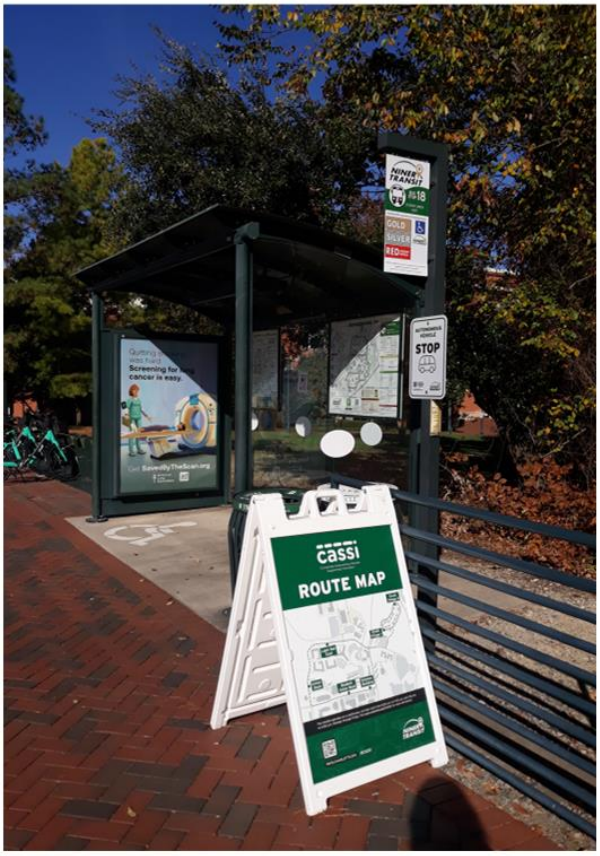

Connected Autonomous Shuttle Supporting Innovation (CASSI) at UNC Charlotte

Executive Summary

July 2024

UNIVERSITY OF NORTH CAROLINA CHARLOTTE

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Integrated Mobility Division
N.C. DEPARTMENT OF TRANSPORTATION

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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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**Additional individuals from NCDOT assisted with the inspection, titling, registration, storage, and transport of the shuttle for the preceding CASSI in Cary's Bond Park project. These individuals are acknowledged in the project's final report.[1] Their accomplishments conveyed to the CASSI at UNC Charlotte project.*

