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Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research

PREPARED BY
Volpe National Transportation Systems Center

AUGUST
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U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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14. ABSTRACT
This report provides a summary of current accessibility practices among transit bus automation demonstrations and pilot projects. It also discusses ongoing research on technologies that may enhance the accessibility of future automated buses and services. The current practices described include projects' approach to complying with regulations implementing the Americans with Disabilities Act of 1990 (ADA), and the role of onboard staff. Research areas covered include boarding and alighting technologies, securement technologies, and wayfinding/communication technologies. The report describes findings to date and future needs.

15. SUBJECT TERMS
Transit, bus, automation, automated driving systems (ADS), accessibility, Americans with Disabilities Act (ADA)

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Abstract

This report provides a summary of current accessibility practices among transit bus automation demonstrations and pilot projects. It also discusses ongoing research on technologies that may enhance the accessibility of future automated buses and services. The current practices described include projects' approach to complying with regulations implementing the Americans with Disabilities Act of 1990 (ADA), and the role of onboard staff. Research areas covered include boarding and alighting technologies, securement technologies, and wayfinding/communication technologies. The report describes findings to date and future needs.

Executive Summary

As public sector agencies investigate the use of driving automation in transit bus applications, the accessibility of vehicles and services for passengers with disabilities is an area of active research and development. Driving automation has the potential to improve mobility for travelers with disabilities by possibly reducing the costs of providing transit service and enabling more extensive, more flexible service. While this promise is exciting, many technologies and services in recent and current pilots and demonstrations have experienced challenges in ensuring regulatory compliance with accessibility requirements, and some of those efforts have identified areas needing further research and development.

While the U.S. transit industry has a long history of working to improve accessibility in public transportation, automated transit bus pilots and demonstrations often bring together actors from the public and private sectors who may be new to either public transportation, accessibility, or both. Many projects are using new vehicle types, or vehicle formats that are less commonly used in transit services.

This scan presents an overview of the ways that several demonstration and pilot projects are addressing identified accessibility challenges, particularly how projects comply with the Americans with Disabilities Act of 1990 (ADA) and the roles of their onboard staff. Also discussed is ongoing research on technologies that may enhance the accessibility of future automated buses and services. These technologies include:

- Boarding and alighting technologies
- Securement technologies
- Wayfinding and communication technologies

To help inform future research projects, the report highlights key findings and broad themes related to the current state of accessibility in transit bus automation:

- Research applications could be broad.
- Automation could improve aspects of accessibility for bus transit.
- Early pilots and demonstrations have helped to bring accessibility for automated transit buses forward.
- Accessible, automated transit buses are still prototypes.
- Accessibility in pilots and demonstrations today relies heavily on the role of the onboard attendant, and there are technical and policy challenges associated with moving toward unstaffed operations.

- Accessibility requirements must be considered for a broad range of vehicles, service types, and rider characteristics.
- Better data are needed on use by passengers with disabilities.

While transit bus automation is at the stage of early pilots and demonstrations, future services and applications may have the potential to improve mobility for passengers with disabilities. Further accessibility research will be required as automated transit bus technologies and pilots continue to evolve and build on each other.

Section 1

Introduction

As public sector agencies investigate the use of driving automation in transit bus applications, the accessibility of vehicles and services for passengers with disabilities is an area of active research and development. Driving automation has the potential to improve mobility for travelers with disabilities by possibly reducing the costs of providing transit service and enabling more extensive, more flexible service. While this promise is exciting, many technologies and services in recent and current pilots and demonstrations have experienced challenges in ensuring regulatory compliance with accessibility requirements, and some of those efforts have identified areas needing further research and development.

While the U.S. transit industry has a long history of working to improve accessibility in public transportation, automated transit bus pilots and demonstrations often bring together actors from the public and private sectors who may be new to either public transportation, accessibility, or both. Many projects are using new vehicle types, or vehicle formats that are less commonly used in transit services. Additionally, some projects are exploring the potential for unstaffed service in the future; the removal of an official staff presence onboard the vehicle represents a major challenge for accessibility, as personnel would not be present to assist passengers.

This scan presents an overview of the ways that several demonstration and pilot projects are addressing identified accessibility challenges. Also discussed is ongoing research on technologies that may enhance the accessibility of future automated buses and services.

The scan is sponsored by the Federal Transit Administration (FTA) Office of Research, Demonstration, and Innovation as part of implementing its Strategic Transit Automation Research (STAR) Plan (Machek et al., 2018). It was conducted by staff from the John A. Volpe National Transportation Systems Center.

Methodology and Limitations

The study team reviewed the literature on transit bus automation and accessibility and conducted interviews with developers of automated driving systems (ADS), bus manufacturers, accessibility equipment vendors, and public sector agencies involved in pilot and demonstration projects. This paper does not focus on accessibility in public transportation generally, but rather focuses narrowly on documenting current practices and challenges in domestic transit bus automation pilots and demonstrations.

