FTA Report No. 0264

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Strategic Transit Automation Research Plan 2.0: 2023-2028

PREPARED BY
Federal Transit Administration
with the support of the
Volpe National Transportation Systems Center

MAY 2024

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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE May 2024	2. REPORT TYPE Final Report	3. DATES COVERED 2022–2023

4. TITLE AND SUBTITLE Strategic Transit Automation Research Plan 2.0: 2023-2028	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Joshua Cregger (0000-0002-6202-1443), Ian Berg (0000-0001-7121-0265),Kelsey Cooper (0000-0001-5488-804X), Alex Cox (0009-0009-3880-2547), Danyell Diggs (0009-0001-6211-0227),Scott Gabree (0000-0002-1834-6910), Sarah Husain (0009-0007-5325-8047), Justin John (0009-0005-3048-5349), Eli Machek (0000-0002-2299-6924), Steven Mortensen (0000-0003-0714-742X), Erin McCurry (0009-0001-2347-719X), Sean Pierce (0000-0001-7296-8799), and Gwo-Wei Torng (0009-0002-8943-8393)	5d. PROGRAM NUMBER 51TF42A121 5e. TASK NUMBER WN977/WN978 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) Volpe National Transportation Systems Center 229 Binney Street Cambridge, MA 02142	8. PERFORMING ORGANIZATION REPORT NUMBER Volpe Report No. DOT-VNTSC-FTA-24-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration Office of Research, Demonstration and Innovation 1200 New Jersey Avenue, SE, Washington, DC 20590	10. SPONSOR/MONITOR'S ACRONYM(S) FTA 11. SPONSOR/MONITOR'S REPORT NUMBER(S) FTA Report No. 0264

12 . DISTRIBUTION/AVAILABILITY STATEMENT
Available from: National Technical Information Service (NTIS), Springfield, VA 22161; (703) 605-6000, Fax (703) 605-6900, email [orders@ntis.gov]; Distribution Code TRI-30

13. SUPPLEMENTARY NOTES
[www.transit.dot.gov/research-innovation/fta-reports-and-publications]

14. ABSTRACT
Since the Federal Transit Administration (FTA) published the Strategic Transit Automation Research (STAR) Plan in 2018, the underlying technologies behind driving automation systems have progressed, and transit agencies face a set of both new and historical constraints, challenges, and priorities. While transit bus automation has the ability to deliver many potential benefits, transit agencies need additional research and policy guidance to make informed decisions related to future technology deployment.

This STAR Plan updates the previous plan and provides a new five-year strategic research and demonstration framework to move the transit industry forward. Key components of the research plan include conducting enabling research on automated transit buses, demonstrating nearly-market-ready prototype technologies in real-world settings, and learning from and sharing knowledge with the transit stakeholder community.

15. SUBJECT TERMS
Transit, bus, automation, technologies, research, demonstrations, strategic plan

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unlimited	101	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The research team would like to thank the stakeholders who contributed their time and expertise during the five years of the first Strategic Transit Automation Research (STAR) Plan by participating in interviews, workshops, webinars, and demonstrations to collectively advance the state of knowledge regarding transit bus automation. Additionally, the team also thanks their U.S. Department of Transportation (USDOT) colleagues for providing valuable insight and guidance throughout the execution of the STAR Plan and the development of this updated plan.

Abstract

Since the Federal Transit Administration (FTA) published the Strategic Transit Automation Research (STAR) Plan in 2018, the underlying technologies behind driving automation systems have progressed, and transit agencies face a set of both new and historical constraints, challenges, and priorities. While transit bus automation has the ability to deliver many potential benefits, transit agencies need additional research and policy guidance to make informed decisions related to future technology deployment.

This STAR Plan updates the previous plan and provides a new five-year strategic research and demonstration framework to move the transit industry forward. Key components of the research plan include conducting enabling research on automated transit buses, demonstrating nearly-market-ready prototype technologies in real-world settings, and learning from and sharing knowledge with the transit stakeholder community.

Executive Summary

Since the Federal Transit Administration (FTA) published the Strategic Transit Automation Research (STAR) Plan in 2018, both the capabilities of driving automation systems and interest in their potential to shape all aspects of the surface transportation system have continued to grow. Transit bus automation technologies are nascent and still emerging (unlike automation for passenger rail operations, which is relatively mature in comparison). The domestic transit bus industry lags behind both light-duty vehicles and heavy-duty commercial trucks in terms of developing, testing, and commercializing automated driving systems.

