charlotte Area Transit System (CATS) captured by NCDOT and UNC Charlotte through two engagement events and exit surveys

Data Collection

Ridership and Operations Data

Beep provided weekly data reports to NCDOT and UNC Charlotte that included ridership and operations data manually captured by the attendant or obtained from the shuttle's computer system. NCDOT and UNC Charlotte compiled Beep's reports for the 23-week pilot period. The dataset includes ridership as number of passengers, number of trips, 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. The dataset also includes the shuttle's disengagements from autonomous mode into manual mode and the reported cause for each event.

NCDOT and UNC Charlotte reviewed and spot checked the data for outliers, duplicates, inconsistencies, and errors on a weekly basis. NCDOT discussed any data issues with Beep to determine the appropriate approach to correct, remove, or standardize the data as required. NCDOT aggregated the data reports to create cumulative datasets week over week.

NCDOT created new fields in the datasets to support their analyses. Created fields include:

- Day of week
- Day of week as number
- Week of year
- Number of weeks into pilot
- Battery percentage used
- Number of passengers per hour operated
- Number of passengers per round trip
- Number of round trips per hour operated
- Incident datetime

NCDOT modeled their approach for reviewing the data reports, creating new data fields, cleaning the data, and sharing the data on Cary's Open Data Portal from the approach developed in partnership with Cary for the CASSI in Cary's Bond Park project.[22] A log that lists the changes to the ridership and operations data that resulted from data cleaning and the creation of new fields is provided on Cary's Open Data Portal along with the final cleaned datasets.[23]

Rider Survey

NCDOT created and implemented an online rider survey using Smartsheet. The survey questions were informed by surveys from prior projects under the CASSI program and were updated to reflect the context of the pilot at UNC Charlotte. The survey was accessible through URL and QR codes at the shuttle stops and inside the shuttle during the pilot period (Figure 10). The survey asked riders about their travel patterns and trip purpose, experience with the shuttle and attendant, and their basic demographics. 62 responses were collected in total. 59 respondents rode the shuttle, and three respondents did not ride the shuttle. The survey questions and response categories are provided in Appendix L.

Figure 10. Quick Response (QR) codes inside the shuttle and on the A-frame signs at the shuttle's stops on UNC Charlotte's main campus that link to the online rider survey. (Images courtesy of NCDOT)

NCDOT downloaded and reviewed the survey responses on a weekly basis during the pilot period. Outliers, duplicates, inconsistencies, and errors were identified and flagged. When the pilot ended, NCDOT performed data cleaning to review the flagged records and then correct, remove, or standardize the data. NCDOT created separate datasets for the raw survey responses as received, the annotated and cleaned survey responses, and the final cleaned dataset used for analyses that was limited to the responses for the respondents that rode the shuttle. A log that lists the changes to the survey responses that resulted from data cleaning is provided on Cary's Open Data Portal along with the final cleaned datasets.[24]

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[22] Ibid.

[23] Cary, NC. (2024, July 12). Cary, NC Open Data Portal. https://data.townofcary.org/pages/homepage/

[24] Ibid.

Engagement with Community Members with Disabilities

In addition to the ridership and operations data from Beep and the results from the rider survey, NCDOT and UNC Charlotte held two engagement events in partnership with Beep to gather feedback about the accessibility of the shuttle and service. NCDOT worked with staff from UNC Charlotte's Office of Disability Services and the Charlotte Area Transit System (CATS) to invite community members with disabilities and their caregivers to view, engage with, and ride the shuttle (Figure 11). While only one disabled person attended an event, staff from UNC Charlotte's Office of Disability Services and paratransit professionals from CATS attended and engaged with the shuttle and service. UNC Charlotte loaned one of their Niner Paratransit vehicles for display at the event alongside the shuttle to enable participants to compare their accessibility features. NCDOT collected participants' feedback on the shuttle's accessibility and usefulness to meet their or their customers' transportation needs through an exit survey. Eleven participants shared their thoughts on their typical trips, what works well for them in the shuttle, and how the shuttle could work better for them.

Figure 11. UNC Charlotte displays their Niner Paratransit vehicle alongside the shuttle. (Image courtesy of NCDOT)

Data Analysis

A sample of the results from the ridership and operations data are provided in Figure 12 and Figure 13. For Figure 13 and subsequent figures displaying data by weeks into the pilot, note that the first week and final week were scheduled as partial weeks of service since the pilot launched on a Wednesday and concluded on a Thursday.

565
Total Riders Served

825
Total Trips

85%*
Uptime

91.0%**
Time Spent in Autonomous Mode

6.2 mph
Average Vehicle Speed on Route

12.6 mph***
Maximum Vehicle Speed on Route

**Includes additional evening service hours on limited dates in November and December; the shuttle was in operation for 625 out of 736 scheduled hours of service.*
***The leading causes of disengagement from autonomous mode into manual mode were lost connection or miscommunication between the shuttle's Onboard Unit (OBU) and the Roadside Units (RSUs) at the signalized intersections and when the shuttle detected a vehicle as an obstacle due to its proximity to the shuttle's path.*
****A maximum vehicle speed on the route of 12.6 mph was reached on only one date during the pilot; the average maximum vehicle speed on the route across all dates was 11.4 mph.*

Figure 12. Results from Beep's ridership and operations data collected during the pilot on UNC Charlotte's main campus. (Image courtesy of NCDOT)

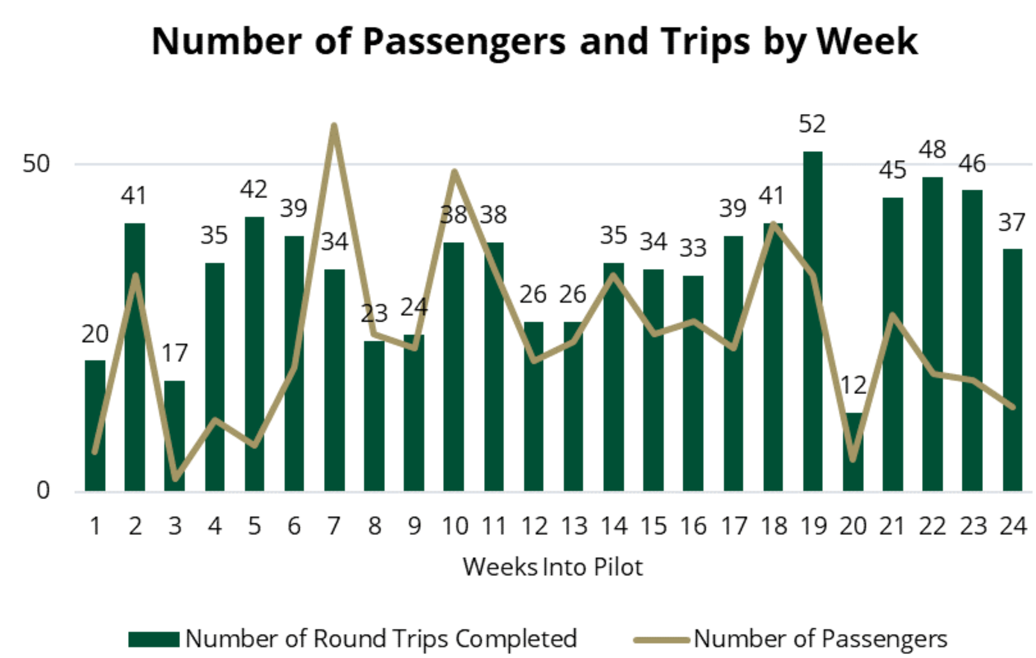

Figure 13. Number of passengers and trips by week during the pilot on UNC Charlotte's main campus based on Beep's ridership and operations data. (Image courtesy of NCDOT)

A sample of the results from the rider survey are summarized in Figure 14.

22% Visited UNC Charlotte to ride the shuttle	**59%*** Rode the shuttle to get to a specific destination	**83%** Had a good experience using the shuttle
92% Had a good experience with the attendant	**56%** Thought the shuttle arrived at their stop within a reasonable amount of time	**61%** Thought they were able to get to their destination in a reasonable amount of time
51% Prefer a driverless shuttle with an attendant	**69%** Would ride the shuttle again	**69%** Support seeing more driverless shuttles on UNC Charlotte's campus

**Includes responses indicating the rider rode the shuttle to get to a specific destination or rode the shuttle both to get to a specific destination and for a fun experience.*

Figure 14. Results from NCDOT's rider survey collected during the pilot on UNC Charlotte's main campus for respondents that rode the shuttle (59 respondents total). (Image courtesy of NCDOT)

Tables that summarize the ridership and operations data and the survey results for respondents that rode the shuttle are provided in Appendix M. Findings from research conducted by Pulugurtha et al. on the perceptions of shuttle and non-shuttle riders are published in a separate report that complements this final report.

Results from the exit survey collected at the engagement events with community members with disabilities and their caregivers, disability services professionals, and paratransit professionals are summarized in Figure 15.

What works well for you in the shuttle?
Open space and head room
Convenient stops
Provides another option for traversing a hilly campus that is full of stairs
Recognizes traffic lights and obstacles in the path
Safety features such as the hard braking and manual override
Seating and space are nice for non-wheelchair users
How could the shuttle work better for you?
Automatic ramp that is wider, more stable, and better accommodates bariatric wheelchair users, scooter users, and some larger motorized wheelchairs
Foldable seats to allow more room for wheelchair placement
Audible stop announcements and instructions (e.g., wear seat belts, no standing, etc.)
Increased seating capacity, bigger space, and larger seats
Automated features so ADA passengers are not entirely dependent on the attendant for assistance
Smoother movement
Determine practices for accessibility for when the vehicle becomes fully autonomous

Figure 15. Results from the exit surveys collected at the engagement events with community members with disabilities and their caregivers, disability services professionals, and paratransit professionals during the pilot on UNC Charlotte's main campus (11 respondents total). (Image courtesy of NCDOT)

Successes

Experience with Shuttle

Feedback from the rider survey indicated that most riders (83% of survey respondents) had a good experience using the shuttle. Those that had a good experience mentioned the shuttle was fun, safe, quicker than walking and less crowded than the bus, convenient, efficient, and helpful for Greek Village riders. Those that did not have a good experience commented that their ride was not smooth; the shuttle was too slow, inconvenient, and spent too much time at the stops; the shuttle does not hold enough people; the shuttle has poor ventilation and stuffy air; and the shuttle makes them late to their destination, holds up other transit on campus, and is not as efficient as other transit on campus.

Experience with Attendant

Feedback from the rider survey showed that most riders (92% of survey respondents) had a good experience with the attendant on the shuttle. Some riders commented on how the attendant spoke with them and showed how the shuttle worked, and that they felt comfortable knowing what the shuttle was seeing and how it responded to hazards. Some riders commented that the attendant was friendly, helpful, and informative and that the shuttle was safe because of the attendant.

Partnerships

Strong partnerships and trusting relationships between NCDOT, UNC Charlotte, CDOT, and Beep contributed to the pilot's successful planning and delivery. The teams held regular meetings to check in on roles and assigned activities, share progress, troubleshoot issues, and work together to craft solutions. UNC Charlotte faculty and students were engaged in a separate research project funded by NCDOT to scientifically study the shuttle and service in a first for the CASSI program. The findings from the research are published in a separate report that expands upon and complements this final report.

Challenges

Service Suspensions

The shuttle was in operation for 625.4 out of 735.5 scheduled hours of service for 85% uptime during the pilot period (Figure 16 and Figure 17). Thirty hours of service were scheduled per week, or six hours per weekday, with additional evening hours added on select dates as summarized in Figure 18. There were 56 days with complete service, 56 days with partial service, two days with complete suspension of service, and three days with no scheduled service.

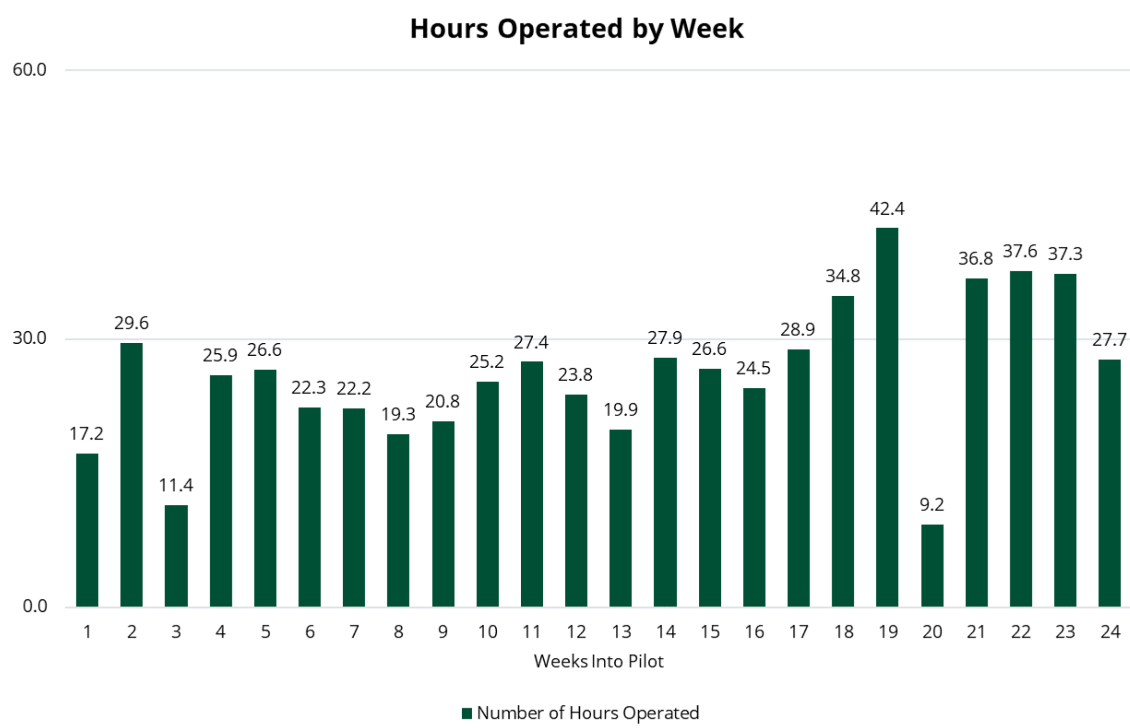

Figure 16. Hours operated by week during the pilot on UNC Charlotte's main campus based on Beep's ridership and operations data. (Image courtesy of NCDOT)

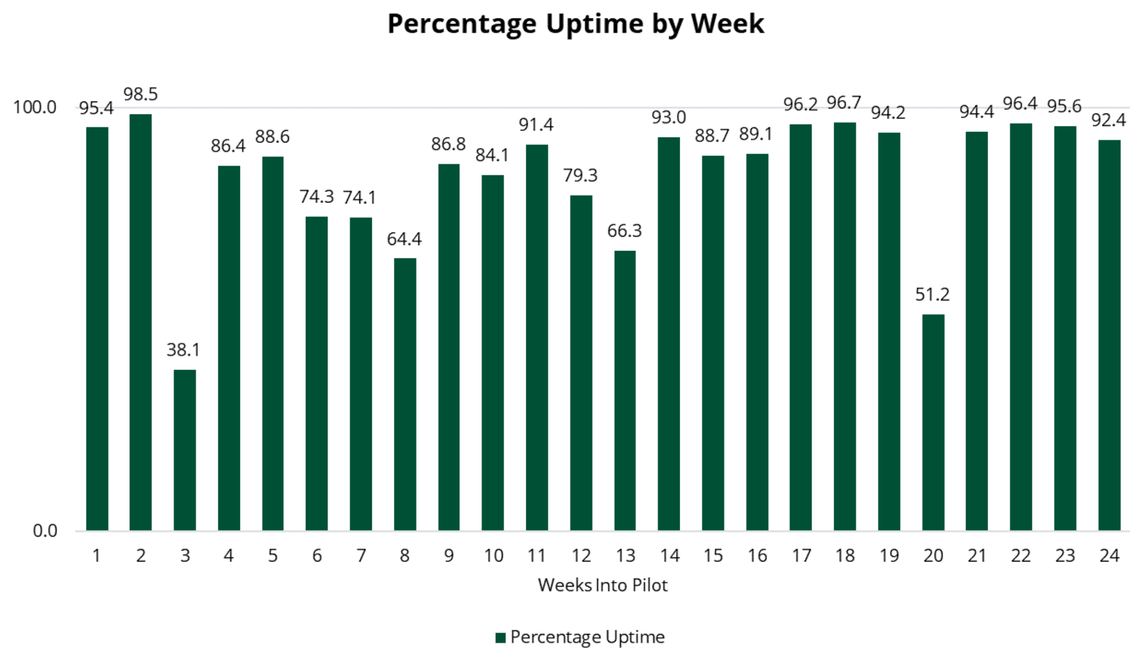

Figure 17. Percentage uptime by week during the pilot on UNC Charlotte's main campus based on Beep's ridership and operations data. (Image courtesy of NCDOT)

Date	Day of Week	Weeks Into Pilot	Evening Service Hours
11/9/2023	Thu	18	Yes; 5:30-8:30 P.M.
11/10/2023	Fri	18	Yes; 5:30-8:30 P.M.
11/13/2023	Mon	19	Yes; 5:30-8:30 P.M.
11/14/2023	Tue	19	Yes; 5:30-8:30 P.M.
11/15/2023	Wed	19	Yes; 5:30-8:30 P.M.
11/16/2023	Thu	19	Yes; 5:30-8:30 P.M.
11/17/2023	Fri	19	Yes; 5:30-8:30 P.M.
11/27/2023	Mon	21	Yes; 5:30-8:30 P.M.
11/29/2023	Wed	21	Yes; 5:30-8:30 P.M.
11/30/2023	Thu	21	Yes; 5:30-8:30 P.M.
12/4/2023	Mon	22	Yes; 5:30-8:30 P.M.
12/6/2023	Wed	22	Yes; 5:30-8:30 P.M.
12/7/2023	Thu	22	Yes; 5:30-8:30 P.M.
12/11/2023	Mon	23	Yes; 5:30-8:30 P.M.
12/13/2023	Wed	23	Yes; 5:30-8:30 P.M.
12/14/2023	Thu	23	Yes; 5:30-8:30 P.M.
12/18/2023	Mon	24	Yes; 5:30-8:30 P.M.
12/20/2023	Wed	24	Yes; 5:30-8:30 P.M.