Section 2 Background

State of Transit Bus Automation

Vehicle automation is a rapidly evolving field, with various vehicle platforms, use cases, service models, and operating environments, resulting in multiple potential paths to commercialization.[1] The relatively low ordering volumes and high level of customization in the domestic bus market, along with the relatively low level of transferability from other vehicle platforms, has resulted in ADS development for transit buses lagging behind the light-duty passenger vehicle and heavy-duty commercial trucking segments. As such, the transit bus automation systems that have been developed are in the pilot testing stage or working toward commercialization.

Despite the nascent state of the market (relative to other ADS market segments), there are dozens of ongoing pilots in operation in the United States and many more have been announced to begin soon. Low-speed automated shuttles with novel designs (e.g., vehicles produced by companies such as EasyMile, Local Motors, and Navya) represent one of the earliest transit bus automation formats, and they are still the most common vehicles used in pilots and demonstrations. In recent years, however, several companies have announced new prototypes using more traditional transit bus platforms (e.g., 40-foot city transit buses, cutaway buses, etc.).

Some demonstration activities are relatively short (lasting only days or weeks), while longer pilot activities may last several months or even a year or two. Often these activities are supported by state or local funds. In many cases, transit bus automation projects have also received Federal funding. Whether publicly or privately operated, Federally funded or not, all such undertakings that are open to public ridership are subject to U.S. Department of Transportation (DOT) accessibility regulations. Transit agencies, communities, and other stakeholders operating pilots and demonstrations do so for a variety of reasons, such as to:

- learn more about the state of the technology and its capabilities
- understand the barriers and challenges to operating an automated transit bus service
- conduct outreach to the community to better understand desires for and sentiment toward the technology
- signal interest in the technology and promote themselves as leaders in new transportation technologies

[1] For more information on the different classifications of driving automation systems, see SAE International's Recommended Practice J3016 (SAE International 2021). This document focuses primarily on ADS, where the system performs the entire dynamic driving task on a sustained basis. Lower levels of automation may be present in specific features of some advanced driver assistance systems (ADAS).

Early pilots can largely be characterized as "parking lot circulators" where test vehicles operate in a closed environment, but recently some pilots have offered more useful and realistic service. Pilots are now more commonly operating in mixed traffic and on routes with useful connections to points of interest or other transit services. Often, service is open to the public and, in some cases, pilots are charging fares to riders. While most transit agencies plan to retain an official staff presence on vehicles for the foreseeable future, some companies are developing and testing capabilities for unstaffed operation, and some agencies have indicated an eventual desire for this option (NJDOT 2021). While the broader use of unstaffed operation for transit service on public roads can be viewed as a distant capability, transitioning to a model without onboard staff has implications for transit bus accessibility, as discussed in detail in Section 4. For the time being, unstaffed vehicle testing has largely been limited to closed campus operations without passengers, especially in the United States.[2]

FTA has published a more detailed assessment of the state of commercialized and prototype products related to automated transit buses (Cregger, Machek, and Cahill, 2021), as well as a regularly updated resource documenting transit bus automation pilots and demonstrations in the United States.[3] More information on projects funded and managed by FTA can be found on the FTA website.[4]

Accessibility Research for Automated Transit

The Americans with Disabilities Act of 1990 (ADA) is a comprehensive civil rights statute that prohibits discrimination on the basis of disability by public and private entities, including in the provision of transportation services. U.S. DOT regulations regarding ADA compliance can be found at Title 49 of the Code of Federal Regulations (CFR), Parts 27, 37, 38, and 39, and include requirements for vehicles, facilities, and operations. ADA applies to any and all vehicles, including those with driving automation technologies, used in service to the public, and there are no exceptions for demonstrations or pilots that are open to the public. For more comprehensive information on accessibility in public transportation, please visit https://www.transit.dot.gov/ADA.

Following is a review of existing automated vehicle accessibility research, highlighting key themes and principles.

[2] In most cases, automated vehicle pilots and demonstrations (including those outside of transit applications) include onboard safety operators who can take control of vehicles when needed. In cases where there is no on board staff presence, automated vehicle operations have included a remote operator as the fallback option for situations where the ADS is unable to manage without human input.
[3] Transit Bus Automation Quarterly Update Q4 2021 | FTA.
[4] FTA-Funded and Managed Transit Bus Automation Demonstrations & Pilots | FTA.

Whereas accessibility in transit, accessibility in automated vehicles, and transit bus automation are all active areas of research, less research has been conducted on accessibility in automated transit buses. Tabattanon, Sandhu, and D'Souza (2019) note that accessibility research has been limited on automated transit (particularly, in their case, for low-speed automated shuttles). They provide a matrix of research (primarily non-automation focused) on transit accessibility for a variety of users and tasks, summarizing recommended design practices. Concentrating on interior circulation within low-speed shuttles, they note that all studies that referenced this issue found that users experienced some level of difficulty.