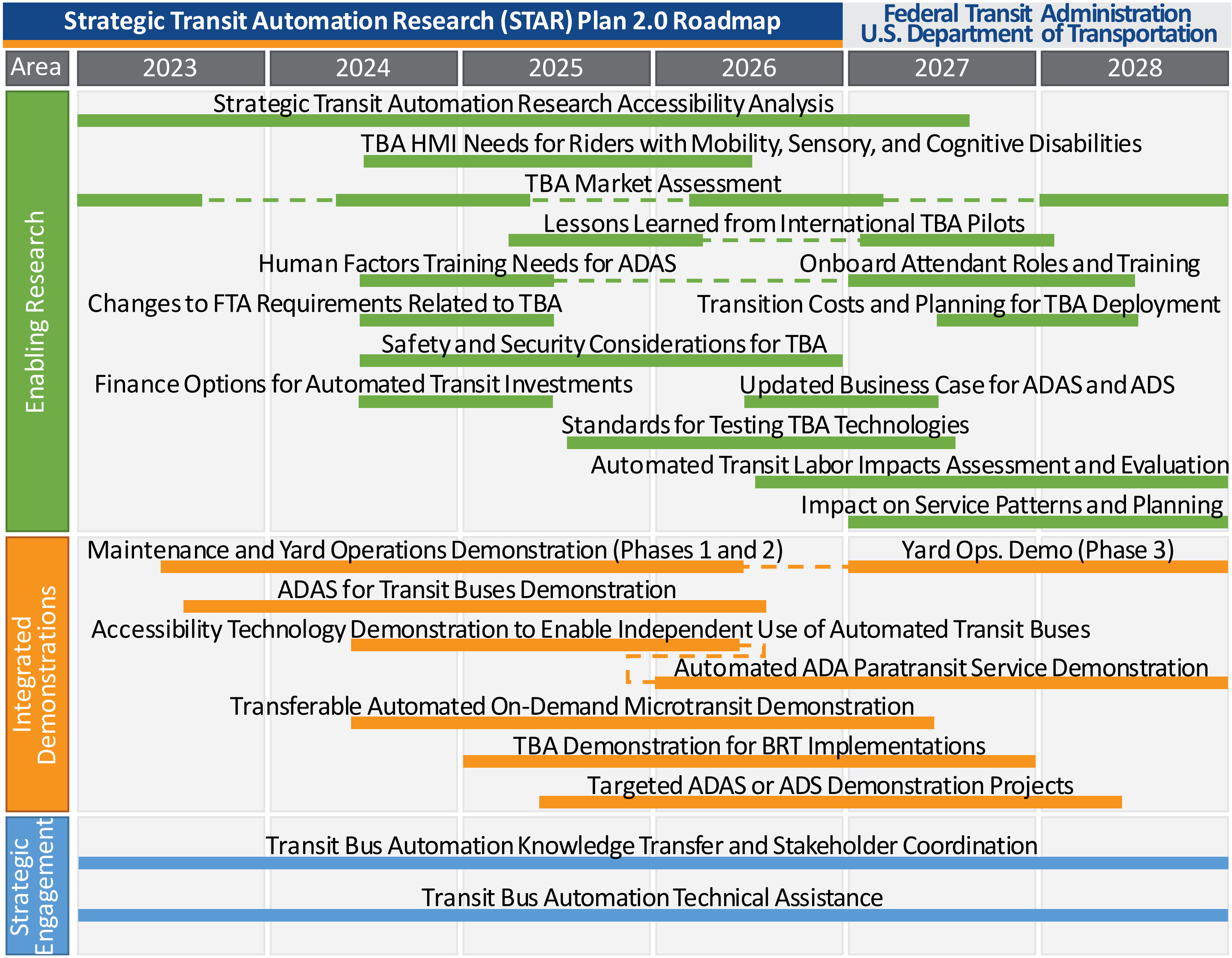
While transit bus automation has the ability to deliver many potential benefits, transit agencies need additional research and policy guidance to make informed decisions related to future technology investment and deployment. The U.S. transit industry often is cautious in adopting new technologies, services, and business models. Although other constraints may play a role, there is also a reasonable unwillingness by transit agencies to invest public funding or to undertake new operational models without clear guidance and leadership from the Federal Government.

FTA has developed a successor to its 2018 STAR Plan (hereinafter referred to as STAR Plan 1.0) that details FTA's intended transit bus automation work through 2028. This new five-year plan (hereinafter referred to as STAR Plan 2.0) establishes a research and demonstration framework to move the transit industry forward (see Figure 1 for an overview of the research roadmap). Key components of the research plan include conducting enabling research on automated transit buses; demonstrating nearly-market-ready prototype technologies in real-world settings; and learning from and sharing knowledge with the transit stakeholder community.

The research plan leverages the core strengths of academia and the public and private sectors and is organized around three complementary work areas: Enabling Research, Integrated Demonstrations, and Strategic Engagement. Efforts under these three areas are designed to complement each other and collectively advance FTA and U.S. Department of Transportation (USDOT) goals in automation.

To understand the current state of the practice, as well as potential benefits, challenges, and risks, the research team studied lessons learned from the work conducted under STAR Plan 1.0, conducted a literature review on transit bus automation, and engaged with stakeholders through a range of different venues. Through these methods, the team identified research needs and priorities, which are reflected and addressed in the proposed activities described throughout the research roadmap.

Figure 2: ***Strategic Transit Automation Research Plan 2.0 Roadmap***



Section 1

Introduction

The world has changed since the Federal Transit Administration (FTA) published the Strategic Transit Automation Research (STAR) Plan in 2018.[1]. The underlying technologies behind driving automation systems have progressed; however, transit agencies face new as well as historical constraints, challenges, and priorities. A nationwide focus on vehicle electrification has rapidly changed the availability of funding for battery electric buses. Coming out of the COVID-19 pandemic, ridership changes, labor shortages, and other factors have contributed to a sharp focus on core service delivery across the transit industry. Transit bus automation could deliver many potential benefits, but transit agencies need additional research and policy guidance to make informed future deployment decisions.