Figure 18. Additional evening service hours during the pilot on UNC Charlotte's main campus. (Image courtesy of NCDOT)

Complete and partial suspensions of service and dates with no scheduled service are summarized in Figure 19. Notably, the third week of the pilot only had 38.1% uptime due to

GNSS signal loss and troubleshooting (13.8 hours lost) and battery insufficiency or charging issues (4.7 hours lost). The twentieth week of the pilot had fewer scheduled hours because of the Thanksgiving holiday. This week only had 51.2% uptime due to inclement weather and an attendant absence due to illness. Across the pilot period, 110 hours of scheduled service were lost in total due to service interruptions, which equates to 15% of the 735.5 total scheduled hours of service or over 18 days of service at six scheduled hours per day. Beep provided additional evening service hours in November and December to make up some of the lost hours of service.

Type	Date	Reason
No scheduled service	September 4	Labor Day
	October 27	Friday afternoon home football game
	November 23	Thanksgiving holiday
	November 24	
Complete suspension of service	July 27	GNSS signal loss and troubleshooting
	October 2	Repairs to the shuttle's motor bracket
Type	**Number of service suspensions**	**Reason**
Partial suspension of service	19	GNSS signal loss and troubleshooting
	17	Battery insufficiency
	10	Inclement weather
	2	Repairs to the shuttle's motor bracket
	2	Charging equipment not working
	2	Controller reset
	2	Navya was connected to the vehicle
	1	Attendant absence due to illness
	1	Attendant late for start of shift
	1	Attendant in mandatory training
	1	Attendant required to upload footage
	1	Research equipment installation

110
Hours of Scheduled Service Lost

15%*
of Total Scheduled Hours Lost

18*
Days of Scheduled Service Lost

**Includes additional evening service hours on limited dates in November and December.*

Figure 19. Summary of complete and partial suspensions of service, dates with no scheduled service, and lost service hours during the pilot on UNC Charlotte's main campus. (Image courtesy of NCDOT)

GNSS Signal Loss

In late August 2023, approximately seven weeks into the pilot, Beep initiated conversations with NCDOT and UNC Charlotte to explore relocating the GNSS antenna closer to the shuttle's storage area. At this point in the pilot, the shuttle was down for 22% of its scheduled hours of service with over half of the lost hours attributable to issues with the GNSS antenna. When the GNSS antenna malfunctioned, the shuttle's attendant needed to physically access the equipment to troubleshoot issues. This meant that the attendant parked the shuttle at the stop closest to McEniry Hall, walked to McEniry Hall, contacted UNC Charlotte staff to gain access to the building's rooftop, used equipment borrowed from UNC Charlotte to connect to the GNSS router, and performed diagnostics which often required a complete system reset to reboot the communication services. During the first seven weeks of the pilot, troubleshooting took approximately four hours per day on average with the shuttle out of service during that time. Figure 20 shows the attendant's path from the nearest stop at the Science Building to McEniry Hall to access the GNSS antenna.

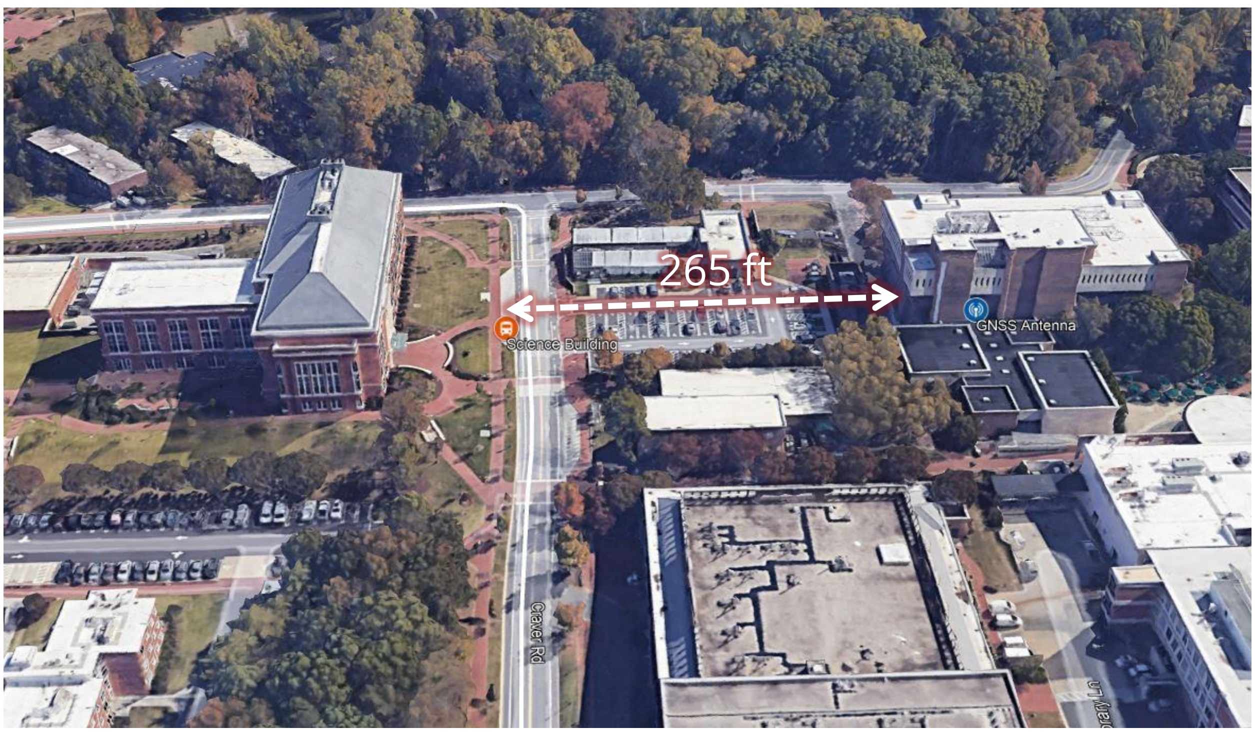

Figure 20. The attendant's path from the nearest stop at the Science Building to McEniry Hall to access the GNSS antenna. (Image courtesy of NCDOT using Google Earth)

Beep hypothesized that the influx of students onto campus after the summer holiday may have interfered with signal quality. Due to documented issues with the GNSS antenna and at the signalized intersections, NCDOT and UNC Charlotte hypothesized that the issue may be with the vehicle's technology rather than the environment, so they requested that Beep further troubleshoot before investing resources to move the antenna away from its current location—which was at an appropriate height and more central location to the shuttle's route compared to the proposed new location near the shuttle's storage area. When the antenna was originally installed on top of McEniry Hall, UNC Charlotte expected to only provide key access to Beep for the work. However, UNC Charlotte also provided a ladder, rope, and staff support to help hoist the heavy equipment to the rooftop since Beep sent only one staff member without the equipment needed to support the work. UNC Charlotte communicated to Beep that they did not have the training or equipment to safely hoist the antenna down from the roof.

Ultimately, in October 2023, Beep decided not to move the GNSS antenna since signal loss became less frequent. Further troubleshooting by Beep with Navya did not yield a definitive root cause.

Battery Insufficiency

In the preceding pilot in Cary's Bond Park, battery insufficiency was an issue due to demand on the shuttle's air conditioning system on hot days exacerbated by the swift loss of cooled air from the shuttle when its large doors are opened.[25] NCDOT and UNC Charlotte proactively implemented a two-hour midday charging period to mitigate battery insufficiency. However, even with midday charging, battery insufficiency led to 14 lost hours of service with an additional seven hours of lost service attributable to charging issues. Beep has a policy to bring shuttles back to storage at 40% battery life since, as the shuttle ages and the battery level decreases, the vehicle enters "emergency mode" when the battery reaches 20-35%, meaning the shuttle will shut down with no steering or propulsion and requires towing. This requirement increases the likelihood of reduced service due to battery insufficiency.

Generally, battery insufficiency was a greater issue at the beginning of the pilot during the warm summer months when the shuttle's air conditioning was needed compared to the cooler fall and winter months.

Disengagement from Autonomous Mode into Manual Mode

According to Beep, the shuttle spent 91.0% of its time on the route in autonomous mode during the pilot period. There were 267 documented disengagements from autonomous mode into manual mode or 2.4 per day on average on days of complete or partial service. The most common causes of disengagement were:

- Signalized intersection (45%)
- Other road users (18%)
- Vegetation (9%)
- Signal loss (8%)

[25] Ibid.

- Station blocked (7%)
- Obstacle detection (5%)
- Fault code/error code (3%)
- Priority zone (3%)
- Shuttle manually deviated from approved path (1%)

The signalized intersections were a common cause of disengagement from autonomous mode into manual mode throughout the pilot period, whereas other road users were a common cause of disengagement prior to week 7 (Figure 21). Vegetation was a common cause of disengagement only through week 5 when UNC Charlotte staff trimmed back overhanging branches that were interfering with the shuttle's operation at certain points on the route.

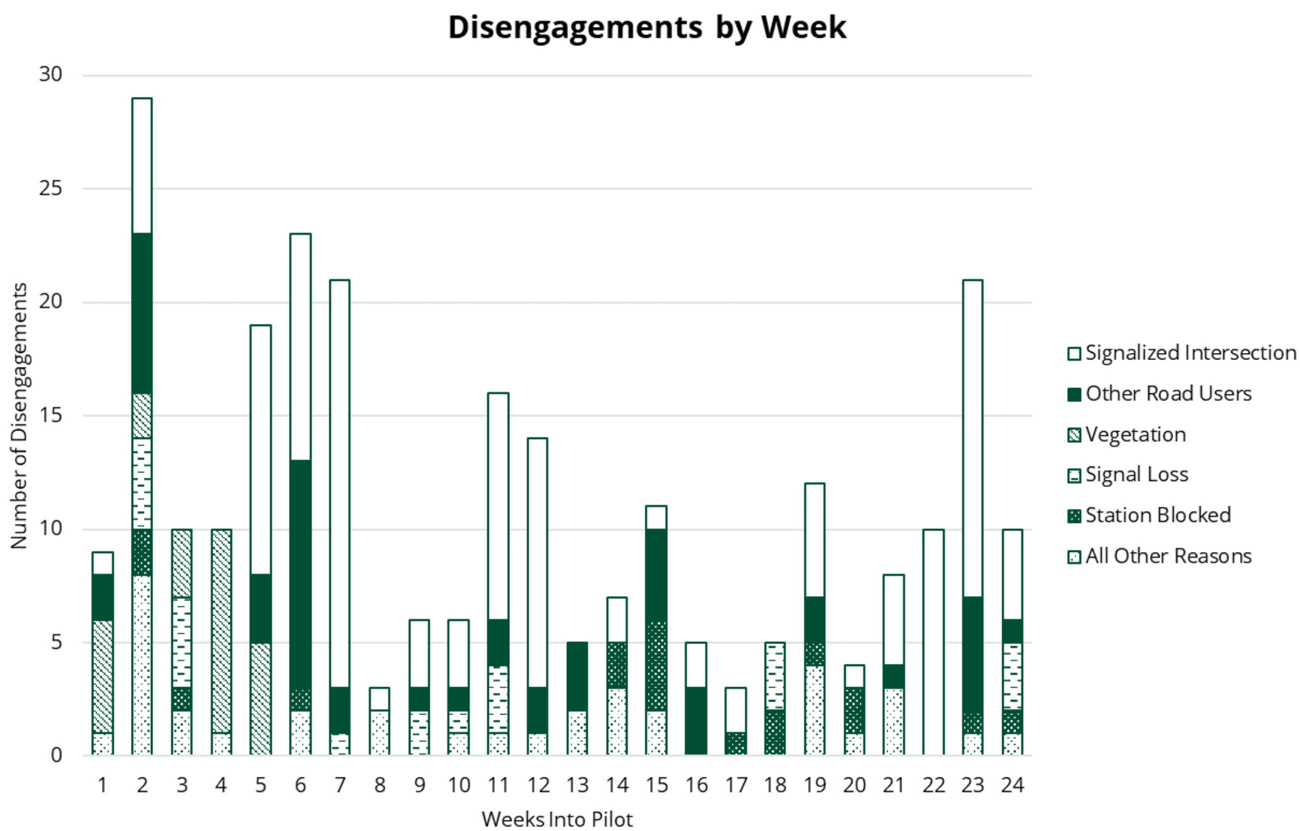

Figure 21. Disengagements by week during the pilot on UNC Charlotte's main campus based on Beep's ridership and operations data. (Image courtesy of NCDOT)

Vehicle-to-Infrastructure Miscommunication

The leading cause of disengagement from autonomous mode into manual mode was when the vehicle's Onboard Unit (OBU) lost connection to or experienced miscommunication with the Roadside Units (RSUs) at the signalized intersections on the route. The vehicle's

OBU was expected to receive messages from the RSU about the signal's phasing and timing and use the information to operate autonomously through each intersection. When a lost connection or miscommunication occurred, the shuttle would sometimes stop at the intersection when the traffic light was green or not proceed on green after stopping when the traffic light was red. The attendant resolved this issue by manually operating the vehicle until autonomous mode could be resumed. The attendant sometimes needed to reset the OBU after resetting the shuttle's User Interface (UI) to resolve the issue. Additional information on the V2I communications including an analysis of the shuttle's behavior at the signalized intersections is provided in Appendix H.

Other Road Users

The second leading cause of disengagement from autonomous mode into manual mode was other road users. This means that the shuttle detected a vehicle as an obstacle due to its proximity to the shuttle's path. The attendant resolved this issue by navigating around the vehicle in manual mode then returning to autonomous mode. This type of disengagement is only in reference to other vehicles, such as passenger cars, buses, and motorcycles, and does not include anyone categorized as a Vulnerable Road User (VRU), such as bicyclists, pedestrians, electric scooters, and skateboarders. Very few disengagements resulted from VRU interacting with the shuttle since the attendant is trained and expected not to disengage and drive manually within the presence of VRU unless necessary. Instead, the attendant is expected to hit the "STOP" button on the shuttle's UI screen if they see a VRU approaching or potentially approaching the shuttle's path. According to Beep, by pressing the "STOP" button, the attendant avoids any manual disengagement.

Shuttle's Comfort

Feedback from the rider survey indicated that some riders felt unsafe or uncomfortable while riding the shuttle due to jerky braking and abrupt stops. The shuttle was programmed to brake sharply when an obstacle was detected by its sensors. The shuttle also braked abruptly when stopping at intersections and upon disengagement from autonomous mode into manual mode.

Shuttle's Speed

Some riders commented on the slow speed of the shuttle. The shuttle was programmed to operate at a defined maximum speed on each segment of the route based on roadway geometry and environmental conditions. The shuttle moved the slowest through parking areas. While the maximum allowable speed of the shuttle was 12 mph as documented in the permission letter from NHTSA, its average speed on the route during the pilot period was 6.2 mph.

Shuttle's Route

Feedback from the rider survey indicated that some riders were dissatisfied with the portion of the shuttle's route from Greek Village to the Science Building (Figure 24). When the route was originally developed, Beep recommended avoiding the unprotected left turn onto Mary Alexander Road from Cameron Boulevard as the shuttle proceeded west from Greek Village towards the Science Building. Instead of turning left onto Mary Alexander Road at the intersection, the approved programmed route directed the shuttle right to Lot 12 where the shuttle made a U-turn back onto Mary Alexander Road and proceeded south straight through the intersection at Cameron Boulevard (Figure 22). While the attendant explained this diversion to riders as meeting a safety need, feedback from the rider survey suggests that some riders found the extra distance and time unnecessary and burdensome. One rider suggested the U-turn took up too much time and made them late for class.

Figure 22. Map showing the U-turn at Lot 12 to enable the shuttle to navigate through the intersection at Cameron Boulevard and Mary Alexander Road without turning left at the traffic signal. (Image courtesy of NCDOT using Google Earth)

Shuttle's Accessibility

During the CASSI in Cary's Bond Park project, feedback was gathered from an engagement event with community members with disabilities and their caregivers and shared with Beep with the expectation that two features of the shuttle could be immediately improved before the shuttle was moved to UNC Charlotte: adding an automatic wheelchair ramp and adding stop announcements.[26] Beep was not able to meet the request. Since the vehicle was manufactured in France, the automatic ramp that was available did not meet existing Americans with Disabilities Act (ADA) requirements in the United States. While the vehicle has an interior speaker system, Beep has no existing service or protocol for incorporating automated stop announcements and other auditory cues.

Additional feedback was gathered by NCDOT and UNC Charlotte from community members with disabilities, staff from UNC Charlotte's Office of Disability Services, and paratransit professionals from the Charlotte Area Transit System (CATS) through two engagement events and exit surveys. This feedback pointed out the same limitations related to the lack of an automatic ramp and audible stop announcements as captured in the CASSI in Cary's Bond Park project (Figure 15). The feedback also noted that the shuttle could benefit from any automated features that ensured ADA passengers are not entirely dependent on the attendant for assistance and from the development of practices for accessibility for when the vehicle becomes fully autonomous.

Lessons Learned

The lessons learned in the areas of technology, route design, infrastructure, operations, data, regulations, and accessibility captured in the preceding CASSI in Cary's Bond Park project are generally applicable to the CASSI at UNC Charlotte project. Those details can be found in the project's final report.[27] Additional lessons learned from the pilot at UNC Charlotte are provided in the following sections.