ADA requirements must be incorporated during initial vehicle design rather than only via retrofitting. In a follow-on to the Tabattanon et al. study, the same researchers describe their efforts to retrofit a commercially available low-speed shuttle using the U.S. Access Board's ADA Accessibility Guidelines for Buses, Over-the-Road Buses, and Vans[5] (Tabattanon and D'Souza, 2021). Their retrofitting process included an attempt to add a ramp and a wheelchair securement device and increase available onboard floor space. However, limitations to the retrofit process meant that the ramp and securement area could not accommodate power wheelchair or scooter users, making it noncompliant, and required an onboard attendant for assistance. They note that they may have been successful if accessibility requirements were incorporated during vehicle design, rather than retrofitting an existing model not built for the U.S. market.

Current interest from people with disabilities in using an automated transit bus is mixed. Whereas research on the perceptions of people with disabilities and older adults concerning automated public transportation is limited, more studies have investigated their general views regarding automated vehicles. Dicianno et al., (2021) reviewed the literature on this topic, highlighting the potential opportunities provided by automated vehicles and the barriers to their accessible deployment. The review notes that accessibility research on public transit and automation is limited. Where present, such research often considers automated vehicles (with a form factor similar to a passenger car) as an alternative to conventional public transit for people with disabilities (particularly those whose disabilities preclude them from driving). Research considering automation integrated into public transit vehicles is less common. However, many of the research themes and recommendations for personal vehicles apply to automated transit vehicles, such as ensuring participatory design and focus on the entire journey rather than just in-vehicle technologies and features.

[5] Appendix A to Part 1192 of 36 CFR.

When asked about their perceptions of automated transit, transit users with disabilities were less likely to be willing to use an automated transit vehicle than transit users overall. This difference was greater for demand-responsive versus fixed-route riders (Kassens-Noor, Kotval-Karamchandani, and Cai 2020). On the other hand, Faber and van Lierop (2020) presented focus groups of older adults (a majority of whom used mobility devices) with different potential service models for automated vehicle deployment. In most cases, the participants preferred the on-demand models to fixed-route, due to the convenience of door-to-door service without a set schedule.

If transit providers consider operations without onboard staff, there are many accessibility-related operator roles outside of driving the vehicle that they must understand. Transit vehicle operators play many roles today that contribute to transit accessibility. Machek et al. (2018) discuss several of these tasks, including:

- Interacting with passengers (e.g., answering questions about the route)
- Ensuring information systems (signage, vehicle locators, stop announcements) are operational and correct
- Positioning the vehicle at a stop to allow a person using a mobility device to maneuver unobstructed
- Operating accessibility equipment (ramps and lifts), including manual operation if necessary
- Securing passengers with mobility devices and asking other passengers to make space
- Making required stop announcements
- Removing obstacles (e.g., garbage) from aisles

Hunter-Zaworski and Hron (1999) found that, for passengers with sensory disabilities, one-on-one interaction is often necessary to solve individual access issues, and that technological advancements may not solve them. However, technology has significantly advanced in the two decades since these findings were published. Park and Chowdhury (2018) found that common barriers to accessing transit in New Zealand among people with physical or vision impairments included bus drivers' level of awareness and poor driver attitude (e.g., skipping stops where a person with a disability was waiting).

Section 3

Accessibility Technology Research and Testing

This section briefly summarizes the state of the practice for transit bus automation-related accessibility technologies, along with current and upcoming research, demonstration, and pilot programs.

Accessibility Technologies That Enable Automated Transit

Private sector firms and public universities are developing various accessibility technologies that could be applicable to both conventional transit operations and automated transit buses. Some of these technologies include systems to support boarding and alighting, wheelchair securement, wayfinding, and other communications.

Boarding and Alighting Technologies

To be accessible, a bus or van must include a lift, ramp, or other level-change mechanism that enables people with mobility impairments, including wheelchair users, to board or disembark the vehicle. The choice of installing a ramp or a lift may depend on the vehicle's floor height and interior configuration. Standards for lifts and ramps for buses and vans are in 49 CFR § 38.23. Lifts must also meet Federal Motor Vehicle Safety Standards requirements at 49 CFR § 571.403. Personnel are required to assist passengers with ramps and lifts when necessary or upon request, and to take vehicles with inoperable lifts out of service (49 CFR § 37.165(f); 49 CFR § 37.163).

Researchers are exploring technologies that could enable ramp or lift use without the presence of transit personnel, although U.S. DOT ADA regulations currently require the presence of such personnel. Ramp research includes studies on the effect (time and perceived exertion) of different ramp slopes and configurations, and on integrating ramps into electric vehicle floors where the batteries may limit the available under-floor space (U.S. Access Board 2021).

Source: Santa Clara Valley Transportation Authority

Figure 3-1 *Passenger using power wheelchair to board automated Local Motors Olli shuttle*

Ramps can work in concert with kneeling technologies that lower the floor of the bus to decrease the ramp slope. Recent advancements in kneeling include systems that adjust the kneel height to the surrounding environment.[6]

Lift research includes developing systems that activate automatically and adjust to the environment (e.g., halting if it encounters obstacles), as well as allowing users to control the lift via voice, button, or mobile phone application (U.S. Access Board, 2021).