This report considers the changes over the past five years (both institutional and technological) and updates the 2018 STAR Plan (hereinafter referred to as STAR Plan 1.0) for the years 2023 to 2028. The 2023 STAR Plan, hereinafter referred to as STAR Plan 2.0, presents a five-year research agenda for transit bus automation, building on the work of the transit industry professionals, technology developers, local governments, and researchers brought together through the STAR program to date. STAR Plan 2.0 was developed through literature review, stakeholder consultation, and analysis of the results of the research and demonstration projects funded through STAR Plan 1.0 to identify research priorities for transit bus automation over the next five years.

Scope

The FTA Office of Research, Demonstration, and Innovation (TRI) is building STAR Plan 2.0 on a strong foundation of transit bus automation research conducted over the past several years under STAR Plan 1.0. The goal of the FTA STAR Plan 2.0 is to advance driving automation systems that meet the needs of public transportation by:

- conducting enabling research on automated transit buses;
- demonstrating nearly-market-ready prototype technologies in real-world settings; and
- learning from and sharing knowledge with the transit stakeholder community.

The focus of the plan is driving automation in the context of transit bus operations, and excludes other transit modes (e.g., passenger rail, ferries). With respect to driving automation systems, the scope includes both advanced driver

[1] Federal Transit Administration. (2018). "Strategic Transit Automation Research Plan." Federal Transit Administration, U.S. Department of Transportation. https://www.transit.dot.gov/research-innovation/strategic-transit-automation-research-plan-report-0116.

assistance systems (ADAS) and automated driving systems (ADS).[2] The scope does not include driver assistance systems without an automation aspect (e.g., driver warnings and alerts), but does include those with automated actuation (e.g., automatic emergency braking). For the purposes of this plan, "bus" is defined broadly to consider a range of passenger capacities and both traditional and novel vehicle designs. The FTA transit automation research team (hereinafter referred to as the "research team") consists of FTA staff and members of the Volpe National Transportation Systems Center (Volpe Center).

The potential impacts of driving automation on public transportation will vary according to the vehicle and service type where it is implemented. The plan considers a broad range of use cases, consistent with STAR Plan 1.0. While minor revisions were made to the use case descriptions to update them and align them with findings from existing research and stakeholder input, STAR Plan 2.0 uses the same set of technology packages and use cases previously identified (see Appendix A for more information).

Summary of Key Findings

Results from the research and demonstrations conducted to date support continued Federal investment in transit bus automation research and inform priorities to focus public sector resources. Results are summarized below.

Many transit agencies are interested in automation technologies. Several transit agencies have hosted pilots and demonstrations, and others are in the planning stages. Although each agency's motivations can vary, most noted the potential for automation to yield significant operational cost savings, safety improvements, and/or the ability to support additional transit service models. These projects are useful in helping to understand the state of the technology and its capabilities, the technological and institutional barriers to implementation, and how driving automation systems can effectively play a role in future transit services.

The limited number of buses sold annually and the difficulty in adapting driving automation systems from one platform to another has slowed the introduction of driving automation systems to transit buses. Market size is a challenge, as the relatively low volume of transit bus production (compared to other vehicle types) translates to high per-unit costs for research and development (R&D), testing, and validation. Prototype novel design vehicles, also referred to as purpose-built vehicles, that are produced at even lower scales also suffer from this challenge. However, some efforts are looking to overcome the challenge of scale through larger multi-vehicle projects or joint procurement activities. It is also difficult to transfer ADAS or ADS from other vehicle formats (i.e., heavy-duty trucks and

[2] SAE. (2021). "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles." SAE International, April 2021. https://www.sae.org/standards/content/j3016_202104/.

light-duty vehicles) due to differing use cases, vehicle architectures and control systems, and other considerations.

Development and commercialization of driving automation systems for transit bus applications is still at an early stage, and transit-specific research and development will take time. System maturity may not be as advanced as it is sometimes portrayed (i.e., in media reporting or marketing materials), and systems are at least several years away from commercial availability or broad revenue service deployment. Challenges related to the difficulty of transferring technologies designed for other modes and vehicle types (e.g., light-duty and commercial trucks) to transit buses, as well as the relatively small and highly customized nature of the transit bus market, mean that it may be difficult for vehicle manufacturers or technology providers to justify large and long-term investments needed to enable the development of systems for transit buses. These challenges represent barriers to product development, and Federal R&D leadership and investment are needed to stimulate continued progress.

Implementing driving automation systems in transit buses will be a substantial investment, and funding it may be a challenge, especially with limited revenue streams and resource constraints. Competing priorities and limited resources to meet core transit agency missions may result in some organizations postponing or cancelling driving automation systems efforts. In many cases, however, public funding enables industry and transit agency partners to conduct demonstration and pilot programs to test and evaluate ADAS and ADS systems for transit buses.

Federal investment in transit bus automation research is critical to creating outcomes that meet public policy goals. The marketplace for ADAS and ADS is immature and volatile, and transit bus passenger service applications require additional considerations beyond those of other service types. The higher risk and uncertainty associated with transit applications may deter investments from private equity firms, and it may even deter some public sector investments. Private sector ADS developers are not organically creating products and services oriented to the needs of public transportation. New entrants to the transit industry have struggled to fully address the requirements of core Federal policies, rules, regulations, and laws such as the Americans with Disabilities Act (ADA) and Buy America; however, progress is being made through private sector participation in federally funded research and demonstration activities.