Technology

The signalized intersections and other road users were the most common causes of disengagement from autonomous mode into manual mode during the pilot period. Information on the V2I communications, including the troubleshooting, problem solving, and issues encountered during the pilot period, are documented in Appendix H. Disengagements due to other road users were often due to parked vehicles either directly in the shuttle's path or adjacent to the travel lane but encroaching on the path. The shuttle is unable to autonomously navigate around obstacles in its path, so it disengages from autonomous mode and comes to a complete stop when it detects a vehicle as an obstacle due to its proximity to its path. The attendant must manually operate the shuttle until the path is clear and conditions are appropriate to proceed in autonomous mode.

GNSS signal loss was a persistent issue throughout the pilot period. The GNSS antenna would sometimes not work properly causing a service interruption while the attendant

[26] Ibid.
[27] Ibid.

worked to reset the system then troubleshoot issues with Navya. As described earlier in this report, the main cause of partial suspension of service (less than one service day per event) was GNSS signal loss and troubleshooting. Further, the attendant was not equipped with all the tools and equipment needed for troubleshooting the GNSS antenna's connectivity issues—UNC Charlotte loaned a computer monitor, mouse, and power strip and also provided repeated access to the roof of the academic building where the antenna was installed.

Route Design

Route design influences how much time an automated vehicle is in autonomous mode compared to manual mode and is guided by the capabilities and limitations of the technology. When the route was originally developed by UNC Charlotte, two areas of concern were identified by Beep based on limitations to the shuttle's technology: the slope of the route at certain points on Craver Road adjacent to the student union that posed a performance risk and an unprotected left turn onto Mary Alexander Road from Cameron Boulevard that posed a safety risk.

Beep worked with the shuttle's manufacturer, Navya, to further analyze the slope on Craver Road. Beep and Navya determined that the slope was within the acceptable threshold according to the shuttle's appropriate operating conditions (Appendix A). Beep recommended avoiding the unprotected left turn onto Mary Alexander Road from Cameron Boulevard since this turn would require intervention from the attendant to safely navigate—the attendant must visually confirm that the roadway is clear then authorize the shuttle to proceed with the turn by touching a button on a touchscreen inside the shuttle. To avoid the unprotected left turn, Beep programmed the shuttle to make a U-turn after turning in the opposite direction of the preferred route. This diversion enabled the shuttle to proceed straight through the intersection after completing the U-turn. While ensuring safety based on the capabilities of the shuttle's technology, the adjustment added length and time to the route.

Any changes to the route or operations are reviewed and confirmed by NHTSA prior to implementation. Changes could include running the 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 shuttle's operator to NHTSA and are expected to conform to the shuttle's appropriate operating conditions.

Infrastructure

Significant investment is sometimes needed to meet an automated vehicle's storage and charging requirements. As detailed earlier in this report, UNC Charlotte invested significant resources to meet requirements for the shuttle's route, storage location, and charging equipment as listed in Appendix B, including equipping a secure, covered parking area with charging equipment, providing support for the GNSS antenna installation and subsequent troubleshooting, creating and installing signs at the shuttle's stops, and trimming back vegetation along the route.

Marketing, Promotion, and Engagement

UNC Charlotte also invested considerable resources towards marketing materials and engagement events, including a webpage, social media campaign, and meeting facilitation with the media and visitors. These activities were essential to ensure the community was able to experience the 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.

Operations

The pilot at UNC Charlotte was unique compared to previous projects under the CASSI program because the campus had multiple existing transportation options for faculty, staff, students, and visitors (Figure 23). UNC Charlotte provides transit, paratransit, scooter share, and bikeshare with supporting infrastructure including shared use paths, bike lanes, and sidewalks as well as designated stops, parking areas, bike lockers, and racks. There are many ways to walk, bike, roll, or ride to destinations on campus. The shuttle shared its route and stops with existing Niner Transit bus services, including the Green, Silver, Gold, Red, and Greek Village routes. The automated shuttle supplemented the conventional shuttles on the Greek Village route. UNC Charlotte's main campus also features a LYNX Blue Line light rail station so community members can easily ride to and from off-campus destinations including downtown Charlotte.

Figure 23. Transportation options on UNC Charlotte's main campus, including transit bus, shuttle, paratransit, light rail, bikeshare, and scooter share. (Images courtesy of UNC Charlotte and CATS)

Feedback from the rider survey combined with the low overall ridership over the 23-week pilot period (565 passengers over 825 trips for an average of less than one passenger per trip) indicated that, while some students appreciated being able to experience and support new technology through the automated shuttle and service, most were choosing other options to reach their destinations on campus, whether due to comfort, convenience, reliability, or some other factor (Figure 24).

As described earlier in this report, the shuttle was in operation for 85% of its scheduled hours of service across the pilot period when accounting for the additional evening service hours in November and December. However, the shuttle's operational performance was inconsistent week to week across the pilot period—for example, weeks 3, 8, 13, and 20 showed uptimes of less than 70% (Figure 17). Further, only 56% of respondents to the rider survey thought the shuttle arrived at their stop within a reasonable amount of time, while

61% of respondents thought they were able to get to their destination in a reasonable amount of time. Only 69% of survey respondents indicated that they would ride the shuttle again or supported seeing more driverless shuttles on UNC Charlotte's campus. Most survey respondents indicated that they would have walked (39%) or taken the bus or other transit (44%) if they had not taken the shuttle—only 7% (4 out of 59 survey respondents) would not have taken the trip.

Like the preceding pilot in Cary's Bond Park, the shuttle was not able to achieve the same level of service as established and standardized transit options due to technology limitations that constrain route and service design options. Unlike the routes for conventional transit on campus, the shuttle's route was designed to avoid uncontrolled left turns to the extent possible—these turns require intervention from the attendant to safely navigate—meaning the route was lengthened with a diversion to meet the safety requirement. Unlike the vehicles used for conventional transit on campus, the shuttle's speed was governed to a maximum of 12 mph to ensure safety including when the shuttle's sharp braking was triggered by obstacles that it detected in its path.

Comments indicating dissatisfaction with the shuttle and service	Comments indicating support for the technology and the experience
It took too long to get to my destination.	It felt safe and was a cool experience.
It would be more beneficial if the shuttle drove a bit faster.	It is a safe and comfortable mode of transportation. I love being a part of the innovation!
The shuttle is too slow.	It is very convenient, quick, and advanced!
It was too slow.	It was a fun experience.
It's too slow.	It was fun.
It's way too slow.	Very fun.
It was WAY too slow.	It was a great experience with the attendant and cool technology.
Because it can only drive 12 mph, it was really slow and took 10 minutes to ride somewhere that should have taken 3.	It was a safe and reliable mode, and I am interested in supporting emerging transportation technologies and multi-modal transportation.
It's extremely slow and I would have to leave 30+ minutes beforehand to get to my destination on time when using the shuttle.	It was convenient and novel!
It's inconvenient, it stops for a long time, and always makes me and my friends late to our destination.	It was very fun to ride the shuttle and experience the future of technology. However, if I'm in a rush I would probably take a regular bus.
The shuttle drives unbelievably slow and instead of getting home in five minutes from the regular bus shuttle, CASSI took 30 minutes for me to get home.	It's very cool and I support furthering technology.

Comments indicating dissatisfaction with the shuttle and service	Comments indicating support for the technology and the experience
The thing goes like 5 miles an hour and holds up traffic and other shuttles that are trying to get students places at a reasonable time making everyone late.	
Having the shuttle not take the left turn at the light for Greek Village and having it do a U-turn takes up too much time and had me late for class.	
There is a shorter route to get from Greek Village to the Science Building, but the bus took a weird turn which was kinda unnecessary.	
The machine needs work for sure. Too much braking, too slow, too much recharge time. What really kills it is the recharge time. The shuttle is barely available.	
The shuttle stops for extended periods of time without warning causing a major inconvenience for students riding.	

Figure 24. Sample comments from NCDOT's rider survey collected during the pilot on UNC Charlotte's main campus for respondents that rode the shuttle (59 respondents total). (Image courtesy of NCDOT)

Service Audits

NCDOT and UNC Charlotte staff rode the shuttle multiple times throughout the pilot period to audit the shuttle and the attendant's performance to ensure the service was meeting expectations. When issues were identified, they were discussed with Beep and resolved with no recurrence. Some items that required attention early in the pilot period were:

- The attendant sometimes did not fulfill expected duties related to the tablet equipped with GPS that was required for real-time tracking on the Passio system—including charging, turning on, or bringing the tablet onboard the shuttle.
- The attendant did not travel the entire route or stop at every designated stop on the route on two documented occasions—this issue resulted on one documented occasion when the primary attendant was on leave and an attendant less experienced with the route and stops covered the service.
- The attendant sometimes did not thoroughly clean the shuttle at the end of each day and had to borrow cleaning supplies from UNC Charlotte.
- Beep, NCDOT, and CDOT needed to troubleshoot the V2I communications at certain signalized intersections on the route.

The service audits were a helpful tool to proactively identify issues and work together to formulate solutions to ensure the best possible experience for riders within the expectations and constraints of a pilot.

Service Suspensions

Service suspensions and interruptions are likely to occur during automated vehicle pilots since the technology is being tested and evaluated while providing passenger service to the public. Learning from the preceding pilot in Cary's Bond Park, NCDOT and UNC Charlotte proactively developed a service interruption plan and protocols to ensure that the campus community was promptly informed when the shuttle was out of service (Appendix G).

However, as previously described in this report, service interruptions due to inclement weather or issues with the shuttle's technology—notably the GNSS antenna and the shuttle's battery—were frequent and disruptive to the point that a considerable number of scheduled hours of service were lost. The attendant is authorized to operate the shuttle manually with passengers onboard when it is necessary to avoid an obstacle blocking the roadway. The attendant then reengages into autonomous mode when safe to do so. The attendant cannot operate the shuttle manually for extended distances under conditions where the shuttle cannot drive on its own since the shuttle has non-conventional driving controls.

UNC Charlotte strategically aligned the shuttle's route with an existing route with service to the same destinations, so the campus community was not wholly dependent on the shuttle for their transportation. UNC Charlotte also intentionally framed the project as a pilot in their marketing and were clear in their communications that the shuttle was being provided as an option not a replacement for a limited time per the advertised pilot period.

Real-Time Tracking

Riders expect consistency with transit schedules including reliable arrival and departure times. UNC Charlotte used AVL technology to provide real-time tracking of the shuttle by integrating the shuttle into their existing Passio service. UNC Charlotte uses Passio to provide the campus community with information on Niner Transit routes, schedules, and real-time tracking.[28] However, real-time tracking does not guarantee service reliability. The results from the rider survey for the pilot at UNC Charlotte showed the lowest level of agreement for the questions that asked about wait and arrival times. Only 56% of respondents thought the shuttle arrived at their stop within a reasonable amount of time, while 61% of respondents thought they were able to get to their destination in a reasonable amount of time.

Several factors could have contributed to the shuttle's unreliability:

- Beep organized and held a virtual training with UNC Charlotte transit operators and staff prior to opening the shuttle to the public. This training advised that Niner Transit would have priority and stop closest to the destination at any stop shared with the

[28] UNC Charlotte. (n.d.). Transportation. https://pats.charlotte.edu/transportation

shuttle. The shuttle may have needed more time between stops if it was frequently yielding the right of way to Niner Transit.

- The results from the rider survey indicated that the shuttle sometimes stopped for a long time. The long stop times could have been intentional if the shuttle's attendant idled at a stop awaiting passengers. The long stop times also could have been the result of the attendant resolving an issue with the shuttle's technology, such as signal loss, connection loss or miscommunication at the signalized intersections, or a software malfunction requiring a hard system reset.
- Additionally, the shuttle is programmed to come to a complete stop when an obstacle is too close or when all required conditions for operation are not met. The shuttle's system prompts the attendant to take control until autonomous operation can resume. The shuttle is 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 time needed for the attendant to safely mitigate issues and intervene during disengagements could have resulted in delay.

Through a separate research project funded by NCDOT and led by Pulugurtha et al., an in-depth analysis was conducted to evaluate the shuttle's operational and safety performance using GPS data from the Passio system, LiDAR data collected using a sensor installed on the shuttle, video data from cameras installed inside the shuttle and at key locations on the shuttle's route, and an expanded set of surveys that captured the perceptions of shuttle and non-shuttle riders. The findings from the research are published in a separate report that complements and expands upon this final report by providing additional analysis and discussion, including on the shuttle's reliability.

Data

Since automated vehicle technology is still in the research and development (R&D) and demonstration phases of development, key performance indicators or measures of success related to its use for public transportation should be sensitive to the limitations of the technology in comparison to conventional options. Shuttles like the one piloted at UNC Charlotte have historically been operated for research and demonstration purposes only and have not been implemented in standardized transit services.

For the pilots in Cary's Bond Park and at UNC Charlotte, the shuttle's attendant manually captured data related to ridership and operations, including the shuttle's disengagements from autonomous mode into manual mode and issues encountered at the signalized intersections. As noted in Appendix H, Beep created a brand-new process for manually logging issues related to the RSUs and OBU for the pilot at UNC Charlotte, which contributed to inconsistencies that were identified between the disengagement and RSU reports as well as incomplete or missing records as acknowledged by Beep.

Improved automation of Beep's data collection processes would enhance the timeliness, accuracy, completeness, uniformity, integration, and accessibility of their ridership, operations, disengagement, and V2I miscommunications-related data compared to their current manual approach.

Regulations

Federal Motor Vehicle Safety Standards (FMVSS) compliance is a key issue for novel-design, low-speed automated shuttles like the one piloted at UNC Charlotte. For the shuttle to operate on public roads and accept passengers, the National Highway Traffic Safety Administration (NHTSA) grants an exemption from FMVSS to the owner and operator of the shuttle after a lengthy application and review process.

Novel-design, low-speed automated shuttles like the one piloted at UNC Charlotte do not meet additional federal regulations such as Federal Transit Administration (FTA) funding requirements and Americans with Disabilities Act (ADA) requirements as documented in multiple federal guidance documents and research reports.[29,30,31,32,33]

Accessibility

Traditional transit service can and is expected to handle accessibility, where vehicles and transit professionals are equipped to accommodate people with disabilities and using mobility devices such as a wheelchair, walker, or cane. The novel-design, low-speed automated shuttle piloted at UNC Charlotte did not include the full set of accessibility-related features needed to serve people with disabilities. While the shuttle included a manual wheelchair ramp and securement system, some community members that attended engagement events around the shuttle's accessibility expressed concern about the ramp's stability and size to accommodate the different dimensions and weights of commonly used mobility devices (Figure 25).

[29] Cregger, Joshua, et al. (2018, September). Low-Speed Automated Shuttles: State of the Practice – Final Report. (FHWA-JPO-18-692). United States Department of Transportation. https://rosap.ntl.bts.gov/view/dot/37060
[30] Federal Transit Administration. (2019, November 1). Transit Bus Automation Policy FAQs. https://www.transit.dot.gov/research-innovation/transit-bus-automation-policy-faqs
[31] Coyner, Kelley, et al. (2021). Low-Speed Automated Vehicles (LSAVs) in Public Transportation. (TCRP Research Report 220). National Academies of Sciences, Engineering, and Medicine. https://nap.nationalacademies.org/catalog/26056/low-speed-automated-vehicles-lsavs-in-public-transportation
[32] U.S. Access Board. (2021, July). Public Forum on Inclusive Design of AVs: Summary Report. https://www.access-board.gov/av/report.html
[33] Berg, Ian, et al. (2022, August). Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research. (FTA Report No. 0228). Federal Transit Administration. https://rosap.ntl.bts.gov/view/dot/64112

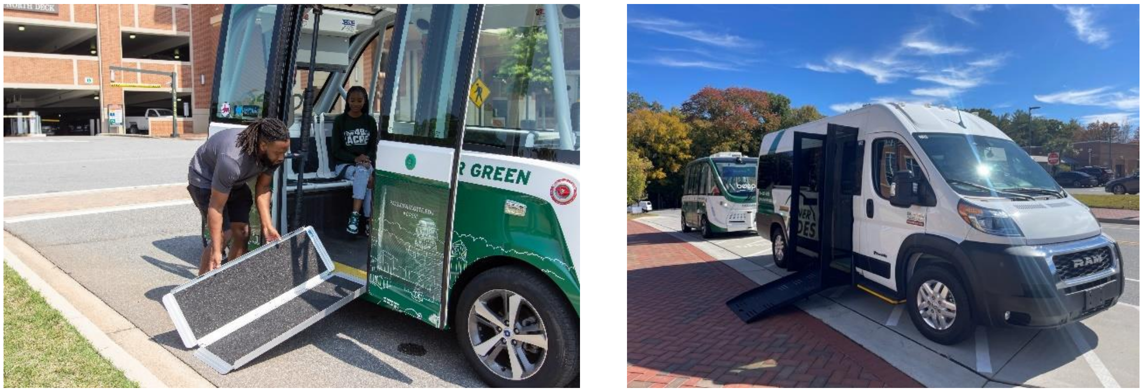

Figure 25. The automated shuttle's manual wheelchair ramp (left) and a Niner Paratransit vehicle's automatic wheelchair ramp (right). (Images courtesy of UNC Charlotte)

The shuttle did not include features to support people with cognitive and sensory disabilities, including features that are standard to conventional transit like audible stop announcements and instructions. As documented in the findings from the preceding pilot in Cary's Bond Park, 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.[34]

Conclusions

NCDOT in partnership with UNC Charlotte and Beep advanced their exploration of shared autonomous vehicles through the pilot of a novel-design, all-electric, low-speed automated shuttle at UNC Charlotte. The pilot advanced NCDOT's goal of incrementally increasing the complexity of projects while learning from past challenges and building on successes. Lessons learned from the preceding project in Cary's Bond Park were applied towards the deployment at UNC Charlotte—the pilot increased the complexity of the V2I communications from a single temporary traffic signal to four naturalistic traffic signals with support from CDOT and featured the longest route and most complex operating environment to date. The project aligned with NCDOT's vision to provide safe, reliable, and useful transit service while familiarizing the public with new technologies and enabling further testing and evaluation.