Securement Technologies

Securement technologies ensure that wheelchairs remain within the securement location while traveling. As with ramps and lifts, a vehicle must contain securement locations and devices (minimum of one or two, depending on vehicle length), the devices must meet standards specified in 49 CFR § 38.23, and personnel must assist passengers in using the devices where necessary or upon request. Voluntary standards promulgated by the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) also exist for occupant tie-down and restraint systems (WC18) and wheelchairs used as seats in motor vehicles (WC19).[7]

[6] New Flyer unveils SmartRider™ advanced bus kneel and smart leveling.
[7] RESNA > AT Standards > Wheelchairs and Transportation (WHAT).

Although many securement systems require that personnel physically assist in securing the passenger's mobility device, some devices allow for a wheelchair user to control the securement independently, such as by clamping onto a mobility device's wheels to secure it.[8] Although such devices are on the market today, there are regulatory and user-experience limitations. For example, these semi-automated devices are only available as rear-facing units; regulations require that vehicles longer than 22 ft have at least one forward-facing securement location. Choi et al. (2020) also note that users of mobility scooters in a study found these semi-automated systems more difficult to use and less acceptable compared to other securement devices.

Academic researchers are working on universal docking interfaces for wheelchairs with automated docking and seat belt deployment. Current research focuses on crash test modeling to determine optimal placement of the anchor and seat belt (U.S. Access Board 2021). Widespread deployment of a universal interface would require acceptance by mobility device manufacturers, which are regulated by the Food and Drug Administration. Other existing universal automatic securement devices, such as the EZ-Lock and Q'Straint QLK, would require modifications to riders' wheelchairs that may reduce functionality in everyday use and that are not funded by third-party insurers.

Related research on ensuring that automated transit buses meet ADA requirements include user studies on the interior layout of both large accessible transit vehicles (U.S. Access Board, 2021; D'Souza, et al. 2019) and low-speed shuttles (Tabattanon, Schuler, and D'Souza, 2020), as the lack of a driver's seat could allow for new onboard configurations.

Wayfinding and Communication Technologies

Passengers with disabilities may require assistance in locating a bus stop or vehicle, notifying the vehicle that they would like to board, or traveling between the bus stop and their initial origin or final destination. Under U.S. DOT ADA regulations, where vehicles or other conveyances for more than one route serve the same stop, the entity must provide a means by which an individual with a visual impairment or other disability can identify the proper vehicle to enter or be identified to the vehicle operator as a person seeking a ride on a particular route.[9]

Once onboard the vehicle, passengers may need to communicate with the vehicle/driver, and the vehicle/driver may need to provide information to passengers. To facilitate this exchange, buses longer than 22 ft are required to have a public address system and stop request systems with auditory and visual acknowledgment.[10] Some existing technologies, such as visual or tactile

[8] Q'STRAINT: QUANTUM Automatic Rear-Facing Wheelchair Securement System.
[9] 49 CFR § 37.167(c).
[10] 49 CFR §§ 38.35 and 38.37.

alternatives to audio announcements, and direct connections to hearing aids, could conceptually be integrated into automated transit buses to increase accessibility. An active area of research involves recommendations for features or interfaces that would enhance accessibility of automated vehicles (not limited to transit buses) for those with sensory or cognitive disabilities (U.S. Access Board, 2021).

U.S. DOT Research in Progress

Several operating administrations and offices at U.S. DOT have sponsored research relevant to transit bus automation and accessibility. This section provides a brief overview of selected activities. Most of these projects are in the planning phase or early in their deployments, so U.S. DOT will continue to glean lessons learned as progress continues.

STAR Plan Integrated Demonstrations

FTA's STAR Plan includes several planned integrated demonstrations, including automated advanced driver assistance systems (ADAS) for transit buses, automated shuttles, automation for maintenance and yard operations, automation for Mobility on Demand, and automated bus rapid transit (BRT).

Integrated Mobility Innovation

FTA selected two Integrated Mobility Innovation (IMI) projects related to transit bus automation in March 2020.[11] These projects are led by the Connecticut Department of Transportation (CTDOT) and the City of Arlington, Texas, and are summarized in Table 3-1.

[11] Integrated Mobility Innovation (IMI) Fiscal Year 2019 Selected Projects | FTA.

Table 3-1 *IMI Project Summaries*

Grantee	CTDOT[12,13]	City of Arlington, Texas[14]
Project Name	Testing and Deployment of Automated Buses on CTfastrak	Arlington RAPID (Rideshare, Automation, and Payment Integration Demonstration)
Federal Funding	$2.0 million	$1.7 million
Service	Fixed-route (CTfastrak BRT corridor), dedicated stretch between New Britain and Hartford, CT	Point-to-point, on-demand, geofenced area in downtown Arlington and the University of Texas at Arlington campus
Vehicles	Three accessible 40-foot battery-electric Xcelsior CHARGE New Flyer transit buses	Four Lexus RH450h hybrid SUVs (not wheelchair-accessible) and one electric Polaris GEM e6 (wheelchair-accessible)
ADS Provider	Robotic Research	May Mobility
Timeline	Buses scheduled for delivery in 2022	Launched to public in March 2021 for a one-year pilot, weekdays 7:00 am–7:00 pm
Service Accessibility Notes	Includes precision docking to minimize gaps between platforms and buses, providing ADA-compliant level boarding	Riders book and pay for rides through a smartphone app or by calling a phone number for service and can indicate if they need the accessible vehicle.