Research Needs

As noted above, transit bus automation is still an emerging technology. While prototype systems exist, there are no commercialized products in the marketplace, and data on performance, costs, and benefits are not yet sufficient to support informed agency decision making. Additional research and development are necessary. This section presents an overview of the high-level research needs this plan will address.

Better data on benefits and costs are needed to inform agency decisions on ADAS and ADS implementation. There appears to be a business case for ADAS in bus transit, as conceptually, ADAS for transit bus applications can provide operational savings that exceed costs; however, costs and capabilities are still evolving. For ADS, estimates of costs and benefits are even more tentative, and thus, it is inconclusive as to whether there is a business case for ADS. More information is needed to understand the business case for both ADAS and ADS in transit bus operations, particularly the impact of ADS on staffing and labor costs. In addition, direct cost savings are not the sole or even primary motivation for some agencies' investments, so agencies need additional contextual information on impacts beyond benefits and costs.

Progress has been made in identifying and clarifying many policy issues, but additional work is needed to translate innovation into Federal policy and guidance. In general, the policy and regulatory environment does not change when introducing the use of automation—standard Federal requirements continue to apply. There are topics where additional clarification will be needed as the component technologies mature. These include accessibility and compliance with ADA, Buy America, Bus Testing Program, National Transit Database (NTD) reporting, Federal Motor Vehicle Safety Standards (FMVSS) compliance, Title VI, useful life, spare ratio, Disadvantaged Business Enterprise (DBE) Program, safety/security regulations, and funding eligibility.

User acceptance for staffed demonstrations has been high but acceptance and the capability of unstaffed operations is unknown. Staffed pilots (those that include a safety driver or onboard attendant) indicate high user acceptance. Passengers also respond favorably in surveys and are open to using transit buses with automation. It is difficult to study aspects of unstaffed service, which could differ significantly. More research is needed on acceptance by other road users, bus operators, and transit agency staff.

Labor and workforce research is needed. The transit workforce is a critical component in providing safe, high-quality mobility. Research needs include training, new roles, and policy response around potential displacement. Workforce development and training should be tailored to meet specific transit agency needs.

There are research gaps for human factors of transit bus operations. This topic is understudied in general and baseline information on working conditions for operators using conventional vehicles is insufficient. Situational human factors issues are likely to be encountered. There is more research to be done on topics including safety, job quality, the human-machine interface (HMI), and comfort.

Better data is needed to support standards and procurement. Some individual applications and technologies may be nearing commercialization, but their success in public transportation is closely related to standardization. Public sector agencies rely on vetted standards for technology and equipment procurement. Robust data to inform standardization activities are lacking.

Section 2

Five-Year Research Roadmap

Approach

The five-year strategic transit automation research roadmap describes a set of research projects that complement each other and collectively advance FTA and USDOT goals in automation. The plan is organized around three complementary work areas: Enabling Research, Integrated Demonstrations, and Strategic Engagement. These work areas and their anticipated outcomes are described in Table 1.

Table 1: ***Work Areas and Anticipated Outcomes***

Work Area	Description	Anticipated Outcomes
Enabling Research	Enabling research tackles questions that must be addressed for the transit industry to engage more broadly with automation technologies. There is a clear Federal role in that objective results and guidance are needed for oversight and stewardship or where a lack of information serves as a disincentive to private and public sector progress.	Enabling research will accelerate the entry of manufacturers, suppliers, and transit agencies into automation by building common understanding of foundational issues (human factors, Federal policy, costs and benefits, etc.) and solutions.
Integrated Demonstrations	Integrated demonstrations will demonstrate automation technologies in real-world settings, which will provide insights on technical issues, user acceptance, and institutional challenges. These demonstrations will also further assess the needs for standards development to ensure interoperability.	Evaluation results and lessons learned will be widely disseminated to transit stakeholders. These projects will spur technology development and grow the industry. These demonstrations also will grow the confidence level for transit agencies considering deployment of automated transit services.
Strategic Engagement	Strategic engagements will both engage with the broader transit community to understand transit automation needs, and leverage research projects and investments led by other agencies. FTA funding and technical assistance will supplement partners' deployment and evaluation activities. The research topics of interest to FTA may be cost-effectively added and research findings can be disseminated.	Strategic engagement will improve quality and usefulness of research by other actors and disseminate findings to a broad community, expanding participation of providers and suppliers. These engagements can also facilitate an ongoing dialogue between stakeholders and the Federal Government.

Project Descriptions

The following sections briefly describe planned projects by year and work area for the five years of the roadmap. Figure 1 in the Executive Summary shows the entirety of the five-year research roadmap. The project descriptions that follow may be adjusted over the lifetime of the plan to incorporate new information as it is attained and to align with funding availability.

Cross-Cutting Activities (2023–2028)

FTA will conduct strategic engagement activities to disseminate transit automation information and research results to both internal (FTA and other modal administrations within USDOT) and external stakeholders, ultimately facilitating deployment. Stakeholders, including the general public, State and local transit agencies, equipment manufacturers, researchers, and policymakers, all play a critical role in developing, deploying, evaluating, and using automated transit technologies. FTA will develop and maintain relationships at the Federal, State, and local levels of government, and with academia and the private sector to continually communicate research results and stay abreast of changing needs and capabilities in the transit industry. Strategic engagement activities will be used to develop a common understanding of transit automation, inform research needs, validate assumptions and findings, identify, and foster partnerships, and enable efficient deployments.