Unique to the pilot at UNC Charlotte compared to past efforts under the CASSI program, the shuttle was offered as an additional option amongst other options in a robust multimodal transportation system. UNC Charlotte designed their transportation system to meet the travel needs of their community with pedestrian, bicycle, transit, and paratransit routes linking key destinations on campus and offering off-campus connections. The shuttle provided redundancy on an existing route with established service. The data and analyses presented in this report indicate that, while some community members

[34] Ibid.

appreciated being able to experience and support new technology through the automated shuttle and service, most were choosing other options to reach their destinations on campus, whether due to comfort, convenience, reliability, or some other factor. The shuttle's slow speed, delay from when the attendant needed to troubleshoot problems or manually operate the shuttle, and route constraints that resulted in a less direct path between destinations contributed to the lower performance of the shuttle compared to conventional transit options. In addition, the shuttle was out of service for a considerable amount of time due to technology issues, notably due to GNSS signal loss and battery insufficiency. These findings suggest that there was no time or connectivity benefit to using the shuttle over other options on campus. Overall, the shuttle's technology needs to advance further to usefully meet the demands of a university campus and the expectations of its community members. Additional findings from research conducted by Pulugurtha et al. are published in a separate report that complements this final report.

Recommendations for Future Work

Automated vehicle pilots under the CASSI program have so far been limited to 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 as a safety fallback and to assist passengers using mobility devices.[35] NCDOT seeks to incrementally increase the complexity of future automated vehicle pilots by considering distinctly different use cases, vehicle form factors, Automated Driving System (ADS) technologies, and service designs and advancing the testing of connected vehicle features.

NCDOT is exploring new options for the next set of pilots under the CASSI program through a Request for Information (RFI) focused on automated transit vehicles and inclusive of 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.[36] NCDOT's goal is to build on their knowledge and partnerships towards the next generation of pilots that demonstrate the latest advances in automated vehicle technology that meet public transportation needs. The RFI is focused on higher levels of automation and asks respondents to clearly describe the presence, role, and responsibility of a human attendant or operator as needed for safety or passenger assistance. NCDOT anticipates using the findings from the RFI to inform their selection of new vehicles, locations, use cases, and vendors for future projects through CASSI and beyond.

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

[36] 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

NCDOT is further exploring how automated vehicles can be tested and integrated into high quality, on-demand transit services that address transportation challenges, including through grant applications[37] to the USDOT Advanced Transportation Technology and Innovation (ATTAIN) program. NCDOT is also supporting N.C. A&T State University[38] to develop shared autonomous vehicles, an innovative rural test track, and automated shuttle pilots between the university and downtown Greensboro.

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

[38] N.C. A&T State University. (n.d.). Connecting the Future: Autonomy at A&T. https://www.youtube.com/watch?v=vPznZwcn1Us

Appendices

Appendix A. Appropriate Operating Conditions for the Navya Autonom

The following are the appropriate operating conditions for the Navya Autonom:

- Route length: ≤ 2 miles
- Posted speed limit: ≤ 25 mph
- Paved roadway surfaces only (asphalt or concrete; smooth surfaces preferred)
- 12-foot travel lanes preferred; ≥ 10-foot travel lanes required
- Operating temperatures: 14 °F – 104 °F; quality of service is impaired by heavy rain, snow, fog, hail, and extreme heat or cold
- Buildings or fixed elements along the route are helpful for localization
- Cellular coverage along the route required (various bands of cellular connectivity may be used depending on the signal strength and area of deployment)
- Dedicated shuttle stops must be provided with a pull off area of at least 69 feet; circulator style route preferred
- Avoid routes where the slope frequently exceeds 7%; maximum slope = 12%
- Avoid routes with high traffic density or dedicate a lane for the shuttle
- Avoid railroad crossings, construction or work zones, and routes that require switching or merging lanes with other traffic
- Ensure vegetation is trimmed and maintained along the route

Appendix B. Appropriate Charging Equipment and Storage for the Navya Autonom

The following are the electrical specifications and storage requirements for the Navya Autonom:

- Electrical Specifications
  - Power: 208V/220V/240V; 50A
  - Outlet type: NEMA 14-50
  - Operating temperatures: 14 °F – 113 °F
- Storage Requirements
  - Storage dimensions: ≥ 23 feet long, 11 feet wide, and 13 feet high
  - Storage temperatures: 32 °F – 86 °F

Appendix C. Key Planning Activities by Category with Responsible Parties and Completion Date

Category	Activity	Responsible Parties	Completion Date
Administrative	Execute contract for the automated shuttle lease and operations	NCDOT/Beep	11/22/2022
Administrative	Deliver shuttle to North Carolina	Beep	12/29/2022
Administrative	Submit exemption application to NHTSA	Beep	5/8/2023
Administrative	Receive NHTSA approval (permission letter)	NHTSA	6/15/2023
Administrative	Complete vehicle inspection, titling, and registration	NCDOT/Beep	2/8/2023 (inspection); 2/17/2023 (titling and registration)
Administrative	Execute general agreement	NCDOT/UNC Charlotte	4/12/2023
Administrative	Execute permission to enter agreement (access agreement)	UNC Charlotte/Beep	5/8/2023
Administrative	Transport shuttle to UNC Charlotte	Beep	6/7/2023
Operations	Confirm public operations period	NCDOT/UNC Charlotte	2/24/2023 (kickoff meeting)
Operations	Confirm hours of operation	NCDOT/UNC Charlotte	2/24/2023 (kickoff meeting)
Operations	Complete route review	NCDOT/UNC Charlotte/Beep	12/6/2022
Operations	Confirm route based on Navya's acceptance of the route's slope	NCDOT/UNC Charlotte/Beep	2/7/2023
Operations	Confirm route based on safety-based revision	NCDOT/UNC Charlotte/Beep	5/3/2023
Operations	Confirm stops on the shuttle's route	NCDOT/UNC Charlotte/Beep	3/28/2023
Operations	Create service interruption plan	NCDOT/UNC Charlotte/Beep	4/18/2023
Operations	Confirm special events	NCDOT/UNC Charlotte	n/a (ongoing during pilot period)
Infrastructure	Prepare storage location and install charging equipment	UNC Charlotte	4/10/2023

Category	Activity	Responsible Parties	Completion Date
Infrastructure	Complete HVAC upgrades	UNC Charlotte	n/a (not needed)
Infrastructure	Install Wi-Fi cradle point	UNC Charlotte	n/a (already present)
Infrastructure	Install temporary modular ADA ramps	UNC Charlotte	n/a (not needed)
Infrastructure	Install signs along the route and at stops	UNC Charlotte	5/3/2023 (aluminum stop signs); 7/12/2023 (plastic A-frame signs)
Infrastructure	Trim vegetation along the route	UNC Charlotte	5/3/2023
Infrastructure	FCC approval (permission letter) for DSRC license	NCDOT/UNC Charlotte	6/2/2023
Infrastructure	Install RSU/OBU	NCDOT/CDOT/UNC Charlotte/Beep	5/30/2023 (RSUs updated and installed); 6/5/2023 (RSUs operational); 6/7/2023 (RSUs programmed)
Infrastructure	AVL integration	UNC Charlotte	7/5/2023 (UNC Charlotte provided tablet to enable use of Passio system)
Marketing and Promotion	Create wrap design	UNC Charlotte	5/19/2023
Marketing and Promotion	Print and install wrap	Beep	6/7/2023; 6/17/2023 (corrections to wrap)
Marketing and Promotion	Create media packet (webpage, news release, and social media post calendar)	NCDOT/UNC Charlotte	6/2/2023 (media packet); 8/29/2023 (first social media post); 9/7/2023 (news release)
Incident Response Plan	Create and confirm Incident Response Plan	NCDOT/UNC Charlotte	6/19/2023
First Responder Workshop	Organize and hold First Responder Workshop	Beep	6/8/2023
Transit Operator Training	Organize and hold virtual training with UNC Charlotte transit operators and staff	Beep	6/23/2023
Data Collection	Create and administer rider survey	NCDOT/UNC Charlotte	6/23/2023

Category	Activity	Responsible Parties	Completion Date
Data Collection	Develop data entry application (in-vehicle tablet)	NCDOT/UNC Charlotte	n/a (used Beep's data collection protocol and procedures)
Data Collection	Collect and share ridership and operations data	Beep	Weekly basis during pilot period
Commissioning	Install GNSS antenna	Beep	5/2/2023
Commissioning	Complete route mapping (environment mapping) using a mobile scanning unit installed on a conventional vehicle	Beep	5/3/2023
Commissioning	Vendor processes mapping data	Beep	5/24/2023
Commissioning	Complete path creation (mapping data analyzed in office)	Beep	5/30/2023
Commissioning	Complete path validation using the shuttle	Beep	6/30/2023
Commissioning	Validate RSU/OBU	Beep	7/11/2023
Commissioning	Train on-site attendant on route	Beep	6/30/2023
Commissioning	Hand off the shuttle and service to on-site attendant	Beep	6/30/2023
Start of Service	Coordinate and complete ribbon cutting event	NCDOT/UNC Charlotte	n/a (ribbon-cutting event cancelled due to adverse weather threat)
Start of Service	Operate shuttle on the route during scheduled hours	Beep	Ongoing during pilot period
Start of Service	Coordinate and complete special events	NCDOT/UNC Charlotte	Ongoing during pilot period
Start of Service	Weekly check in meetings	NCDOT/UNC Charlotte	As needed
Start of Service	Weekly check in meetings	NCDOT/Beep	Weekly basis during pilot period

Appendix D. Joint and Individual Responsibilities per the General Agreement Between NCDOT and UNC Charlotte for the CASSI at UNC Charlotte Project

NCDOT:

- Provide a fully functioning autonomous shuttle per the contract between NCDOT and Beep for the term of the agreement.
- Coordinate with UNC Charlotte on any agreed upon wrapping or branding of the shuttle for the project.
- Collaborate with Beep and UNC Charlotte to provide and honor a project schedule with target dates and milestones by providing information, reviewing information, and meeting as needed to meet various key milestones.
- Provide project management, including coordination of the project with UNC Charlotte, Beep, any third-party operator involved in operations of the shuttle, and other partners designated by UNC Charlotte.
- Assist Beep in coordinating with UNC Charlotte on passenger engagement prior to passengers boarding the shuttle and provide general information to the public about the CASSI program and the project underway.
- Handle all communications with Beep unless otherwise directed by UNC Charlotte.
- Provide UNC Charlotte with all data on operations of the shuttle received from Beep, including, but not limited to, data on ridership, stop departure times, route performance, disengagements, and interventions.
- Develop a plan for data sharing with UNC Charlotte prior to the start of public operations.
- Develop and administer a rider survey for the project in consultation with UNC Charlotte.
- Set a schedule of public operations in consultation with UNC Charlotte and Beep to operate up to forty (40) hours per week only during weekdays, excluding public holidays.
- Facilitate weekly or biweekly project meetings with UNC Charlotte and Beep through conference call.
- Notify UNC Charlotte immediately of anything impacting the shuttle, route, or operations in accordance with the project's Incident Response Plan.
- Confirm that operations of the shuttle are compliant or have received appropriate documentation from NHTSA prior to the shuttle operating on the route.
- Purchase and maintain all insurance policies for operations of the shuttle for the project.
- Ensure that Beep and its permitted subcontractors purchase and maintain all insurance policies for operations of the shuttle for the project (except worker's compensation and professional liability) and that Beep names UNC Charlotte and its officers, agents, employees, and volunteers as an additional insured on their policy.

- Confirm that operations of the shuttle, including those conducted by Beep or a third-party operator, are compliant with all applicable state and local public health guidelines related to the COVID-19 pandemic.
- Coordinate with UNC Charlotte on any press and media information related to the project.
- In the manner and only to the extent permitted under North Carolina law, including but not limited to the NC Tort Claims Act, GS 143-291, et seq., and without waiver of its sovereign immunity, agree to indemnify and hold harmless the University of North Carolina, UNC Charlotte, and all their officers, employees, and agents from and against any and all actions, suits, damages, liability, or other costs or expenses, which may arise as a result of the negligence of any officer, employee, or agent of NCDOT; this obligation shall survive termination of the agreement for any reason.

UNC Charlotte:

- Complete on-site work for the project (e.g., temporary signage installation, infrastructure improvements, etc.) and provide secure storage and charging facilities in accordance with Beep's requirements as mutually acceptable to UNC Charlotte for the shuttle for the term of the agreement.
- Work closely with NCDOT to meet a project schedule with target dates and milestones by providing information, reviewing information, and meeting as needed to meet various key milestones.
- Provide an operating schedule for services that total forty (40) hours per week (during weekdays) and accounts for holidays; public operations will total eight (8) hours each weekday, and six (6) of those hours will include passenger carrying services.
- Provide storage location, charging equipment, and power supply for the shuttle that is compliant with information provided by NCDOT and Beep.
- Furnish site modifications determined by Beep to be necessary for public operations, including, but not limited to, temporary signage, appropriate accessibility ramp connections, OBU/RSU validation, and other items mutually agreed to in writing between UNC Charlotte, NCDOT, and Beep and as provided within Beep's Route Analysis documentation.
- Furnish a building roof with adequate support, coverage, and access to support Beep's need for a temporary antenna as mutually agreed to in writing among UNC Charlotte, NCDOT, and Beep.
- Provide NCDOT with branding and logo information for design of a shuttle wrap (as applicable); shuttle wrap design shall be limited to logos and branding of UNC Charlotte, NCDOT, and Beep.
- Notify NCDOT immediately of anything impacting the shuttle, route, or operations in accordance with the project's Incident Response Plan to be developed by NCDOT and UNC Charlotte.

- Coordinate with NCDOT on passenger engagement prior to passengers boarding the shuttle and provide general information to the public about the CASSI program and the project underway.
- Coordinate with NCDOT on any press and media information related to the project.
- Review and approve, if appropriate, necessary plans and documents to facilitate public operations under the demonstration program, including, but not limited to, materials submitted to NHTSA and additional reports required by NCDOT.
- Participate in weekly or biweekly project meetings with NCDOT and Beep held through conference call.
- Inform NCDOT immediately of any concerns or issues that arise pertaining to any responsibilities of NCDOT, Beep, or a third-party operator.
- Inform NCDOT immediately of any safety-related concerns or incidents in accordance with the agreed upon, documented safety protocol.
- Agree to consider and apply recommendations and instructions from reports produced by Beep, including, but not limited to, the Route Analysis documentation.
- Provide NCDOT with contact information for a local designee who can be accessible 24/7 in the event of an emergency.
- In the manner and only to the extent permitted under North Carolina law, including but not limited to the NC Tort Claims Act, GS 143-291, et seq., and without waiver of its sovereign immunity, agree to indemnify and hold harmless NCDOT and all their officers, employees, and agents from and against any and all actions, suits, damages, liability, or other costs or expenses, which may arise as a result of the negligence of any officer, employee, or agent of NCDOT; this obligation shall survive termination of the agreement for any reason.

NCDOT and UNC Charlotte:

- Work collaboratively to facilitate the deployment of a fully operational shuttle leased by NCDOT and capable of operating on non-flat surfaces on a predetermined fixed route as shown in the Route Analysis documentation.
- Make every effort to jointly and with Beep adhere to the project schedule.
- Provide a public operation period of six (6) months, from June 26, 2023 through December 21, 2023; public operations will total eight (8) hours each weekday, and six (6) of those hours will include passenger carrying services; public operations are provided only during weekdays, excluding holidays, unless otherwise specified in writing between NCDOT, UNC Charlotte, and Beep.
- Define predetermined stops for the shuttle to provide public transportation service to destinations within UNC Charlotte's main campus.