Accelerating Innovative Mobility

FTA selected two Accelerating Innovative Mobility (AIM) projects related to transit bus automation.[15] These projects are led by the Metropolitan Transit Authority of Harris County (Houston METRO) and the Western Reserve Transit Authority (WRTA) and are summarized in Table 3-2.

[12] New Flyer to deploy first automated heavy-duty transit bus in North America; supporting Connecticut's pursuit of integrated mobility.
[13] Robotic Research to Help CTDOT Make U.S. Transportation History on CTfastrak by Automating First Heavy-duty Transit Buses for Revenue Service Deployment.
[14] City of Arlington Launches First-of-its-Kind, On-Demand Self-Driving Shuttle Service with RAPID Program.
[15] FY20 Accelerating Innovative Mobility (AIM) Project Selections | FTA.

Table 3-2 *AIM Project Summaries*

Grantee	Houston METRO [16]	Western Reserve Transit Authority[17]
Project Name	Shuttle of the Future	Enhancing Life with Automated Transportation for Everyone (ELATE)
Federal Funding	$1.5 million	$2.3 million
Service	Fixed-route, serving Texas Southern University, the University of Houston, and Houston's Third Ward	Deployments to augment fixed-route and paratransit service in Mahoning County, Ohio, and Santa Clara Valley, California (partnering with the Santa Clara Valley Transportation Authority, VTA)
Vehicles	"EZ ZEUS" automated cutaway bus based on the ADA-compliant ZEUS 400 shuttle bus by Phoenix Motorcars	"AV Star+" automated cutaway bus based on the ADA-compliant EV Star+ shuttle bus by GreenPower Motor Company
ADS Provider	EasyMile	Perrone Robotics
Timeline	Testing to begin in 2022	Testing in Q3 2022, followed by one year of operations at WRTA and then one year of operations at VTA
Service Accessibility Notes	The vehicle meets ADA accessibility standards	The vehicle meets ADA accessibility standards. One of the project partners (VTA) developed a "playbook" documenting requirements for accessible automated transit buses (VTA, 2021). WRTA and VTA also are members of the Connected and Automated Transportation Users Forum (CATUF), which developed a specification for accessible automated vehicles to be used by other CATUF members in their respective procurements.

Inclusive Design Challenge

The Inclusive Design Challenge is a two-stage prize competition sponsored by the Office of the Assistant Secretary for Transportation Policy that seeks design solutions to enable people with physical, sensory, and cognitive disabilities to use ADS-dedicated vehicles. Stage I solicited technical proposals for inclusive design features. In Stage II, 10 semifinalists developed prototypes of their solutions, resulting in demonstrations and three finalist prizes awarded in the summer of 2022.

Whereas the focus of the Challenge is on personally owned or privately operated vehicles (rather than public transit), several semifinalist concepts could also

[16] Phoenix Motorcars wins grant with Houston Metro and EasyMile for development of first FMVSS compliant autonomous shuttle bus in the US.
[17] Accessible Automated Electric Vehicles Request for Proposals.

apply to transit use cases.[18] Some focus on human-machine interfaces allowing users to communicate with vehicles, navigate to a pick-up/drop-off location, or reserve and plan trips. Others focus on physical vehicle components, such as automated ramps and wheelchair securement systems.

ITS4US

The Complete Trip – ITS4US Deployment Program is a three-stage program of the Intelligent Transportation Systems Joint Program Office to identify ways to provide more efficient, affordable, and accessible transportation options for underserved communities that often face greater challenges in accessing essential services. Five awardees completed concept development (Phase 1), with four proceeding to design and testing (Phase 2) and operation and evaluation (Phase 3).[19]

One of the ITS4US projects will include the deployment of an automated shuttle with accessibility features.[20] Although the other projects do not directly focus on automation or transit, the wayfinding, trip planning, and data standardization applications that the teams are developing may pertain to transit bus automation.

NHTSA AWTORS Development

The National Highway Traffic Safety Administration (NHTSA) sponsored a recently completed project to prototype an automated wheelchair tie-down and occupant restraint system (AWTORS).[21] The hardware designed for this project meets the universal docking interface geometry specification in the RESNA WC18 and WC19 voluntary standards. It allows a wheelchair user to engage the tie-down system via hand or voice control, and to secure the occupant with a three-point seat belt via hand control. These prototypes were tested using simulation, volunteers, and crash testing, with results available in a summary presentation[22] with a report forthcoming.