Strategic Engagements	
Transit Bus Automation Knowledge Transfer and Stakeholder Coordination	This project will transfer knowledge gained from research and demonstration projects to internal and external audiences. Activities could include presentations and participation in conference talks and panels at in-person and virtual events sponsored by the American Public Transportation Association (APTA), ITS America, the National Rural ITS Conference, the Transportation Research Board (TRB), and the Automated Road Transportation Symposium. It also includes production of outreach materials suitable for distribution to transit stakeholders and the general public. These materials include fact sheets, infographics, briefing decks, websites, knowledge cafes, or videos. Knowledge transfer activities could also include strategic partnerships which leverage research projects and investments led by other agencies. FTA funding and technical assistance could supplement partners' deployment and evaluation activities, so research topics of interest to FTA may be cost-effectively added and research findings can be more broadly disseminated. FTA will also convene internal and external stakeholders on core topics related to transit automation research. As part of this activity, FTA will continue to convene the Transit Bus Automation Community of Practice, composed of FTA-funded and managed transit bus automation project teams.
Transit Bus Automation Technical Assistance	This project is designed to assist local DOTs, transit agencies, and metropolitan planning organizations (MPOs) with practical guidance on demonstration projects, field operational tests, and small-scale deployments. It is intended to include aspects of test design, evaluation, data collection, and reporting. This technical assistance will build on the research projects described above as well as findings from the integrated demonstrations. Through this activity, FTA will coordinate with potential deployers to provide them with information and guidance that will help improve the outcomes from these deployments. Topics could include state-of-the-practice fundamentals, assistance with pilot design and evaluation, and clarification of Federal policy, rules, and regulations. Delivery mechanisms for technical assistance could include document review (e.g., planning documents, evaluation plans and reports, and final reports), one-on-one technical assistance meetings, peer-to-peer exchanges, site visits, or other technical assistance options.

Year Zero (2023)

Projects in 2023 are a continuation of work from the STAR Plan 1.0, in addition to preparing for the release of STAR Plan 2.0.

Enabling Research	
Accessibility Analysis	*Project began during STAR Plan 1.0.* This project refines needs for accessibility research as part of the integrated demonstrations. *Project concludes in Year Four*.

Integrated Demonstrations	
Automated Transit Bus Maintenance and Yard Operations Demonstration (Phases 1 and 2)	*Project began during STAR Plan 1.0*. This is an integrated demonstration project focusing on Society of Automotive Engineers (SAE) Automation Level 4 in transit maintenance yard settings. Specific use cases may include precision movement for fueling/charging, maintenance, bus wash, and automated remote parking and recall. *Project concludes in Year Three and is followed by a Phase 3 demonstration program in Year Four*.
ADAS for Transit Buses Demonstration	*Project began during STAR Plan 1.0*. This project funds engineering activities leading to the demonstration of ADAS use cases, such as requirements, architecture, and design development; equipment installation and integration; and pre-demonstration testing. Workforce engagement, training, and skills development activities related to the demonstration are also included. Projects will consist of an operational demonstration in revenue service lasting at least 12 months. *Project concludes in Year Three*.

Year One (2024)

The first year will launch several demonstration programs that will inform future research in the second through fifth year, as well as finalizing work from STAR Plan 1.0.

Enabling Research	
Accessibility Analysis	*Continuing Project*. *Project concludes in Year Four*.
Transit Bus Automation HMI Needs for Riders with Mobility, Sensory, and Cognitive Disabilities	This project will advance current research on HMI technologies designed for people with mobility, sensory (e.g., vision or hearing), or cognitive disabilities to use automated transit buses safely and independently. This could include user testing (simulated/mocked-up or in revenue service), or integration with an ADS-equipped bus, depending on the state of existing research. This project could potentially advance standards development. *Project concludes in Year Three*.
Transit Bus Automation Market Assessment	This project is a follow-on to the initial Transit Bus Automation Market Assessment Report, first published in 2019 with subsequent updates. The latest edition was released in summer 2023.[3] Under STAR Plan 2.0, the Transit Bus Automation Market Assessment project will continue those updates to enable to report to remain relatively current. To the extent possible, this project will research the availability, costs, and capabilities of systems and products related to transit bus automation, with an emphasis on the domestic bus market in the United States. *Project concludes in Year Five (with work on new editions starting in Year One, Year Three, and Year Five).*
Bus Operator Human Factors Training Needs for ADAS	This study will address human factors issues associated with the bus operator's use of ADAS on transit buses in revenue service, such as mode confusion and overreliance. It will draw on both existing literature and comparisons from other modes, direct experience from the early stages of transit deployment (based on interviews or focus groups with deployers), and scan existing commercial driver's license (CDL) and operator training requirements to identify ADAS-specific training needs. It will conclude with a high-level guidance document outlining best practices for ADAS HMI design, ADAS training, and other areas with potential human factors considerations, as well as a set of areas for follow-up research and curriculum development. Additionally, this effort will consider how to evaluate the impact of ADAS on human factors issues using naturalistic driving data that may be collected pre- and post-ADAS during integrated demonstration projects. *Project concludes in Year Two.*
Changes to FTA Requirements Related to Transit Bus Automation	This project will study and recommend transit automation-related updates to transit bus provider requirements, including to the NTD, transit asset management (TAM) plans, Public Transportation Agency Safety Plans (PTASP), and Surface Transportation Security Training. NTD updates related to transit bus automation may include, but are not limited to, definitions, forms, reporting, reporting criteria, and financial information. The project will also recommend updates to TAM Plan requirements and/or guidance, especially for determining useful life benchmarks, state of good repair, performance measures, and other TAM elements as needed. The research will include recommendations for updating PTASP requirements and Surface Transportation Security Training requirements, many of which did not exist during the period covered by STAR Plan 1.0. *Project concludes in Year Two.*