Appendix E. Basic Project Timeline per the General Agreement Between NCDOT and UNC Charlotte for the CASSI at UNC Charlotte Project

Activity	Timeline	Responsible Parties
Official project kickoff meeting	2/24/2023	NCDOT/UNC Charlotte/Beep
Submit exemption application to NHTSA	3/31/2023	Beep
Confirm wrap design	5/23/2023	NCDOT/UNC Charlotte
Receive NHTSA approval (permission letter)	6/5/2023	NHTSA
Vehicle arrives to UNC Charlotte	6/5/2023	Beep (transport/loading/unloading)
Wrap print and installation	6/6/2023	Beep
Complete infrastructure updates	5/15/2023	NCDOT/UNC Charlotte
Commissioning by Beep	5/15/2023 - 6/23/2023	Beep
Operations (6 months)	6/26/2023 - 12/22/2023	Beep
Vehicle picked up	1/8/2024	Beep

Appendix F. Operating Conditions Approved by NHTSA for the Navya Autonom Used for the CASSI at UNC Charlotte Project per the Permission Letter to Beep Dated June 15, 2023

- Vehicle operations must conform to all applicable terms and conditions described in NHTSA's September 30, 2021 letter "NHTSA Review of June 2021 Dunedin Incident and Resulting Safety Operations Mitigations," NHTSA's May 3, 2022 letter "NHTSA Review of 2021 Local Motors Olli Incidents and Resulting Vehicle Platform and Operational Mitigations," NHTSA's July 7, 2022 letter "Modified Intersection Operations for NAVYA Vehicles," and NHTSA's February 1, 2023 letter "Suspension of NAVYA Vehicles from Operations Involving Public Interaction and Return to Service Plan for Mitigation Implementation."
- The grant of permission applies only to the vehicle in the research and demonstration program as described in the permission letter from NHTSA. If Beep seeks to import or use any additional nonconforming vehicles for testing or demonstration purposes, regardless of whether they are the same model as the one that is the subject of the permission letter, Beep will need to separately request and receive permission from NHTSA prior to importation or operation.
- The vehicle's entry and presence in the United States must be in compliance with all U.S. Customs and Border Protection ("CBP") requirements.
- The vehicle may only be operated with a trained safety operator on board who, at all times, can take immediate control of or stop the vehicle should the need arise.
- The vehicle must be configured in such a way to allow movement, in either autonomous or manual mode, out of the path of vehicles, pedestrians, and obstacles. The safety operator must have a means to take control of the vehicle at any time to move it to a safe location.
- The vehicle must allow the safety operator to activate a horn or other audible warning at all times. The horn or other audible warning must be capable of emitting continuous and uniform sound audible under normal conditions from a distance of not less than 200 feet while activated.
- The vehicle and its operation must comply with all state and local laws and requirements at all times. Each vehicle must be duly permitted, if applicable, and authorized to operate within all properties and upon all roadways traversed by the route in the manner and conditions described in the permission letter from NHTSA.
- The vehicle may not be operated in adverse weather and road conditions, which include heavy precipitation, such as heavy rain, heavy snow, fog, or hail; sustained wind speeds greater than 25 mph; or temperatures below 14 °F or above 104 °F.
- Before operating the vehicle under any conditions other than those specified in the permission letter from NHTSA, Beep must either a) request and receive permission from NHTSA if any such change in condition relates to public road operation or to any operation that involves members of the public or b) notify NHTSA if the change solely

involves operation of the vehicle off public roads without interaction with members of the public at least seven (7) calendar days prior to making any of the desired changes.

- Apart from the safety operator, standing passengers are not permitted while operating the vehicle with members of the public on board.
- The vehicle must display the following labels formatted in a manner that can be easily read and be located in a place that is readily visible:
  - A label or labels, affixed to the interior and exterior of the vehicle, warning prospective and actual occupants that the vehicle does not comply with all applicable Federal motor vehicle safety standards.
  - A label or labels, affixed to the interior of the vehicle, warning occupants that the vehicle is a research and demonstration vehicle that may stop suddenly and of the need to fasten their seat belts.
  - A label or labels, affixed to exterior of each vehicle, warning other road users that the vehicle may stop suddenly.
- Safety operators must be regularly trained and monitored. All safety operators shall receive specific training on passenger safety and emergency response scenarios. Operator performance monitoring shall occur at least as frequently as described in Beep's application.
- Beep must notify NHTSA whenever the vehicle is involved in a crash or any other situation in which it posed a risk to the safety of any individual(s), whether such individual(s) were inside or outside of the vehicle at the time of the incident. These include, but are not limited to, situations in which the safety operator or another road user (including pedestrians) reacted to avoid an imminent crash, instances in which the vehicle deviated from the prescribed route, unexpected lane departures, and any situations that resulted in injury to vehicle occupants, pedestrians, bicyclists, or other road users. For any such incident that results in a crash or injury, Beep must provide notification of the incident within twenty-four (24) hours of the event. For any other qualifying event, Beep must provide notification within 5 days of the event. All such notifications shall include a full description of the event. When applicable, copies of all accident report(s) concerning the occurrence prepared by State or local law enforcement authorities must be provided within five (5) business days of when those reports become available. In addition, Beep must provide, as soon as practicable: (1) any video footage captured by cameras onboard the vehicle, or otherwise in Beep's possession, from the time of the incident; and (2) if applicable, a description of anticipated steps or mitigations to prevent or address similar future occurrences.
- Beep must submit a monthly report to NHTSA on the 15th of each month listing all unplanned disengagements occurring during the previous month during operation of the vehicle that involves interaction with the public. The report must include a description of the event(s) that triggered the disengagement, including, how any pedestrians, vehicles, or other objects were involved, as applicable. The report must also include the date, time, location, weather conditions, and speed immediately prior to disengagement. Further, the report must list the ADS software version, the total

number of miles accumulated in the reporting period and, separately, the number of miles accumulated with the Autonomous Driving System engaged.

- Beep must provide NHTSA with documentary proof that the vehicle has been exported or destroyed not later than thirty (30) days following the end of the period for which it has been admitted to the United States.
- Beep must submit an annual report to NHTSA on the status of all vehicles imported by Beep with active permissions as of the date of the report. The report should identify, by vehicle identification number (VIN), all vehicles that remain in the United States. The report should also identify all vehicles removed from service, the reasons for their removal, and their disposition.

Appendix G. Service Interruption Plan for the CASSI at UNC Charlotte Project

Background

Beep operates a Navya Autonom shuttle for the UNC Charlotte project under their contract with NCDOT and in partnership with UNC Charlotte for the CASSI program. Beep provides an attendant on the shuttle as a safety backup and to provide customer service. The following provides guidance on actions to be taken by Beep, UNC Charlotte, and NCDOT in the event of service interruptions such as attendant absence, inclement weather, battery insufficiency, special events, construction impacts to the route, or if demand exceeds the capacity of the shuttle. This plan has been reviewed and approved by the teams.

<u>If the assigned attendant is unavailable, the following actions will be taken:</u>

Beep, UNC Charlotte, & NCDOT

1. Attendant sends down time notification via email to the site operations manager, UNC-C, and NCDOT.
    - UNC-C communicates the interruption to students and the public through the Passio webpage and app, UNC-C's CASSI project webpage, and social media. Notifications through social media will be posted <u>if the down time is more than 60 minutes.</u>
2. Site operations manager immediately assesses if down time of attendant will exceed past current day/shift.
3. Site operations manager sends the expected duration of down time via email to UNC-C and NCDOT.
    - UNC-C updates the Passio webpage and app, their CASSI project webpage, and social media as needed.
4. Five (5) additional trained attendants are ready to deploy as needed. A replacement attendant will be on site no earlier than four (4) hours from notification.

<u>If the shuttle cannot be operated due to inclement weather (heavy rain, heavy snow, fog, or hail or in sustained winds greater than 25 mph) or battery insufficiency, the following actions will be taken:</u>

Beep, UNC Charlotte, & NCDOT

1. Attendant sends down time notification via email to the site operations manager, UNC-C, and NCDOT.
    - UNC-C communicates the interruption to students and the public through the Passio webpage and app, UNC-C's CASSI project webpage, and social media. Notifications through social media will be posted <u>if the down time is more than 60 minutes.</u>

2. Site operations manager immediately assesses if down time of attendant will exceed past current day/shift.
3. Site operations manager sends the expected duration of down time via email to UNC-C and NCDOT.
    - UNC-C updates the Passio webpage and app, their CASSI project webpage, and social media as needed.

If the shuttle cannot be operated due to special events or construction impacts on campus, the following actions will be taken:

Beep, UNC Charlotte, & NCDOT

1. Attendant will notify UNC-C and NCDOT if they encounter construction or any other issue on the route that interrupts the shuttle operation. UNC-C will notify the attendant and the site operations manager of any known construction impact or special event.
    - UNC-C communicates the interruption to students and the public through the Passio webpage and app, UNC-C's CASSI project webpage, and social media. Notifications through social media will be posted if the down time is more than 60 minutes.
2. Site operations manager immediately assesses if down time of attendant will exceed past current day/shift.
3. Site operations manager sends the expected duration of down time via email to UNC-C and NCDOT.
    - UNC-C updates the Passio webpage and app, their CASSI project webpage, and social media as needed.

Special Events and Holidays

- Friday football games will take place a few times this fall on campus.
    - Service will stop around 2:00 p.m. and will not operate after this time unless advance notice is given.
- Fall Break: October 9-10, 2023
    - UNC-C will not be closed, but students may not be on campus. The shuttle will operate as usual.
- Labor Day: September 4, 2023
    - Campus will be closed on Monday. No shuttle operations will occur on this day.
- Thanksgiving: November 23-24, 2023
    - Campus will be closed Thursday through Friday. No shuttle operations will occur on these days.

Appendix H. Vehicle-to-Infrastructure (V2I) Communications

Overview

The CASSI at UNC Charlotte project met the North Carolina Department of Transportation (NCDOT)'s goal of incrementally increasing the complexity of projects while learning from past challenges and building on successes. The pilot increased the complexity of the Vehicle-to-Infrastructure (V2I) communications from a single temporary traffic signal in the preceding CASSI in Cary's Bond Park project to four naturalistic traffic signals and featured the longest route and most complex operating environment to date. NCDOT, the University of North Carolina at Charlotte (UNC Charlotte), the Charlotte Department of Transportation (CDOT), Beep, Inc. (Beep), and additional technology vendors worked together to problem-solve and accomplish the tasks that were critical for the V2I integration that enabled the shuttle to autonomously navigate the four signalized intersections on its route. UNC Charlotte owns and maintains the traffic signals and roads on the shuttle's route. UNC Charlotte partners with CDOT for signal operations.

Partners

Each team contributed to the V2I integration in the following ways:

NCDOT

- Provided the Roadside Units (RSUs) from a previous project and updated their software.
- Applied to the Federal Communications Commission (FCC) for a Dedicated Short-Range Communications (DSRC) license.
- Recreated the signal environment (controller, ethernet switch, Onboard Unit (OBU), RSU, and software) in their lab to inform testing and diagnostics in the field.
- Created MAP files.
- Assisted CDOT, Kapsch, and Beep with testing and validation in the field.

UNC Charlotte

- Provided support to upgrade the Central Processing Unit (CPU) modules in the existing controllers at each signalized intersection.

CDOT

- Provided the CPU modules to retrofit the existing controllers.
- Provided the unmanaged Ethernet switches.
- Upgraded the software from OASIS to EOS.
- Installed and programmed the RSUs.
- Conducted testing and validation in the field in coordination with NCDOT, Kapsch, and Beep.

Beep

- Provided support for the OBU in coordination with Navya.
- Conducted testing and validation in coordination with NCDOT and CDOT to ensure the shuttle received communications from the traffic signals.
- Transmitted information about the V2I integration to the National Highway Traffic Safety Administration (NHTSA) as a part of their Federal Motor Vehicle Safety Standards (FMVSS) exemption application towards gaining permission to operate the shuttle on the route and with passengers.
- Ensured compliance with the shuttle's approved operating conditions.

United States Department of Transportation (USDOT)

- Loaned an OBU and a mobile modem to NCDOT through their loaner program.
- Offer a free, publicly accessible webpage[39] with:
  - "ISD Message Creator" tool that NCDOT used to create a MAP file.
  - "Message Validator" tool that NCDOT used to verify and validate code.

Additional technology vendors

- OBU hardware and software
  - Navya
- RSU hardware, software, and antennas
  - Kapsch TrafficCom North America (Kapsch)
- Signal system software
  - Econolite
    - Oasis
    - EOS

Equipment

The RSUs used for the pilot were Kapsch RIS-9160 – V2X Roadside ITS Station.[40] The RSUs had antennas already attached from their previous project. The antennas were replaced with Mobile Mark 6 dB 5.9 Ghz since the original ones were not optimized for use in the CASSI at UNC Charlotte project. The controllers at each location were 2070 form factor, installed in the 2000s and 2010s, and retrofitted in June 2023 with 2070-1C CPU modules capable of operating EOS software.

[39] USDOT. Tool Library Using SAE J2735 3/2016. (n.d.). https://webapp2.connectedvcs.com

[40] Kapsch TrafficCom. (n.d.). Technical Manual Roadside ITS Station RIS-9160-xx0x. https://fccid.io/XZU9160/User-Manual/User-and-Installers-manual-3874195

NCDOT purchased the OBU through their contract with Beep. The OBU is an Unex OBU-201U[41] that is fully integrated with the shuttle's Automated Driving System (ADS) software. Navya provides support to Beep for the OBU's operation.

Locations

Images of the four signalized intersections on the shuttle's route are provided in Figure 26.

Figure 26. The four signalized intersections on the shuttle's route on UNC Charlotte's main campus: Cameron Boulevard/Poplar Lane (upper left), Cameron Boulevard/Mary Alexander Road (upper right), Craver Road/Student Union (bottom left), and Craver Road/Cameron Boulevard (lower right). (Images courtesy of NCDOT)

Tasks

In addition to applying for and receiving a DSRC license from the FCC, NCDOT completed the following tasks to set up the RSUs and controllers with support from CDOT, Kapsch, and Econolite as needed:

[41] Federal Communications Commission. (2017, March 6). OBU-201U Specification. https://apps.fcc.gov/els/GetAtt.html?id=201591

- Updated the RSU live and recovery software.
- Updated the RSU firmware.
- Added Signal Phasing and Timing (SPaT) and MAP information to the RSUs' IFM tables.
- Edited wave0 radio channel (control and service) to 180 in the RSUs.
- Created intersection maps using USDOT's Connected Vehicles website (for EOS to import Intersection ID from MAP data because the SPaT data does not contain that ID).
- Encoded MAP information using USDOT's Connected Vehicles website, created map.data hex file, then loaded the file into the EOS controllers.
- Created MAP and SPaT header files then loaded the files into the EOS controllers.
- Confirmed with Beep that the shuttle could communicate with the RSUs.
- Conducted troubleshooting during set up and throughout the pilot period.

Beep requested information from NCDOT to include in their waiver application to NHTSA and as needed to complete testing and validation—the Intersection ID (unique identifier for the intersection per SAE J2735),[42] Signal Group ID (all possible movement variations are assigned a unique value within the intersection per SAE J2735),[43] and Channel (180 for DSRC). Beep programmed this information into the shuttle so it could receive communications from the RSUs at the signalized intersections. Beep communicated that they used SPaT messaging only. NCDOT provided the requested information to Beep in a diagram that included the four intersections on the route (Figure 27).

[42] SAE International. (2023, September 22). J2735 V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_202309/

[43] Ibid.

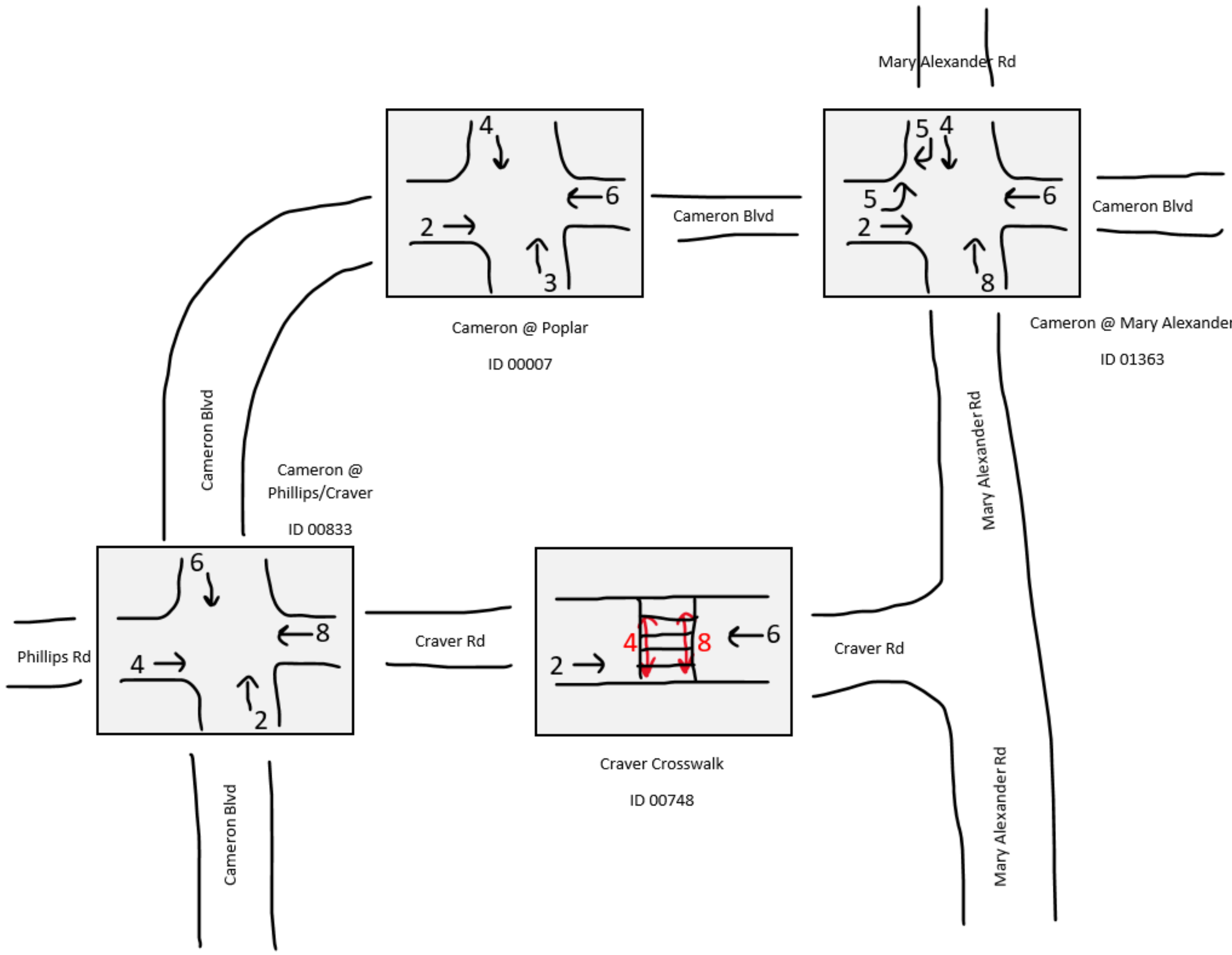

Figure 27. Diagram with signalized intersections, Intersection IDs, and Signal Group IDs provided upon request to Beep by NCDOT. (Image courtesy of NCDOT)

Troubleshooting and Problem Solving

NCDOT and CDOT assisted Beep with testing and validation to ensure the shuttle received communications at the traffic signals and was able to autonomously navigate the intersections prior to accepting passengers. Beep encountered several issues at the traffic signals while completing their commissioning activities towards opening the shuttle to the public compounded by inclement weather and signal issues with the Global Navigation Satellite System (GNSS) antenna.