UTC Program – ASPIRE Center

In summer 2020, U.S. DOT's University Transportation Centers (UTC) program awarded a grant to establish a UTC focusing on the implications of accessible automated vehicles and mobility services for people with disabilities. The Automated Vehicle Services for People with Disabilities – Involved Responsive Engineering (ASPIRE) Center has four initial aims: conduct a systematic literature review; gain understanding of the needs of transportation users

[18] Inclusive Design Challenge Semifinalists | US Department of Transportation.
[19] USDOT ITS4US Deployment Program.
[20] ICF-Buffalo ITS4US Kick-Off Slides.
[21] Development of an Automated Wheelchair Tiedown and Occupant Restraint System (umich.edu).
[22] UMTRI Wheelchair Transportation Safety Open House Slides.

and service providers; perform data synthesis, extrapolation, analysis, and modeling; and investigate the impact on the transportation system and its users.[23] To date, a literature review (Dicianno et al., 2021) has been published.

Other Transit Bus Automation Pilots and Demonstrations

Several public sector agencies have sponsored transit bus automation pilots and demonstrations, typically in partnership with low-speed automated shuttle operators and vendors. Two of these projects are briefly reviewed here as context. Additional information about these and other similar projects can be found in FTA's quarterly updates on transit bus automation activities.

Santa Clara Valley Transportation Authority

The Accessible Automated Electric Vehicle (AAeV) project by Santa Clara Valley Transportation Authority (VTA) has created a series of use cases and documented requirements for accessible automated transit buses. The project team is working toward a demonstration at the Veterans Administration Palo Alto Health Care System campus in California. The project includes exploratory research for the use of artificial intelligence to detect passengers who may need the ramp deployed, and it has funded a policy study with the Mineta Transportation Institute (Riggs and Pande, 2021). The AAeV team has documented their requirements in a project playbook (VTA, 2021).

Jacksonville Transportation Authority

As part of its long-term Ultimate Urban Circulator program, which is working toward the use of an automated transit bus in a hybrid elevated and surface application, the Jacksonville Transportation Authority has independently evaluated the accessibility of low-speed automated shuttles through its Test-and-Learn Program,[24] conducted through the agency's Innovation and Automation division at test tracks.

[23] Tier 1 University Transportation Center (UTC) grant | Human Engineering Research Laboratories | University of Pittsburgh.
[24] JTA's Ultimate Urban Circulator (jtafla.com).

Section 4 Findings to Date

Based on the literature review and stakeholder interview results, this section summarizes the current state of accessibility in transit bus automation and discusses general themes. These findings can inform future research projects, and lessons from current projects can build on these initial findings.

Research applications could be broad. Investment in accessibility research related to ADS-equipped transit buses may also find application in both conventional transit vehicles and those with ADAS features. For example, although much of the research on improvements to mobility device securement for automated vehicles is motivated by the possibility of operating without onboard staff or enabling the independent use of a personally owned ADS-equipped vehicle, successful innovations could be used in a traditional service to speed boarding and alighting for passengers using mobility devices.

Automation could improve aspects of accessibility for bus transit. In addition to the wide-ranging potential of automation to facilitate more responsive and available accessible service, interviewees also highlighted the opportunities afforded by automation to improve accessibility. One example was the use of precision docking to always stop at an accessible stop or platform. Others speculated that onboard staff who are no longer needed to operate the vehicle could provide enhanced customer service.

Early pilots and demonstrations have helped to bring accessibility for automated transit buses forward. Interviewees from both the public sector and industry discussed how these projects created an opportunity to work together and with the disability community to identify issues and test strategies for addressing them. Several project teams have convened focused workshops and outreach events to showcase the accessibility features of their vehicles and to test how well these features are working for passengers with a range of disabilities.

Accessible, automated transit buses are still prototypes. All vehicles in fixed-route service must be accessible. There are no "purpose-built" accessible, automated vehicles operating as part of permanent, regular service. However, manufacturers have work underway, prototypes exist, and some pilot projects are testing them. In the interim, accessibility is generally addressed through two approaches:

- **Upfit a vehicle that already complies with accessibility standards to add an ADS.** The New Flyer/Robotic Research Xcelsior CHARGE bus for the CTDOT project, the Phoenix Motorcars/EasyMile EZ ZEUS bus, and the GreenPower/Perrone Robotics AV Star+ bus all begin with an existing bus platform and add automation capabilities. This approach leverages the past 30 years of accessibility progress in the transit bus industry but requires the integration of automation equipment. Since these vehicles are designed for manual driving, they retain conventional equipment such as the driver's seat, steering wheel, mirrors, and so on. One interviewee noted that client requests to automate features such as vehicle door opening and closing can be difficult to accommodate on a vehicle platform designed for manual operation.