[3] Cregger, J., Cooper, K., Husain, S., and McCurry, E. (2023). "Transit Bus Automation Market Assessment." FTA Report No. 0255. https://www.transit.dot.gov/research-innovation/transit-bus-automation-market-assessment-report-0255.

Enabling Research	
Safety and Security Considerations for Transit Bus Automation	The discussion will highlight areas where transit automation could enhance safety and security as well as challenges that might arise around transit automation projects. This project will summarize safety and security considerations related to transit bus automation, including cybersecurity, and explore how first responders are trained to interact with ADS- and ADAS-equipped vehicles for applicability to transit bus automation. Topics related to first responder training may include personal safety, security considerations, training scalability, staying current on technology relevant to first response, procedural training best practices, understanding how to interact with diverse technologies, appropriate communications, and the specific needs for police, fire, and emergency medical services response. Safety, security, and first responder interactions with electric vehicles may also have applicable technology transfer elements. *Project concludes in Year Three.*
Finance Options for Automated Transit Investments	This project will assist transit agencies in their planning through the development of (non-binding) guidance on Federal funding programs that may be relevant to transit automation investments. This review also may include interviews with stakeholders and a recap of the literature on innovative finance for transit investments, with a focus on automation. *Project concludes in Year Two*

Integrated Demonstrations	
Automated Transit Bus Maintenance and Yard Operations Demonstration (Phases 1 and 2)	*Continuing Project. Project concludes in Year Three and is followed by a Phase 3 demonstration program in Year Four*.
ADAS for Transit Buses Demonstration	*Continuing Project. Project concludes in Year Three*.
Accessibility Technology Demonstration to Enable Independent Use of Automated Transit Buses	This project will test and demonstrate technologies which would enable people with disabilities to perform tasks without assistance from onboard staff. This could include securing mobility devices such as wheelchairs or interacting with the vehicle through human-machine interfaces (request stops, obtain route information, etc.). This project is not necessarily envisioned to take place in revenue service, or on a vehicle equipped or operating with an ADS. The goal is to advance assistive technologies toward independent use through user testing and integration in vehicle platforms that transit bus automation deployments may use. *Project concludes in Year Three and is followed by a related demonstration program focused on paratransit service, which begins in Year Three.*
Transferable Automated On-Demand Microtransit Demonstration	On-demand microtransit, while still serving a very small number of American transit riders, has seen increased interest and experimentation from transit agencies. It offers the potential to serve communities where demand is too low or dispersed to support high-quality fixed-route service, such as in small towns and rural areas. Providing origin to destination service gives more flexibility and is generally likely to appeal to riders. While basic feasibility of this use case has been shown, the transferability of previous demonstrations from one system to another, or even from one route to another, is relatively difficult. This demonstration would set a high bar for a scalable, transferable system. *Project concludes in Year Four.*

Year Two (2025)

During the second year, some initial projects will conclude. Based on preliminary results of that work, planning and execution for the demonstrations will become the focus. A project to develop transit bus automation testing standards will also be initiated.

Enabling Research	
Lessons Learned from International Transit Bus Automation Pilots	This project will examine lessons learned from international transit bus automation projects to report on the state-of-the-practice of transit bus automation abroad. The research team will review publicly available documentation and conduct outreach to international researchers to understand developments, trends, and findings from pilot and demonstration projects outside the United States. *Project concludes in Year Five (with work on new editions starting in Year Two and Year Four)*.
Human Factors Training Needs for ADAS	*Continuing Project. Project concludes in Year Two*.
Changes to FTA Requirements Related to Transit Bus Automation	*Continuing Project. Project concludes in Year Two.*
Finance Options for Automated Transit Investments	*Continuing Project. Project concludes in Year Two*.
Standards for Testing Transit Bus Automation Technologies	In partnership with FTA's Office of Infrastructure and Asset Innovation, this project will develop transit bus automation testing standards to set benchmarks for safety, performance, and maintenance for transit bus automation technologies, as well as determine whether the presence of automation technologies may require changes to current bus testing procedures, such as fuel economy measurement. The project team will complete an industry standards assessment, assess gaps, then work with the appropriate entities to create or modify testing standards. The frequency of standards updates will also be determined as part of this project. The project team will coordinate with stakeholders as needed, including transit agencies, academic partners, standards development organizations such as SAE or APTA, and/or industry/private sector representatives. The safety, performance, and maintenance standards would then be tested. The project team will work with transit bus automation manufacturers to conduct full or partial vehicle testing to validate the testing standards. The standards would undergo an iterative testing and update process to ensure effective testing outcomes. *Project concludes in Year Four*