NCDOT, CDOT, and Beep met on June 28, June 30, and July 3, 2023 to assess progress on the RSU and OBU testing and validation. CDOT was in the field on June 29, 2023 to make changes to the SPaT messages based on problem solving with NCDOT and Kapsch. NCDOT and CDOT were in the field on July 3, July 7, and July 11, 2023 to perform troubleshooting on the RSUs and signal controllers. Based on their on-site work on July 11, 2023, CDOT and NCDOT in coordination with Beep confirmed that the RSUs at all four traffic signals were working and the shuttle could operate autonomously through the intersections. The shuttle opened to the public on July 12, 2023. From the troubleshooting that occurred in June and July, NCDOT learned that MAP information was needed to ensure the SPaT messages were complete (added map.header and map.data so the SPaT messages can pull the correct intersection ID) and that both Radio A and Radio B needed to be set to different channels to mitigate communication failures (changed wave1 radio to transmit on 178).

On August 8, 2023, Beep informed NCDOT that there were issues at the signalized intersections on the route. According to Beep, the shuttle's User Interface (UI) screen indicated that the problem was at the RSU level (Figure 28); that the issue was intermittent, with no clear pattern, and going on for days; and that the shuttle's attendant was tracking the issue and when it occurred, with more intermittence occurring in the afternoon compared to the morning. NCDOT requested further information about how many days the issue had been occurring, what information was being tracked, and if any tests had been performed on the OBU to ensure that it was not a contributing factor (and the results from testing if it was performed).

Figure 28. Error messages on the shuttle's UI screen. (Image courtesy of Beep)

NCDOT, CDOT, and Beep met on August 10, 2023 to discuss the issues and determine possible mitigations. Beep provided an initial report of the manually tracked issues along with images from the shuttle's UI screen in advance of the meeting and reiterated that there did not appear to be a pattern for the intermittence and that the Student Union intersection appeared to have a different issue than the other signalized intersections on the shuttle's route. For the crosswalk at the Student Union, Beep proposed to reduce the shuttle's programmed speed on the route segment so there was more time for the shuttle to receive communications from the traffic signal. Beep also agreed to provide more detailed reports documenting the RSU and OBU issues on a weekly basis to NCDOT and CDOT. Beep began providing these reports in mid-August with events starting on August 1, 2023.

NCDOT proposed a two-step update to optimize the signal-to-noise ratio by tuning into the exact frequency at each intersection. The update involved: 1) replacing the antennas at each intersection since the RSUs were functioning outside the existing antennas' specified GHz range and 2) changing the secondary channel to another frequency to minimize any noise interfering with the RSU and OBU communications. CDOT provided a bucket truck and staff support to help change out the antennas in the field and NCDOT coordinated with Beep to operate the shuttle through the intersections once the new antennas were installed to test the update.

On August 16, 2023, NCDOT installed two new 5.9 GHz antennas at each of the two most problematic intersections —Cameron Boulevard/Mary Alexander Road and Cameron Boulevard/Poplar Lane. NCDOT also adjusted the secondary channel from 180 to 176 and boosted the power level to 100% on the RSUs at all four intersections to compensate for the incorrect antennas at the two remaining intersections awaiting upgrades.

NCDOT rode the shuttle on August 21, 2023 to check on the shuttle's performance and service. NCDOT rode for three loops of the route and documented that the attendant had to manually operate the shuttle through the Cameron Boulevard/Poplar Lane intersection for two out of three loops. The shuttle successfully navigated the intersection autonomously only when the signal was green on approach. The shuttle was unable to navigate the intersection autonomously when it stopped on the red first. Further, the attendant had to manually operate the shuttle through the crosswalk at the Student Union regardless of whether the signal was green or red on approach. At the time, Beep was working on a solution for the Student Union crosswalk that involved slowing the shuttle's programmed speed.

NCDOT requested that Beep share the error logs from the shuttle and signal strength and quality information to help inform troubleshooting decisions, but Beep never shared any software-produced data logs. Beep determined that signal strength was not categorized directly in the stored logs. Beep then pulled logs from Navya and suggested that the shuttle was not receiving any signal from the RSUs. Beep asked NCDOT to confirm whether the RSUs were working and sent an engineer to UNC Charlotte from August 25-28, 2023 to diagnose the V2I issues. Based on their on-site diagnostics, Beep did not identify a root cause for the issues. Beep explained that the shuttle was not receiving SPaT messages during their first day on site, so the engineer checked the cables inside the shuttle that connected the OBU with the shuttle's switches and PCs to ensure there were no broken, frayed, or damaged cables. The engineer found no problems with the cables. V2I communications worked as expected on the second day when Beep tested the shuttle on the route. The engineer adjusted the shuttle's programming at the pedestrian crossing areas on the route to improve performance since students had returned to campus after the summer holiday.

Beep asked if NCDOT or CDOT had completed any work on the RSUs while they were on site—neither NCDOT nor CDOT had performed any work during that time. Beep reported that the communications at the signalized intersections were working well through the end of August except at the Student Union crosswalk and recommended increasing the timing by adding five seconds to the green phase. CDOT fulfilled this request on September 1, 2023 by increasing the green phase to 30 seconds between crossings.

Based on subsequent weekly reports from Beep that summarized issues at the signalized intersections, there were minimal problems with communications between the RSUs and OBU from September through November 2023. Beep notified NCDOT and CDOT on December 6, 2023 that the shuttle was not receiving communications at the Craver Road/Cameron Boulevard intersection and would not proceed on the green phase. CDOT reset the system on the same day which appeared to resolve the issue. CDOT reset the system again on December 12, 2023 for the same issue. No additional issues beyond random intermittence were encountered through the end of the pilot period on December 21, 2023.

Data Analysis

Based on data reports provided by Beep, the signalized intersections were a common cause of disengagement from autonomous mode into manual mode throughout the pilot period.[44] 119 out of 267 or 45% of disengagements were attributable to the signalized intersections across the entire pilot period as documented by Beep in their weekly "disengagement report," or one disengagement per day on average on days of complete or partial service. Further, Beep attempted to capture all issues at the signalized intersection in their weekly "RSU report," including events that did not result in disengagement from autonomous mode into manual mode.

Beep categorized events as disengagements attributable to a signalized intersection only if the attendant needed to manually operate the shuttle across the entire intersection. Beep programmed a "stop node" into the shuttle's route at the intersection approach. If the shuttle disengaged from autonomous mode at the stop node, the attendant could pull past the point manually then reengage into autonomous mode without the action qualifying as a "signalized intersection" disengagement—the event would likely be classified as a

[44] The shuttle is programmed to automatically disengage from autonomous mode and come to a complete stop when an obstacle is too close or when all required conditions for operation are not met. The attendant can also manually disengage from autonomous mode when deemed necessary. The attendant uses an industrial controller connected to the shuttle to take over driving or to perform an emergency stop.

different type of disengagement. If the attendant was able to resume autonomous mode before clearing the intersection, the event would be captured only in the RSU report.

Beep captured events in the RSU report starting August 1, 2023 through the end of the pilot period. Beep admitted that the report may not include every qualifying event since the attendant could have been occupied by other tasks and unable to record some occurrences. The report contained 100 total entries with 59 entries matching those in Beep's disengagement report. Figure 29 summarizes the error readings captured by Beep from the shuttle's UI screen and Figure 30 provides descriptions of the shuttle's behavior across the recorded events in the RSU report.

According to the RSU report, the shuttle was first at the intersection for 93% of the events where known, and the traffic light was green when the shuttle arrived at the intersection for 63% of events where known. 46% of events occurred at Craver Road/Cameron Boulevard, 24% of events occurred at Craver Road/Student Union, 17% of events occurred at Cameron Boulevard/Poplar Lane, and 13% of events occurred at Cameron Boulevard/Mary Alexander Road. 38% of events occurred during the morning shift (8:30-11:30 a.m.), 56% of events occurred during the afternoon shift (1:30-4:30 p.m.), and 6% of events occurred during the evening shift (5:30-8:30 p.m. only on select dates in November and December).

Error Reading	Count of Events
No errors	27
N/A	26
RSU sends messages but they are corrupted.	15
No messages sent by RSU; RSU sends messages but they are corrupted.	13
Decision communication error	9
No messages sent by RSU.	5
Nothing appeared on the UI running events screen.	2
RSU sends messages but they are corrupted or nothing appeared on the UI running events screen.	1
Was not able to wait and see what appeared on the UI running events screen because of traffic.	1
Switch front head	1

Figure 29. Error readings recorded by Beep in their RSU report. (Image courtesy of NCDOT)

Shuttle Behavior	Count of Events
Shuttle was unable to proceed through the intersection in autonomous mode.	44
Not recorded	26
Shuttle slowed down at the intersection when the traffic signal was green.	3
Shuttle approached the intersection when the traffic signal was red and stopped; shuttle did not immediately proceed through the intersection in autonomous mode when the traffic signal turned green.	3
Commencement and graduation was today.	2
Shuttle approached the intersection as the traffic signal changed from green to red.	2
Shuttle slowed down at the intersection then proceeded through in autonomous mode.	2
Shuttle did not immediately proceed through the intersection in autonomous mode when the traffic signal turned green.	2
Issues at the intersections appear to happen more during the evening shift than during the morning shift.	1
Shuttle stopped in the middle of the intersection when the traffic signal was green; attendant took over and operated the shuttle in manual mode.	1
Shuttle approached the intersection as the traffic signal changed from green to red and stopped; shuttle did not immediately proceed through the intersection in autonomous mode when the traffic signal turned green.	1
Shuttle braked sharply at the intersection when the traffic signal was green.	1
Shuttle was unable to proceed through the intersection in autonomous mode for multiple cycles of the traffic signal.	1
Shuttle braked sharply before the intersection then proceeded through in autonomous mode.	1
Intersection has a lot of pedestrian and car traffic.	1
Shuttle did not immediately proceed through the intersection in autonomous mode when the traffic signal turned green and was delayed for two cycles of the traffic signal.	1
Shuttle stopped at the intersection but did not proceed through in autonomous mode.	1
RSUs worked correctly during the morning shift but were not working during the afternoon shift.	1
Shuttle was delayed for 10 to 15 seconds before proceeding through the intersection in autonomous mode; shuttle was unable to proceed through the intersection in autonomous mode for multiple cycles of the traffic signal.	1
Shuttle did not proceed through the intersection in autonomous mode when the traffic signal was green.	1
Shuttle was unable to proceed through the intersection in autonomous mode for two cycles of the traffic signal.	1
Shuttle performance at the intersections has declined during the afternoon shift since the antennas were replaced.	1
Shuttle proceeded through the intersection in autonomous mode then stopped.	1

Shuttle Behavior	Count of Events
Shuttle approached the intersection as the traffic signal changed from green to red and stopped; shuttle did not immediately proceed through the intersection in autonomous mode when the traffic signal turned green and was delayed for one to two cycles of the traffic signal.	1

Figure 30. Shuttle behavior recorded by Beep in their RSU report. (Image courtesy of NCDOT)

<u>Lessons Learned and Recommendations for Future Work</u>

The root cause of the communication issues between the shuttle's OBU and the RSUs at the four signalized intersections on the shuttle's route was never determined by Beep or Navya.

Analysis of the data from Beep's disengagement and RSU reports and observations by NCDOT in the field indicated that the shuttle occasionally had trouble when it first stopped on the red phase before proceeding on green or when the signal changed from red to green as the shuttle approached. The shuttle also sometimes slowed or braked sharply when entering an intersection on the green phase. However, the data overall did not indicate a singular pattern or factor behind the issues.

The error messages captured from the shuttle's UI screen by Beep and shared in their RSU reports appeared programmed and standardized to indicate that an RSU was the problem when communications were not working. Beep did not provide data to NCDOT or CDOT that would help determine if the OBU was contributing to the communication issues. The OBU was fully integrated with the shuttle's ADS software and Navya provided support to Beep for the OBU's operation. Beep did not share any technical data, such as error logs generated from the shuttle's system, with NCDOT or CDOT. Error logs produced by the shuttle's system would have been more useful for problem solving than the manual data entries that Beep provided through the weekly RSU report. Without software-produced error and data logs and without knowing how the shuttle's ADS and OBU are using the SPaT data, NCDOT were unable to establish with certainty the true pattern and root cause of issues with the V2I communications.

Problem solving would have further benefitted from improved and more frequent communication, a standardized test plan and checklists to guide the troubleshooting process, and better coordination from Beep for the testing and validation during their commissioning process. Beep did not provide a structured schedule or process for the V2I integration that actively considered the support needed from NCDOT and CDOT. Beep created a brand-new process for manually logging issues related to the RSUs and OBU for the pilot at UNC Charlotte, which contributed to inconsistencies that were identified between the disengagement and RSU reports as well as incomplete or missing records as acknowledged by Beep.

Future work will benefit from the following:

- Greater structure, predictability, and coordination around the testing and validation of the V2I equipment during Beep's commissioning process, including a standardized test plan and checklists so all contributing teams know what to expect, are informed, and are prepared to accomplish the work.
- Improved automation of Beep's data collection processes to enhance the timeliness, accuracy, completeness, uniformity, integration, and accessibility of their ridership, operations, disengagement, and V2I miscommunications-related data compared to their current manual approach.
- More resources from Beep towards troubleshooting and problem solving, including staff support, technical data, and specifics on their root cause analyses. The shuttle's attendant is not a signals technician and has no direct connection to or relationship with Navya to access support for the OBU. The attendant must communicate with the "Beep Command Center" (BCC) based in Lake Nona, Florida to have problems routed for consideration. The attendant must also juggle the demands of manually capturing data about issues at the signalized intersections with their other assigned duties as a safety operator, including providing customer service, collecting data on ridership and disengagements, and acting as a safety fallback. This recommendation extends to troubleshooting and problem solving for other enabling technology, including the GNSS antenna, which fell on the attendant throughout the pilot period.

Appendix I. UNC Charlotte's Media Advisory for the CASSI at UNC Charlotte Project

UNIVERSITY OF NORTH CAROLINA CHARLOTTE news

MEDIA ADVISORY:
Electric, driverless shuttle being piloted at UNC Charlotte

What: An event to introduce CASSI, an autonomous shuttle on UNC Charlotte's campus, as part of a partnership between UNC Charlotte Parking and Transportation Services, NCDOT and Beep.

When: 10:00 a.m., Tuesday, Aug. 29, 2023; Media arrival at 9:30 a.m.

Why: CASSI (Connected Autonomous Shuttle Supporting Innovation) is an all-electric, autonomous shuttle running at UNC Charlotte for a pilot project until December 2023.

- The driverless, low-speed shuttle runs a six-stop route on the UNC Charlotte campus at no cost to riders.
- There is an attendant in case of any emergencies and to assist passengers.
- Having CASSI on campus will help sharpen autonomous vehicle technology for future adoptions.
- CASSI offers an opportunity for UNC Charlotte researchers as they collaborate with our pilot partners in a 'working lab' environment.

Where: Popp Martin Student Union bus stop (Craver Rd.)

Who: University and student leadership, NCDOT, Beep and other elected officials

Media Information:

- Please RSVP if you are attending
- Media should arrive by 9:30 a.m.
- Media members are welcome to do a ride-along in CASSI following the event

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Appendix J. Beep's News Release for the CASSI at UNC Charlotte Project

Sep 07, 2023

North Carolina Department of Transportation and Beep Launch Autonomous Shuttle Pilot Project at UNC Charlotte

Pilot tests an autonomous shuttle in a university setting for six months

LAKE NONA, Fla. September 7, 2023 — Beep Inc., a leading provider of autonomous and electric shared mobility solutions, today announced a second project with the North Carolina Department of Transportation (NCDOT) as part of its Connected Autonomous Shuttle Supporting Innovation (CASSI) program. The project brings shared autonomous mobility to the University of North Carolina at Charlotte (UNC Charlotte), showcasing the role of advanced technology in clean, connected campus transportation. The six-month pilot project will enable NCDOT and the university's faculty, staff and students to research and evaluate the vehicle and service in a real-world, campus environment.

"This project reflects a commitment from UNC Charlotte and NCDOT to use new and advanced technologies to improve public transportation and meet our future needs," said NCDOT Secretary Eric Boyette.

The shuttle's six-stop, 2.2-mile route connects the Popp Martin Student Union, Greek Village, academic buildings and dormitories and the main campus light rail station located on the LYNX Blue Line. The LYNX Blue Line operates along 18 miles with 26 stations, connecting users to 11 park-and-ride facilities and directly to the UNC Charlotte campus. Connecting to the light rail system with Beep's shared autonomous mobility service provides riders with additional access to existing transportation services on campus. The UNC Charlotte project continues to advance NCDOT's goal of incrementally increasing the complexity of projects under the CASSI program, while learning from past challenges and building on successes. The project features the longest route, most traffic signals and most complex operating environment to date for the CASSI program.

Riders will have the opportunity to take a survey to provide feedback about their experience riding on the autonomous shuttle. The survey will capture perceptions of the shuttle's safety, comfort and convenience. NCDOT will use the survey results to implement enhancements to the service.

"The intent of this pilot is to introduce autonomous technologies to the campus community and provide insight on how and where we may be able to leverage this and similar platforms on campus in the future," said UNC Charlotte Associate Vice Chancellor for Business Services Doug Lape. "Our partnership with NCDOT and Beep has allowed this opportunity to take place at UNC Charlotte."