- **Retrofit an inaccessible automated vehicle with accessibility equipment**. The needs involved here vary depending on the base vehicle, but typically include a ramp, either manual or automated, wheelchair securements, and automated stop announcement systems. As production transit buses are generally designed to meet ADA requirements, the relevant vehicles may be conventional passenger vehicles (e.g., sport utility vehicle or minivan), a neighborhood electric vehicle (e.g., Polaris GEM), or a novel-designed low-speed automated shuttle. These vehicles have been used in automated transit pilots in the United States. Examples of the types of features added in demonstration projects include:
  - Portable, built-in, and/or electronically actuated ramps
  - Manual securements and seat belts
  - Improved fonts and font sizes for readability
  - Improved lighting for visibility
  - Larger tonal range for door opening and closing chimes
  - Braille signage
  - Adding or relocating exterior door opening and ramp deployment buttons
  - Lighting changes and audible cues for stops and departures

Source: May Mobility

Figure 4-1 *Two examples of accessible vehicles developed by May Mobility: (L) Polaris GEM e6 low-speed vehicle retrofitted with ramp; (R) Toyota Sienna minivan outfitted with BraunAbility ramp*

Accessibility in pilots and demonstrations today relies heavily on the role of the onboard attendant, and there are technical and policy challenges associated with moving toward unstaffed operations. Projects identified through the literature review and interviews uniformly rely on onboard staff to provide general customer assistance, to deploy mobility equipment, and to secure mobility devices. In some cases, this includes duties for which there are already commercialized automated applications for traditional transit buses (e.g., making verbal stop announcements). However, due to the small size of many pilot programs or the added effort of integrating these systems into novel-design vehicles, the operator chooses to have onboard staff perform these duties.

Roles varied across deployments, but the responsibilities identified by interviewees included:

- Manually operating ramps and securement devices
- Assisting with boarding and alighting as needed
- Serving as ambassadors for the technology and providing customer education
- Making verbal stop announcements
- Helping riders use a mobile app
- Answering passenger questions during the ride

Some non-driving responsibilities, such as announcing stop departures and arrivals and inputting passenger counts, have been successfully automated in conventional transit service; some pilots incorporate these features as well. This review did not identify mature technological approaches that could fulfill all these roles today, although research is ongoing.

At present, even if an ADS were able to handle all driving tasks, onboard staff presence is still needed to provide accessible service. Interviewees offered varied opinions on the feasibility and desirability of unattended service in the future. Some suggested that removing a staff person from the vehicle could reduce labor costs and simplify scheduling, thus theoretically enabling expanded, more responsive options to better serve passengers. However, there are clearly several technological challenges and interviewees identified many positive benefits to passengers in having a staff person on board.

A transit agency could choose to retain an onboard staff member even if all driving tasks were automated. That person could provide additional or improved services for riders. If the official staff presence were removed from the bus, all the non-driving roles and responsibilities of a bus operator would need to be automated or otherwise addressed. With respect to accessibility, that would include ramp or lift deployment, securing passengers and belongings, aiding with boarding and alighting, providing information and assisting with wayfinding, announcing stops (including upon request), and other tasks.

Although some of the operator's non-driving tasks could be automated or otherwise addressed, many of the systems to manage those responsibilities either do not exist or are still in an early stage of development. More research and development work is needed before broader deployment without onboard personnel as a fallback is possible. For example, there is ongoing research into the use of computer vision technologies to detect passengers waiting at a bus stop who may require the use of a ramp to board. However, a person's physical appearance as perceived on a camera or through a lidar unit may not indicate whether they require or prefer a ramp. Similarly, one vendor has added an external button a customer can push to request ramp deployment, but this may not be useful for passengers needing a ramp if they are unable to reach or push a button. The vendor alternatively envisions use of a mobile app in the future to request deployment, but this again would not work for all passengers. In another example of a pilot service providing on-demand rides, the mobile app used to request rides allows users to indicate their preference for a wheelchair accessible vehicle that deploys a ramp upon arrival.

Finally, onboard personnel are highly valued by passengers in surveys and focus groups. It is unclear how these services would be received without personnel on board (if ADA regulations were modified in the future to permit such operations in the United States). Although unstaffed operations have been trialed in Europe, these projects are not focused on accessibility. Examples include unstaffed EasyMile and Navya shuttle operations in France, Germany, and Norway as discussed in the FTA Transit Bus Automation Market Assessment report (Cregger, Machek, and Cahill, 2021), and the recently announced unstaffed EasyMile shuttle service on the Oncopole health campus in Toulouse, France.[25] Further research is needed here.

[25] EasyMile at the Rencontres Nationales du Transport Public 2021 in Toulouse, showcasing its fully autonomous shuttle service in the city

Source: Beep

Figure 4-2 *Passenger using power wheelchair secured by onboard personnel in Navya automated shuttle*

Accessibility requirements must be considered for a broad range of vehicles, service types, and rider characteristics:

- *Vehicle platforms have different accessibility issues*. Issues related to novel vehicle platforms are not directly related to the use of automation, but rather to the introduction of a new, or uncommonly used, vehicle form factor. As the use of such vehicles during the pilot and demonstration phase of transit bus automation research has been significant, these challenges are briefly described here.