Integrated Demonstrations	
Transit Bus Automation Demonstration for BRT Implementations	There is interest among transit agencies in bus rapid transit (BRT), with many existing systems and 30 BRT projects in the FTA Capital Investment Grants Program (CIG) pipeline. This BRT demonstration project will build upon the lessons learned from the CTfastrak automation project conducted during the course of STAR Plan 1.0. Examples of BRT applications could include platooning, precision docking, proper use of transit signal prioritization or queue jumps, safe boarding/alighting of passengers, and the safe transportation of bicycles with either front racks or onboard. Many BRT projects in the CIG pipeline will operate on a combination of bus-only guideways and mixed traffic lanes. These deployments, also known as "BRT light" systems, can be easier and quicker to implement because they do not have the same level of infrastructure investment as full BRT deployments. There are specific automation applications to explore. Topics may include the safe transition between fixed-guideway and mixed traffic operations, automated onboard camera enforcement of bus-only lanes, proper use of transit signal prioritization or queue jumps, and lane-keeping operations on repurposed or otherwise narrow lanes and shoulders. *Project concludes in Year Four.*
Targeted ADAS or ADS Demonstration Projects	These demonstration projects will drill down into how ADAS or ADS systems could address a specific research question, problem statement, or identified transit agency need, with the goal of project conclusions being directly applicable elsewhere. Such targeted projects could include a variety of different service types which may not be addressed or may be inadequately addressed by other integrated demonstrations. Some examples of use cases or service types that could be addressed under this effort include: • **Additional Transit Bus ADAS Applications** that address certain features not yet tested or only partially tested through other efforts. • **ADS Applications for Temporary Transportation Service** during sporting events (e.g., 2026 World Cup or the 2028 Olympics) or other large events using fixed-route or on demand services connecting venue sites and augmenting existing transit options in the surrounding areas. Currently, certain common patterns of challenges can be seen across multiple demonstrations. Examples addressed under this integrated demonstration might include projects exploring a specific ADA requirement, energy and emissions impacts, high-occurrence collision types, difficult intersections located in a service area, unprotected left-hand turns, or object recognition and localization challenges related to environmental changes (seasonal vegetation growth, gravel dust, snowbanks, etc.). The particular challenges that will be addressed may evolve closer to the date of the planned demonstrations. *Project concludes in Year Five.*

Year Three (2026)

The third year will be a continuation of many projects started in the previous two years, including demonstration programs. Results from human factors and finance research will be used to inform the updated business case for ADAS and ADS.

Enabling Research	
Transit Bus Automation HMI Needs for Riders with Mobility, Sensory, and Cognitive Disabilities	*Continuing Project. Project concludes in Year Three.*
Safety and Security Considerations for Transit Bus Automation	*Continuing Project. Project concludes in Year Three.*
Updated Business Case for ADAS and ADS	This study will update the previous business case report.[4] It will estimate the potential return on investment or business case for a range of transit bus automation technologies. The goal is to support informed decision-making on the part of transit agencies who may be contemplating such investments, but lack reliable information on product pricing and capabilities, as well as information on operational impacts such as run times or labor costs. *Project concludes in Year Four.*
Automated Transit Labor Impacts Assessment and Evaluation	This project will produce a qualitative analysis of the labor-related considerations with transit bus automation, including potential workforce changes, perspectives of organized labor, legislative and regulatory provisions, and other societal factors. The research will include both driving and non-driving tasks of bus operators, as well as related operations and maintenance personnel. It should include engagement with transit agency staff working in bus operations and maintenance and labor unions to incorporate needed perspectives. To the extent possible, this project will also incorporate labor-related findings from the integrated demonstrations, such as measured changes in staffing levels, job responsibilities, labor hours, and training needs. This may allow a more quantitative approach to estimating automation's impacts on transit employment levels, workforce needs, and wages. *Project concludes in Year Five.*

Integrated Demonstrations	
Automated ADA Paratransit Service Demonstration	This demonstration would examine the potential benefits of adding automation to paratransit services. While there may be safety, logistical, and cost benefits to automating paratransit services, there are still many gaps in technology and the magnitude of these potential benefits is not yet known. This project could measure user acceptance of automated paratransit as an "opt in" alternative to traditional paratransit, explore the theory that ADS-controlled vehicles provide a smoother ride than traditional vehicles (and the impact that has on overall ride quality), or demonstrate automated accessibility features in the real world. *Project concludes Year Five.*

[4] FTA. (2023). "Assessing Transit Providers' Internal Business Case for Transit Bus Automation." Transit Automation Research website, Federal Transit Administration, U.S. Department of Transportation, accessed August 2023, https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-02/FTA-Report-No-0187.pdf.

Year Four (2027)

The fourth year will focus heavily on new enabling research that will leverage insights from demonstration programs in the previous three years, as well as explore new topics. Two of the earlier demonstration programs will conclude this year.