The pilot follows a successful inaugural project at the Town of Cary's Fred G. Bond Metro Park, where a four-stop, 1.6-mile route provided an innovative and environmentally friendly mobility option for Cary residents and visitors.

"We are proud that the North Carolina Department of Transportation has again placed its trust in Beep to play an ongoing role in the CASSI program statewide," said Beep CEO Joe Moye. "Our experience in deploying safe, effective shared autonomous mobility services for many thousands of passengers across the country will directly benefit the UNC Charlotte community in ensuring another positive result from this important program, which is transforming the future of mobility."

About Beep

Beep delivers the next generation of autonomous, shared mobility solutions through its software and services. Specializing in planning, deploying and managing autonomous shuttles for private and public communities, Beep safely connects people, places and services with autonomous networks that reduce congestion, eliminate carbon emissions, improve road safety and enable mobility for all. Beep leverages the data and learnings from its deployments to enhance and advance the safety, experience and operating capabilities of autonomous platforms. For more information visit www.ridebeep.com.

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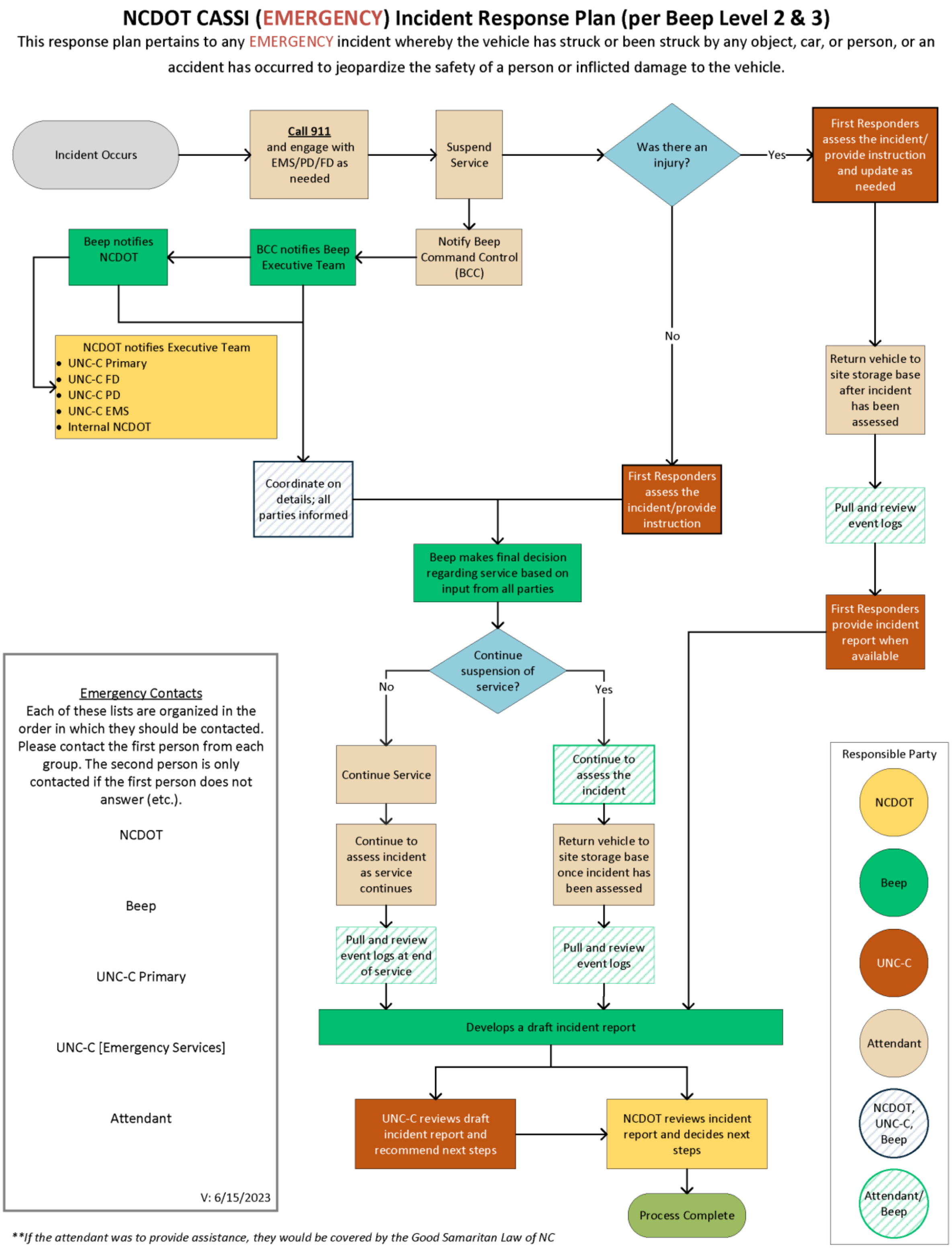
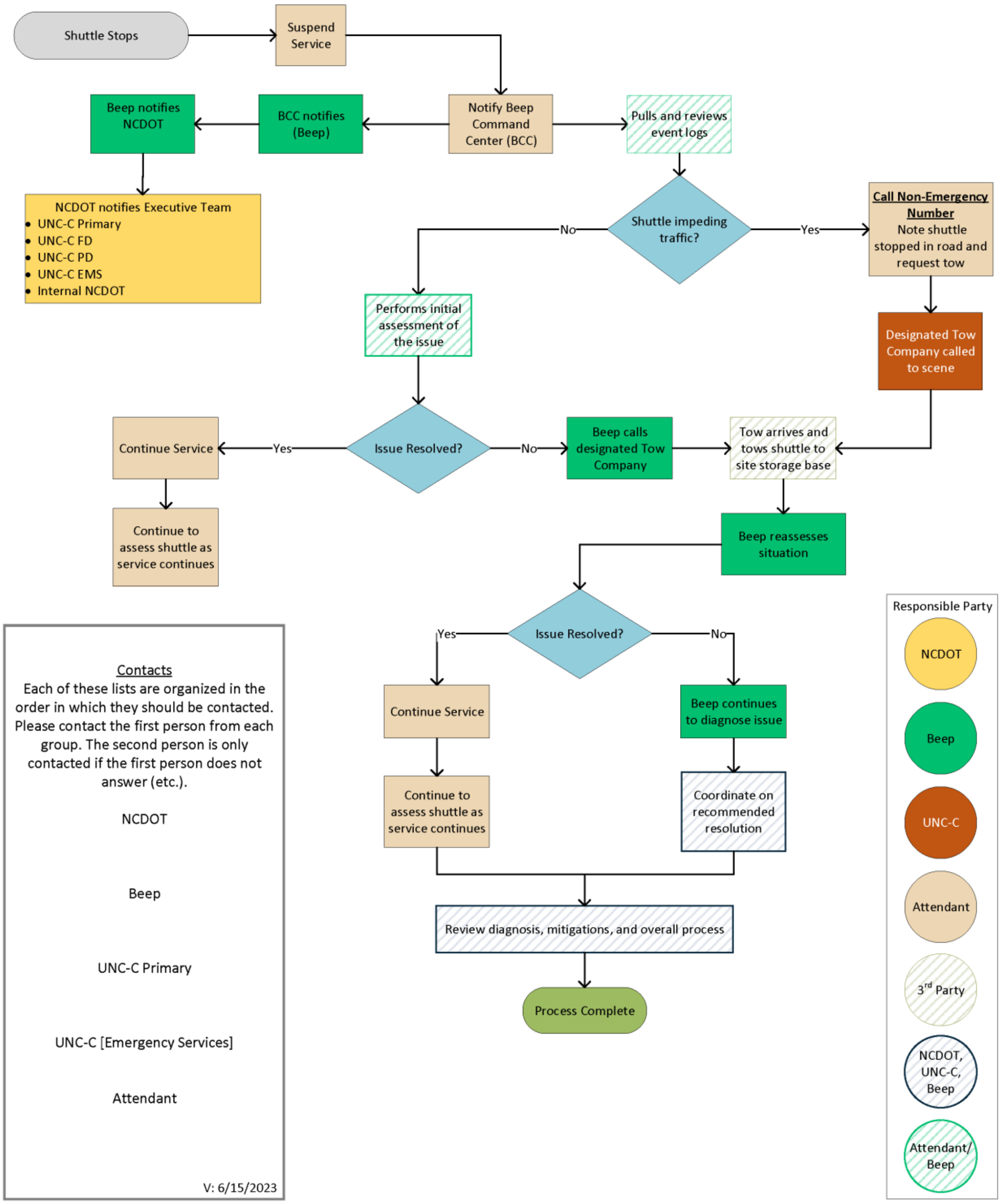
Appendix K. Incident Response Plan for the CASSI at UNC Charlotte Project



NCDOT CASSI (Non-Emergency) Incident Response Plan (per Beep Level 1)

This response plan pertains to any non-emergency incident whereby the vehicle has become immobilized for reasons that do not pertain involvement with another vehicle, pedestrian, or object.



Appendix L. Survey Questions and Response Categories Included in the Rider Survey for the CASSI at UNC Charlotte Project

Survey Questions	Response Categories
Did you ride the driverless shuttle?	Yes or No
What are your thoughts on driverless shuttles?	Free response
How many times have you taken the driverless shuttle in the past?	0 times, 1-2 times, 3-5 times, 5-10 times, More than 10 times, or Daily
Where did you get on the shuttle?	Student Union West, Student Union Deck, Light Rail East, Greek Village #1, Greek Village #8, or Science Building
Where did you get off the shuttle?	Student Union West, Student Union Deck, Light Rail East, Greek Village #1, Greek Village #8, or Science Building
Did you visit UNC Charlotte to ride the shuttle?	Yes or No
How did you get to UNC Charlotte?	Walk, Bike, Scooter, Skateboard, Bus, Light rail, Other transit, Carpool, or Personal vehicle
I had a good experience using the shuttle.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
The shuttle arrived at my stop within a reasonable amount of time.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
I was able to get to my destination in a reasonable amount of time.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
I had a good experience with the attendant on the shuttle.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
I prefer a driverless shuttle with an attendant.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
I support seeing more driverless shuttles on UNC Charlotte's campus.	1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree, or 5 – Strongly disagree
Where on campus would you like to see driverless shuttles?	Free response
BEFORE riding the shuttle, I felt that driverless vehicles are:	1 – Very safe, 2 – Safe, 3 – Neither safe nor unsafe (no opinion), 4 – Unsafe, or 5 – Very unsafe

Survey Questions	Response Categories
AFTER riding the shuttle, I feel that driverless vehicles are:	1 – Very safe, 2 – Safe, 3 – Neither safe nor unsafe (no opinion), 4 – Unsafe, or 5 – Very unsafe
If you felt unsafe while riding the shuttle, please tell us why.	Free response
Did you ride the driverless shuttle for a fun experience or to get to a specific destination?	Fun experience, Specific destination, Both, or Other
Please provide your reason for riding the driverless shuttle.	Free response
If you had not taken the driverless shuttle, which of the following modes of transportation best describes how you would have traveled?	Walk, Bike, Bus or other transit, Carpool, Personal vehicle, Other mode, or Would not have taken the trip
What other mode would you have used to travel?	Free response
Would you ride the shuttle again?	Yes, Maybe, or No
Why or why not?	Free response
Did you use a mobility device during your trip (e.g., wheelchair, cane, crutches, or walker)?	Yes or No
The shuttle comfortably accommodated my mobility device.	Yes or No
What works well in the shuttle to accommodate your mobility device?	Free response
How could the shuttle better accommodate your mobility device?	Free response
Please share any additional feedback about your ride.	Free response
What is your age?	Under 18, 18-29, 30-49, 50-69, or 70 and over
What is your gender?	Female, Male, Nonbinary, Other, or Prefer not to say
What is your race or ethnicity?	White, Hispanic or Latino, Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, or Prefer not to say

Survey Questions	Response Categories
What is your highest level of education?	Less than 9th grade, 9th to 12th grade (no diploma), High school graduate or equivalency, Some college (no degree), Associate degree, Bachelor's degree, Master's degree, Professional degree, Doctorate degree, or Prefer not to say
What is your annual household income?	Less than $15,000, $15,000-$24,999, $25,000-$34,999, $35,000-$49,999, $50,000-$74,999, $75,000-$99,999, $100,000-$149,999, $150,000 or greater, or Prefer not to say
What is your association with UNC Charlotte?	Faculty/staff, Student, Visitor, or Other
What is the zip code of your residence?	Free response
What is your major or area of study?	Free response
Do you live on campus?	Yes or No
How did you hear about the driverless shuttle? Select all that apply.	Signs or flyers on campus, Advertisement in UNC Charlotte's newsletter, Press release from UNC Charlotte or NCDOT, UNC Charlotte social media or webpage, NCDOT social media or webpage, From a friend or family member, or Other
Created Date	Automatic timestamp when a survey is submitted

Appendix M. Ridership, Operations, and Rider Survey Results for the CASSI at UNC Charlotte Project

For tables displaying data by weeks into the pilot, note that the first week and final week were scheduled as partial weeks of service since the pilot launched on a Wednesday and concluded on a Thursday.

Table 1. CASSI at UNC Charlotte – Key Characteristics and Summary Statistics.

Category	UNC Charlotte
Operator	Beep
Vehicle	Navya Autonom
Pilot Period	July 12-December 21, 2023 (23 weeks)
Number of Shuttles	One shuttle
Operating Days	Five days, Monday-Friday
Hours of Service	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	6 hours (additional evening hours added in November and December)
Number of Unique Routes	One route
Route Miles	2.2 miles
Number of Stops	Six stops
Number of Days in Operation	112
Number of Days with Complete Service	56
Number of Days with Partial Service	56
Number of Days with Complete Suspension of Service	2
Number of Days with No Scheduled Service	3
Scheduled Hours of Operation	735.5
Actual Hours of Operation	625.4
Percentage Uptime	85.0%
Number of Disengagements	267
Average Number of Disengagements per Day	2.4
Percentage Time in Autonomous Mode	91.0%
Average Vehicle Speed	6.2 mph
Maximum Vehicle Speed	12.6 mph
Number of Trips	825
Number of Passengers	565
Average Passengers per Trip	Less than 1
Average Passengers per Vehicle per Day	5.0
Average Trips per Vehicle per Day	7.4
Number of Ramp Deployments	0
Average Number of Ramp Deployments per Day	0

Table 2. CASSI at UNC Charlotte – Trips, Ridership, Ramp Deployments, and Wheelchair Securements by Week and Overall.

Weeks Into Pilot	Number of Round Trips Completed	Number of Passengers	Number of Passengers per Round Trip	Number of Ramp Deployments	Number of Wheelchair Securements
1	20	6	0.3	0	0
2	41	33	0.8	0	0
3	17	2	0.1	0	0
4	35	11	0.3	0	0
5	42	7	0.2	0	0
6	39	19	0.5	0	0
7	34	56	1.6	0	0
8	23	24	1.0	0	0
9	24	22	0.9	0	0
10	38	49	1.3	0	0
11	38	34	0.9	0	0
12	26	20	0.8	0	0
13	26	23	0.9	0	0
14	35	33	0.9	0	0
15	34	24	0.7	0	0
16	33	26	0.8	0	0
17	39	22	0.6	0	0
18	41	41	1.0	0	0
19	52	33	0.6	0	0
20	12	5	0.4	0	0
21	45	27	0.6	0	0
22	48	18	0.4	0	0
23	46	17	0.4	0	0
24	37	13	0.4	0	0
Across 23-week pilot period	825	565	0.7	0	0

Table 3. CASSI at UNC Charlotte – Scheduled Hours, Hours Operated, Percentage Uptime, and Battery Percentage Used by Week and Overall.

Weeks Into Pilot	Number of Scheduled Hours	Number of Hours Operated	Percentage Uptime	Average of Battery Percentage Used
1	18.0	17.2	95.4	56.3
2	30.0	29.6	98.5	56.0
3	30.0	11.4	38.1	37.8
4	30.0	25.9	86.4	44.0
5	30.0	26.6	88.6	53.6
6	30.0	22.3	74.3	55.4
7	30.0	22.2	74.1	61.2
8	30.0	19.3	64.4	46.0
9	24.0	20.8	86.8	55.0
10	30.0	25.2	84.1	54.2
11	30.0	27.4	91.4	43.8
12	30.0	23.8	79.3	36.8
13	30.0	19.9	66.3	35.6
14	30.0	27.9	93.0	31.0
15	30.0	26.6	88.7	26.8
16	27.5	24.5	89.1	39.8
17	30.0	28.9	96.2	34.6
18	36.0	34.8	96.7	42.8
19	45.0	42.4	94.2	42.6
20	18.0	9.2	51.2	17.0
21	39.0	36.8	94.4	30.0
22	39.0	37.6	96.4	30.0
23	39.0	37.3	95.6	30.6
24	30.0	27.7	92.4	26.8
Across 23-week pilot period	735.5	625.4	85.0	41.3

Table 4. CASSI at UNC Charlotte – Vehicle Speed at Disengagement, Number of Disengagements, and Number of Disengagements by Type by Week and Overall.