  Fundamental challenges stem from the fact that some vehicles were originally developed for other markets (e.g., EasyMile and Navya shuttles were developed by French companies) and thus not designed to comply with American accessibility requirements and standards. Minimal progress has been made in retrofitting these vehicles with ramps, securements, and other equipment, but those features are often not yet available from manufacturers as standard equipment or compliant with Federal requirements. Domestically produced neighborhood electric vehicles (e.g., Polaris GEM e6 shuttles) have had limited use in public transportation applications, are only street-legal under certain circumstances, and similarly require retrofitting for accessibility.[26]

[26] Neighborhood electric vehicles must comply with Federal Motor Vehicle Safety Standard No. 500 on low-speed vehicles (49 CFR § 571.500) to operate on public roadways, and individual states may have further requirements.

Floor space of automated transit buses is at a premium—securements take up space, ramps take up space, and users of wheelchairs/scooters need more floor space to turn and navigate the bus interior. This is particularly acute for vehicles with a smaller footprint, such as low-speed automated shuttles or cutaways. Another challenge involves the underfloor space of electric vehicles. Batteries are heavy and often located under the vehicle floor. This limits the available space for a built-in ramp to also go under the floor, or it may result in needing a lift instead of a ramp if the floor height is raised to the point where a ramp is not a feasible level-change mechanism. Project teams note that maneuverability onboard smaller vehicles can be challenging for staff, passengers using mobility devices, and other passengers. For smaller vehicles, passenger capacity is significantly reduced in practice when mobility devices are onboard. This may create operational challenges in a fixed-route use case.

- *On-demand and fixed-route applications may have diverse needs, and on-demand services are experimenting to identify the right options to meet accessibility requirements*. One interviewee pointed out that side-entry ramps work well for transit vehicles using fixed curbside stops, but rear-entry may be a better fit for demand-response applications where vehicles may use one-way streets or driveways. Compared to fixed-route pilots, there are fewer ongoing automated on-demand pilots in public transportation. Of these, at least one project team intends to use a fully accessible fleet, while another is using a mix of inaccessible and accessible vehicles. Under the ADA, all vehicles used in demand-responsive service must be accessible to and usable by persons with disabilities, including wheelchair users. An exception to use inaccessible vehicles may only occur where service meeting specific regulatory criteria for equivalence can be demonstrated.[27] These criteria include:
  - Response time
  - Fares
  - Geographic area of service
  - Hours and days of service
  - Restrictions or priorities based on trip purpose
  - Availability of information and reservations capability
  - Any constraints on capacity or service availability

Further research may be needed as innovation continues in the demand-response sector to identify the best options for providing equivalent service to all users, which is likely to vary by location and use case.

[27] 49 CFR § 37.77.

- *Diverse riders may require diverse approaches*. Several interviewees stressed that the existing accessibility standards, which represent a minimum, are insufficient to offer high quality service for all potential users. Substantial diversity among persons with disabilities means this is a challenging goal to achieve in practice. However, the interviewees also expressed optimism regarding the potential for automation to improve mobility over baseline, at least for a subset of the population.

Better data are needed on use by passengers with disabilities. Interviewees noted that most vehicles are capable of tracking ramp deployments and kneeling, but it is the client agency's decision whether to use these capabilities. Ramp deployments are only a partial indicator of usage by passengers with disabilities, as many disabilities do not require the use of a ramp, and the ramp may also be deployed to accommodate passengers with strollers or luggage. Although surveys have found a high level of interest in automated vehicles from respondents with disabilities (Dicianno et al. 2021; Bray 2021), some interviewees noted relatively low numbers of ramp deployments during pilots that were not specifically targeting passengers with disabilities or seniors. Further research would be required to understand if passengers lacked sufficient information about the accessibility of the service or pilot, if they had concerns about its accessibility, if the vehicle met ADA requirements, or if these ridership patterns are related to the pilot's location and operational characteristics.

Section 5 Conclusion

Transit bus automation is at the stage of early pilots and demonstrations. Researchers have posited the potential for automation to improve mobility for passengers with disabilities, but accessible, automated transit buses are still prototypes. Accessible operation without onboard personnel is not possible today and several technical and policy challenges to this concept remain.
This is an evolving area where pilots build upon each other and make iterative improvements; further research is required as the situation continues to change.

Appendix A Organizations Interviewed

- Beep
- BraunAbility
- GreenPower
- Local Motors
- May Mobility
- Minnesota Department of Transportation
- Navya
- New Flyer
- Santa Clara Valley Transportation Authority

Acronyms and Abbreviations

AIM	Accelerating Innovative Mobility
ADA	Americans with Disabilities Act of 1990
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
CFR	Code of Federal Regulations
CTDOT	Connecticut Department of Transportation
ELATE	Enhancing Life with Automated Transportation for Everyone
FTA	Federal Transit Administration
RESNA	Rehabilitation Engineering and Assistive Technology Society of North America
U.S. DOT	United States Department of Transportation
VTA	Santa Clara Valley Transportation Authority

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