[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).*

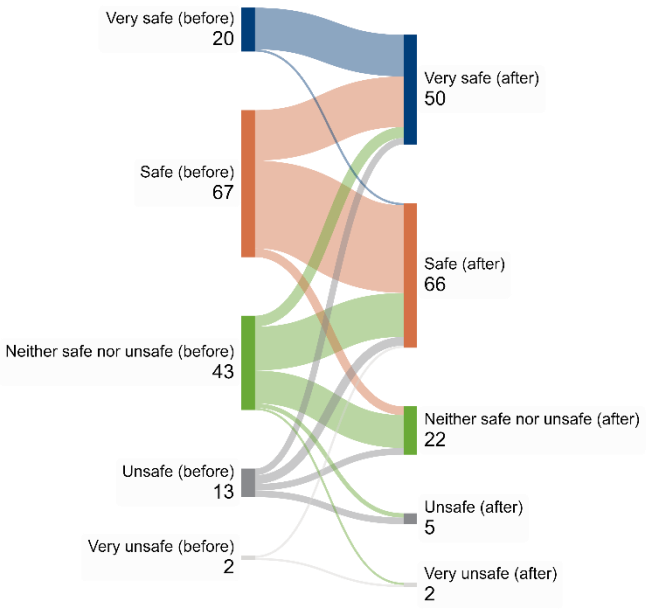
Common Successes

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

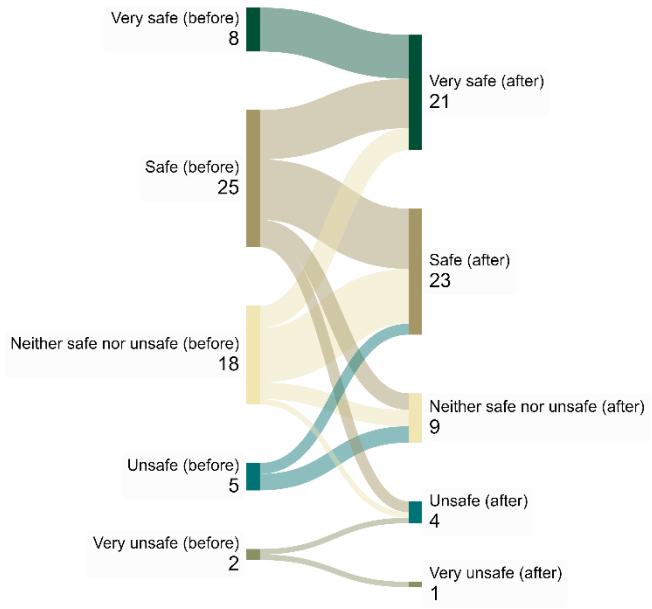
- **Riders generally had a good experience with the shuttle and the attendant on the shuttle.** Feedback from rider surveys indicated that most riders had a good experience with the shuttle (92% and 83% of survey respondents respectively) and a good experience with the attendant on the shuttle (97% and 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

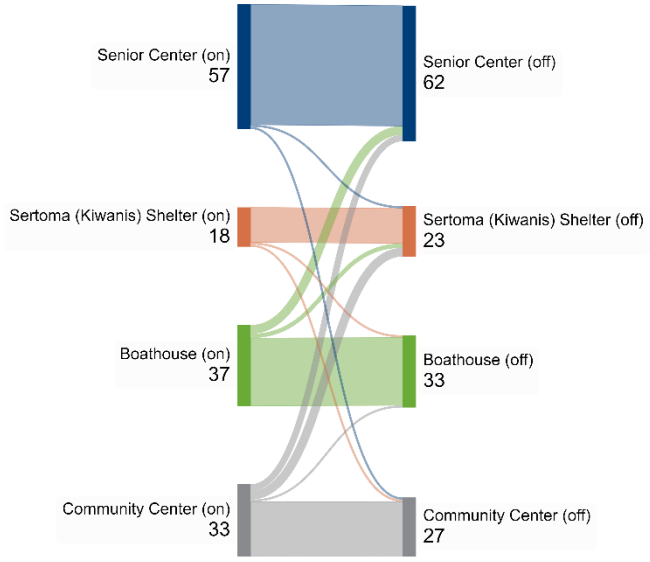
Key differences between the pilots in Cary's Bond Park and at UNC Charlotte include:

- **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

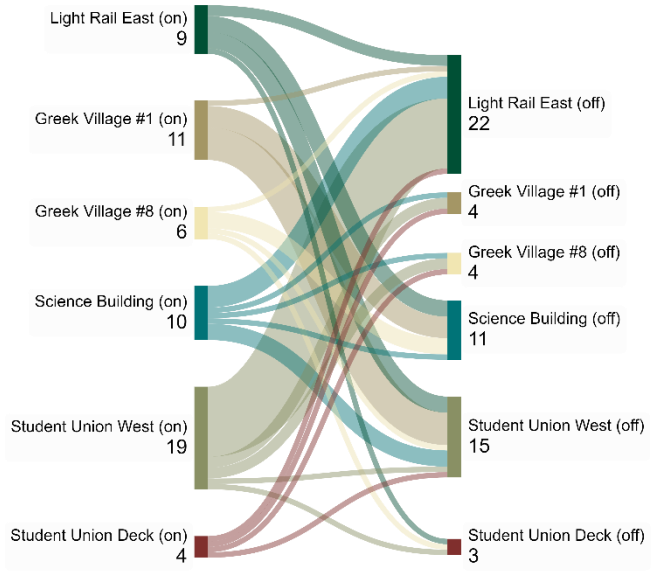
pilot in Cary's Bond Park rode the shuttle for a fun experience or both a fun experience and to get to a specific destination, compared to 74% of survey respondents for the pilot at UNC Charlotte. 59% of survey respondents for the pilot at UNC Charlotte rode the shuttle to get to a specific destination 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

For more information about the CASSI program, please visit:

ncdot.gov/cassi

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