Weeks Into Pilot	Average of Vehicle Speed at Disengagement	Number of Disengagements	Number of Disengagements by Type					
			Signalized Intersection	Other Road Users	Vegetation	Signal Loss	Station Blocked	All Other Reasons
1	3.6	9	1	2	5	0	0	1
2	2.9	29	6	7	2	4	2	8
3	3.6	10	0	0	3	4	1	2
4	4.4	10	0	0	9	0	0	1
5	4.0	19	11	3	5	0	0	0
6	3.4	23	10	10	0	0	1	2
7	0.9	21	18	2	0	1	0	0
8	2.3	3	1	0	0	0	0	2
9	2.6	6	3	1	0	2	0	0
10	0.7	6	3	1	0	1	0	1
11	2.9	16	10	2	0	3	0	1
12	2.6	14	11	2	0	0	0	1
13	2.0	5	0	3	0	0	0	2
14	1.1	7	2	0	0	0	2	3
15	2.6	11	1	4	0	0	4	2
16	1.8	5	2	3	0	0	0	0
17	1.7	3	2	0	0	0	1	0
18	4.0	5	0	0	0	3	2	0
19	0.8	12	5	2	0	0	1	4
20	1.5	4	1	0	0	0	2	1
21	2.0	8	4	1	0	0	0	3
22	0.7	10	10	0	0	0	0	0
23	1.5	21	14	5	0	0	1	1

Weeks Into Pilot	Average of Vehicle Speed at Disengagement	Number of Disengagements	Number of Disengagements by Type					
			Signalized Intersection	Other Road Users	Vegetation	Signal Loss	Station Blocked	All Other Reasons
24	2.8	10	4	1	0	3	1	1
Across 23-week pilot period	2.4	267	119	49	24	21	18	36

Table 5. CASSI at UNC Charlotte – Average Vehicle Speed, Maximum Vehicle Speed, Percentage Time in Autonomous Mode, and Percentage Uptime Overall as Reported by Beep.

Across 23-week pilot period per Beep's calculations	
Average Vehicle Speed	6.2 mph
Maximum Vehicle Speed	12.6 mph
Percentage Time in Autonomous Mode	91.0%
Percentage Uptime	85.0%

Table 6. CASSI at UNC Charlotte – How many times have you taken the driverless shuttle in the past?

How many times have you taken the driverless shuttle in the past?	Number of Respondents	Percentage of Respondents
0 times	24	41%
1-2 times	28	47%
3-5 times	6	10%
5-10 times	1	2%
More than 10 times	0	0%
Daily	0	0%
Grand Total	59	100%

Table 7. CASSI at UNC Charlotte – Where did you get on the shuttle?

Where did you get on the shuttle?	Number of Respondents	Percentage of Respondents
Light Rail East	9	15%
Greek Village #1	11	19%
Greek Village #8	6	10%
Science Building	10	17%
Student Union Deck	4	7%
Student Union West	19	32%
Grand Total	59	100%

Table 8. CASSI at UNC Charlotte – Where did you get off the shuttle?

Where did you get off the shuttle?	Number of Respondents	Percentage of Respondents
Light Rail East	22	37%
Greek Village #1	4	7%
Greek Village #8	4	7%
Science Building	11	19%
Student Union Deck	3	5%
Student Union West	15	25%
Grand Total	59	100%

Table 9. CASSI at UNC Charlotte – Did you visit UNC Charlotte to ride the shuttle?

Did you visit UNC Charlotte to ride the shuttle?	Number of Respondents	Percentage of Respondents
Yes	13	22%
No	45	78%
Grand Total	58	100%

Table 10. CASSI at UNC Charlotte – How did you get to UNC Charlotte?

How did you get to UNC Charlotte?	Number of Respondents	Percentage of Respondents
Walk	11	19%
Bike	0	0%
Scooter	0	0%
Skateboard	0	0%
Bus	1	2%
Light rail	1	2%
Other transit	3	5%
Carpool	5	8%
Personal vehicle	38	64%
Grand Total	59	100%

Table 11. CASSI at UNC Charlotte – I had a good experience using the shuttle.

I had a good experience using the shuttle.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	32	54%
2 – Agree	17	29%
3 – Neither agree nor disagree	1	2%
4 – Disagree	4	7%
5 – Strongly disagree	5	8%
Grand Total	59	100%

Table 12. CASSI at UNC Charlotte – The shuttle arrived at my stop within a reasonable amount of time.

The shuttle arrived at my stop within a reasonable amount of time.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	23	39%
2 – Agree	10	17%
3 – Neither agree nor disagree	8	14%
4 – Disagree	6	10%
5 – Strongly disagree	12	20%
Grand Total	59	100%

Table 13. CASSI at UNC Charlotte – I was able to get to my destination in a reasonable amount of time.

I was able to get to my destination in a reasonable amount of time.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	22	37%
2 – Agree	14	24%
3 – Neither agree nor disagree	4	7%
4 – Disagree	11	19%
5 – Strongly disagree	8	14%
Grand Total	59	100%

Table 14. CASSI at UNC Charlotte – I had a good experience with the attendant on the shuttle.

I had a good experience with the attendant on the shuttle.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	52	88%
2 – Agree	2	3%
3 – Neither agree nor disagree	4	7%
4 – Disagree	0	0%
5 – Strongly disagree	1	2%
Grand Total	59	100%

Table 15. CASSI at UNC Charlotte – I prefer a driverless shuttle with an attendant.

I prefer a driverless shuttle with an attendant.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	17	29%
2 – Agree	13	22%
3 – Neither agree nor disagree	19	32%
4 – Disagree	5	8%
5 – Strongly disagree	5	8%
Grand Total	59	100%

Table 16. CASSI at UNC Charlotte – I support seeing more driverless shuttles on UNC Charlotte's campus.

I support seeing more driverless shuttles on UNC Charlotte's campus.	Number of Respondents	Percentage of Respondents
1 – Strongly agree	33	56%
2 – Agree	8	14%
3 – Neither agree nor disagree	7	12%
4 – Disagree	5	8%
5 – Strongly disagree	6	10%
Grand Total	59	100%

Table 17. CASSI at UNC Charlotte – BEFORE riding the shuttle, I felt that driverless vehicles are:

BEFORE riding the shuttle, I felt that driverless vehicles are:	Number of Respondents	Percentage of Respondents
1 – Very safe	9	15%
2 – Safe	25	42%
3 – Neither safe nor unsafe (no opinion)	18	31%
4 – Unsafe	5	8%
5 – Very unsafe	2	3%
Grand Total	59	100%

Table 18. CASSI at UNC Charlotte – AFTER riding the shuttle, I feel that driverless vehicles are:

AFTER riding the shuttle, I feel that driverless vehicles are:	Number of Respondents	Percentage of Respondents
1 – Very safe	21	36%
2 – Safe	23	40%
3 – Neither safe nor unsafe (no opinion)	9	16%
4 – Unsafe	4	7%
5 – Very unsafe	1	2%
Grand Total	58	100%

Table 19. CASSI at UNC Charlotte – Did you ride the driverless shuttle for a fun experience or to get to a specific destination?

Did you ride the driverless shuttle for a fun experience or to get to a specific destination?	Number of Respondents	Percentage of Respondents
Fun experience	23	40%
Specific destination	14	24%
Both	20	34%
Other	1	2%
Grand Total	58	100%

Table 20. CASSI at UNC Charlotte – If you had not taken the driverless shuttle, which of the following modes of transportation best describes how you would have traveled?

If you had not taken the driverless shuttle, which of the following modes of transportation best describes how you would have traveled?	Number of Respondents	Percentage of Respondents
Walk	23	39%
Bike	0	0%
Bus or other transit	26	44%
Carpool	0	0%
Personal vehicle	6	10%
Other mode	0	0%
Would not have taken the trip	4	7%
Grand Total	59	100%

Table 21. CASSI at UNC Charlotte – Would you ride the shuttle again?

Would you ride the shuttle again?	Number of Respondents	Percentage of Respondents
Yes	41	69%
Maybe	8	14%
No	10	17%
Grand Total	59	100%

Table 22. CASSI at UNC Charlotte – Did you use a mobility device during your trip (e.g., wheelchair, cane, crutches, or walker)?

Did you use a mobility device during your trip (e.g., wheelchair, cane, crutches, or walker)?	Number of Respondents	Percentage of Respondents
Yes	1	2%
No	58	98%
Grand Total	59	100%

Table 23. CASSI at UNC Charlotte – What is your age?

What is your age?	Number of Respondents	Percentage of Respondents
Under 18	3	5%
18-29	46	78%
30-49	5	8%
50-69	5	8%
70 and over	0	0%
Grand Total	59	100%

Table 24. CASSI at UNC Charlotte – What is your gender?

What is your gender?	Number of Respondents	Percentage of Respondents
Female	32	54%
Male	21	36%
Nonbinary	4	7%
Other	0	0%
Prefer not to say	2	3%
Grand Total	59	100%

Table 25. CASSI at UNC Charlotte – What is your race or ethnicity? Mark one or more boxes.

What is your race or ethnicity?	Number of Respondents	Percentage of Respondents
White	26	44%
Hispanic or Latino	3	5%
Hispanic or Latino AND White	2	3%
Black or African American	12	20%
Black or African American AND Hispanic or Latino	1	2%
American Indian or Alaska Native	0	0%
Asian	8	14%
Native Hawaiian or Other Pacific Islander	0	0%
Prefer not to say	7	12%
Grand Total	59	100%

Table 26. CASSI at UNC Charlotte – What is your highest level of education?

What is your highest level of education?	Number of Respondents	Percentage of Respondents
Less than 9th grade	0	0%
9th to 12th grade (no diploma)	2	3%
High school graduate or equivalency	4	7%
Some college (no degree)	21	36%
Associate degree	8	14%
Bachelor's degree	11	19%
Master's degree	8	14%
Professional degree	0	0%
Doctorate degree	3	5%
Prefer not to say	2	3%
Grand Total	59	100%

Table 27. CASSI at UNC Charlotte – What is your annual household income?

What is your annual household income?	Number of Respondents	Percentage of Respondents
Less than $15,000	3	5%
$15,000-$24,999	7	12%
$25,000-$34,999	3	5%
$35,000-$49,999	3	5%
$50,000-$74,999	5	8%
$75,000-$99,999	6	10%
$100,000-$149,999	8	14%
$150,000 or greater	5	8%
Prefer not to say	19	32%
Grand Total	59	100%

Table 28. CASSI at UNC Charlotte – What is your association with UNC Charlotte?

What is your association with UNC Charlotte?	Number of Respondents	Percentage of Respondents
Faculty/staff	2	3%
Student	46	78%
Visitor	8	14%
Other	3	5%
Grand Total	59	100%

Table 29. CASSI at UNC Charlotte – Do you live on campus?

Do you live on campus?	Number of Respondents	Percentage of Respondents
Yes	31	67%
No	15	33%
Grand Total	46	100%

Table 30. CASSI at UNC Charlotte – What is the zip code of your residence?

What is the zip code of your residence?	Number of Respondents	Percentage of Respondents
28027	1	6%
28078	1	6%
28205	4	24%
28213	3	18%
28223	1	6%
28262	5	29%
28269	2	12%
Grand Total	17	100%

Table 31. CASSI at UNC Charlotte – Where on campus would you like to see driverless shuttles?

Where on campus would you like to see driverless shuttles?	Number of Respondents
No	1
A direct route from South Village to the Union would be awesome.	1
All over	1
Another driverless shuttle for nighttime for the Greek Village route would be nice.	1
Anywhere	1
Anywhere there are major hills!	1
Around class halls like Fretwell	1
Bioinformatics Building	1
Central campus, connecting to locations immediately off campus	1
East and west of the campus	1
Everywhere	1
Everywhere really, but especially in the uppermost parts of campus that can be harder to commute to without a car.	1
Everywhere!! They are awesome!! Super cool!	1
Football shuttles, Greek Village	1
Friday Building	1
From the Marriott to the football stadium	1
Greek Village	1
I would like to see driverless shuttles being very useful during odd hours or during holidays (when they can work reliably without any attendants). For regular hours, I think the current route is sufficient until the autonomous shuttle becomes as effective as a regular bus in terms of passengers and speed.	1
I would like to see them in more of the rural areas of campus. The Science Building and Union are great locations already.	1
I would not. They are a waste of valuable money provided by myself and other students which could be put towards things we need such as residential updates.	1
In the South Village and East Deck area	1
More shuttles using the same route would be awesome.	1
N/A	1
Near residence halls	1
Near South Village	1
Near the library	1
North Village to Colvard	1
Not really anywhere	1
Nowhere	1
Routes going from the Student Union to South Village	1

Where on campus would you like to see driverless shuttles?	Number of Respondents
Same places they're at now, but more	1
Student Union, South Village	1
The library !!!!	1
Union Deck to Science Building	1
Whenever I use the bus system on campus, I am usually travelling between stops in the North Village. Because the two main bus lines (Green/Gold) that travel through North Village are relatively infrequent, unreliable, and often full at peak hours, having driverless shuttles stopping at only North Village or South Village stops could relieve the pressure on the main bus lines while making intra-campus/intra-village travel for students like me more simple to plan for.	1
With the current technology, nowhere. It is not very comfortable nor efficient currently.	1
Grand Total	36

Table 32. CASSI at UNC Charlotte – If you felt unsafe while riding the shuttle, please tell us why.

If you felt unsafe while riding the shuttle, please tell us why.	Number of Respondents
Not a smooth ride.	1
Grand Total	1

Table 33. CASSI at UNC Charlotte – Please provide your reason for riding the driverless shuttle.

Please provide your reason for riding the driverless shuttle.	Number of Respondents
Grand Total	0

Table 34. CASSI at UNC Charlotte – Would you ride the shuttle again? Why or why not?

Would you ride the shuttle again? Why or why not?	Number of Respondents
Because it can only drive 12 mph, it was really slow and took 10 minutes to ride somewhere that should have taken 3.	1
Because it’s so cool! And super efficient.	1
Because it's fun.	1
Easy to ride.	1
Extremely slow, poor ventilation, air was stuffy.	1
For learning more about the shuttle.	1
For something different.	1
Fun.	1
I enjoyed it!	1
It felt safe and was a cool experience.	1

Would you ride the shuttle again? Why or why not?	Number of Respondents
It is a safe and comfortable mode of transportation. I love being a part of the innovation!	1
It is very convenient, quick, and advanced!	1
It took too long to get to my destination.	1
It was a fun experience.	1
It was a great experience with the attendant and cool technology.	1
It was a lot quicker than walking and not as crowded as taking the bus.	1
It was a safe and reliable mode, and I am interested in supporting emerging transportation technologies and multi-modal transportation.	1
It was an easy drive to where I needed to go.	1
It was convenient and novel!	1
It was fun.	1
It was too slow.	1
It was very fun to ride the shuttle and experience the future of technology. However, if I'm in a rush I would probably take a regular bus.	1
It was WAY too slow.	1
It’s extremely slow and I would have to leave 30+ minutes beforehand to get to my destination on time when using the shuttle.	1
It’s inconvenient, it stops for a long time, and always makes me and my friends late to our destination.	1
It’s quicker than walking.	1
It's quiet.	1
It's the only other quick way of getting from Greek Village to the Union, and it's cute.	1
It's too slow.	1
It's very cool and I support furthering technology.	1
It's way too slow.	1
Only if it is more convenient than the Greek Village shuttle which it is almost never.	1
Shuttle is slow, spends 15 minutes at some stops, and can only hold 8 people.	1
The driver was a great driver. Really explained the auto features and overall had a great time using the bus.	1
The shuttle drives unbelievably slow and instead of getting home in five minutes from the regular bus shuttle, CASSI took 30 minutes for me to get home.	1
The shuttle felt very safe to ride in, and through conversation with the attendant and watching the shuttle's interface screen, I felt very comfortable knowing what the shuttle was seeing and how it responded to hazards. At no point did the shuttle feel as if it was out of control.	1
The shuttle is too slow.	1

Would you ride the shuttle again? Why or why not?	Number of Respondents
The thing goes like 5 miles an hour and holds up traffic and other shuttles that are trying to get students places at a reasonable time making everyone late.	1
Very fun.	1
Yes. Very friendly attendant and a fun experience.	1
Grand Total	40

Table 35. CASSI at UNC Charlotte – Please share any additional feedback about your ride.

Please share any additional feedback about your ride.	Number of Respondents
An awesome attendant explained to me how it worked while I rode.	1
Attendants were very friendly and helpful.	1
Great attendant.	1
Having the shuttle not take the left turn at the light for Greek Village and having it do a U-turn takes up too much time and had me late for class.	1
It was overall good. Helpful for Greek Village riders.	1
It would be more beneficial if the shuttle drove a bit faster.	1
Shuttle brakes suddenly, making it very likely for you to fall out of the seat since there is no shoulder strap.	1
Shuttle has very abrupt/jarring stops that take away from the enjoyment of the ride.	1
Super cool attendant, very informative and helpful.	1
The AI used was a little hanky, had to do a couple hard resets for CASSI.	1
The machine needs work for sure. Too much braking, too slow, too much recharge time. What really kills it is the recharge time. The shuttle is barely available.	1
The operator on board was great!	1
The shuttle stops for extended periods of time without warning causing a major inconvenience for students riding.	1
The stopping was very jerky, especially when the vehicle was departing a stop.	1
There is a shorter route to get from Greek Village to the Science Building, but the bus took a weird turn which was kinda unnecessary.	1
This is a great solution for the last half-mile transport that we all need. I think it would also make a great replacement for the disability SUVs on the walkways.	1
While I understand that for safety reasons the shuttle should brake quickly, I wish it was a bit more smooth and less sudden.	1
Grand Total	17

Table 36. CASSI at UNC Charlotte – What is your major or area of study?

What is your major or area of study?	Number of Respondents
Accounting	1
Bioinformatics	1
Biology	4
Biology and Spanish	1
Business	1
Communications	1
Computer Science	7
Criminal Justice	1
Criminal Justice and Political Science	1
Dance and Communications	1
Double Major in Public Health and Dance, Minor in Biology	1
Elementary Education	1
Exercise Science	1
Finance	1
Geography – Urban Planning	1
Health Systems Management	1
History	1
Management	1
Marketing	1
Mechanical Engineering Technology	1
Psychology	2
Public Health	1
Sociology	1
Transportation Engineering	1
Undecided	1
Writing, Rhetoric and Digital Studies	1
Grand Total	36