Enabling Research	
Accessibility Analysis	*Continuing Project. Project concludes in Year Four*.
Onboard Attendant Roles and Training	Onboard attendants are currently key players in pilots and demonstrations of automated transit buses. This is a relatively new type of position in the transit industry and the range of job responsibilities can vary significantly. This study will review current practice in the industry and assess questions related to potential training needs and how onboard attendants may take on customer-facing and operational responsibilities. Methodology may include "ride-alongs," site visits, and discussion with sponsors of current demonstrations. The project may build upon the previous analysis (see appendix C of STAR Plan 1.0) of non-driving operator responsibilities. For the purposes of this project, it will be assumed that onboard attendants will no longer need to serve as safety operators, but instead focus on the customer-facing responsibilities and other non-driving tasks provided as services to riders. *Project concludes in Year Five*.
Standards for Testing Transit Bus Automation Technologies	*Continuing Project. Project concludes in Year Four.*
Updated Business Case for ADAS and ADS	*Continuing Project. Project concludes in Year Four*.
Impact on Service Patterns and Planning	This project will investigate how deployment of transit bus automation (beyond small-scale pilots) could affect service provision. This project may include potential changes to fixed-route design considerations, as well as changes to on-demand/point-to-point service provision. Other topics could include integration with legacy systems, garage or yard capacity and design, and fleet mix. Depending on the state of deployments when this project is started, the research will rely on one or more of the following: a literature review; qualitative methods, including a mix of interviews, surveys, and focus groups, to understand passenger and transit agency attitudes, values, and expectations regarding potential changes; and/or quantitative modeling to investigate scenarios. The final report can be used as a form of market research for transit agencies as they plan future services. *Project concludes in Year Five.*
Transition Costs and Planning for Automated Transit Bus Deployment	Transit agencies moving to automation would likely face costs and operational complexities during a transition period when they would operate a mix of vehicles capable of varying levels of driving automation. This research project will produce a practical reference guide for agencies covering key transition areas, such as vehicle maintenance; human factors, labor, and training issues; customer communication; maintaining consistency in the passenger experience; and transit service planning. *Project concludes in Year Five.*

Integrated Demonstrations	
Automated Transit Bus Maintenance and Yard Operations Demonstration (Phase 3)	This project will build on Phases 1 and 2 of the projects funded under STAR Plan 1.0. Phase 1 sought innovative yard operations projects leading to proof-of-concept demonstrations, equipment installation or integration, and testing, to be completed within 12 months of project award. Phase 2 was envisioned to result in a longer-term operational demonstration with additional functionality (e.g., additional vehicles, yard coverage, or an expansion of automated functionality). To follow up on this work, a new project element – Phase 3 -- will focus on large-scale implementation. Examples may include a scalable solution that can be easily adapted and implemented in different environments, a project that would expand to all vehicles in a bus yard, or an effort exploring potential advancements or additional needs in bus yard design and configuration made possible or are required through automation. *Project concludes in Year Five*.
Transferable Automated On-Demand Microtransit Demonstration	*Continuing Project. Project concludes in Year Four*.
Transit Bus Automation Demonstration for BRT Implementations	*Continuing Project. Project concludes in Year Four*.

Year Five (2028)

During the fifth year, continuing projects will conclude as well as the three remaining integrated demonstrations. This year will look back on work completed during the period covered by STAR Plan 2.0 to assess the current state of transit automation research and begin to build out lessons learned for potential future follow-on work.

Enabling Research	
Transit Bus Automation Market Assessment	*Continuing Project (with work on new editions starting in Year One, Year Three, and Year Five). Project concludes in Year Five.*
Lessons Learned from International Transit Bus Automation Pilots	*Continuing Project (with work on new editions starting in Year Two and Year Four). Project concludes in Year Five.*
Onboard Attendant Roles and Training	*Continuing Project. Project concludes in Year Five.*
Automated Transit Labor Impacts Assessment and Evaluation	*Continuing Project. Project concludes in Year Five.*
Impact on Service Patterns and Planning	*Continuing Project. Project concludes in Year Five.*
Transition Costs and Planning for Automated Transit Bus Deployment	*Continuing Project. Project concludes in Year Five.*

Integrated Demonstrations	
Automated Transit Bus Maintenance and Yard Operations Demonstration (Phase 3)	*Continuing Project. Project concludes Year Five.*
Automated ADA Paratransit Service Demonstration	*Continuing Project. Project concludes Year Five.*
Targeted ADAS or ADS Demonstration Projects	*Continuing Project. Project concludes Year Five.*

Section 3 Overview of Existing Conditions and Research Needs

To develop STAR Plan 2.0, the research team assessed the progress made during the five-year period covered by STAR Plan 1.0, including research results and broader trends in the driving automation and transit industries. In addition, stakeholders were consulted through a request for information, in-person stakeholder consultation at industry conferences, a convening at USDOT headquarters, and consultation with subject matter experts (advocates, associations, and academia).

Stakeholder Input

On June 2, 2022, FTA posted a notice of request for information (RFI) to gather input from public and industry stakeholders on the next phase of research, collaboration and engagement, technology development, and demonstration of ADS or ADAS necessary to improve the safe and efficient provision of public transportation and sustain the associated workforce.[5] In total, FTA received 33 comments from industry, transit agencies, academia, and private citizens.

FTA also held listening session events during the 2022 Automated Road Transportation Symposium (ARTS22) on July 20, 2022, and the APTAtech Conference on August 16, 2022. During those sessions, staff presented FTA's transit bus automation work to date and solicited questions and comments from attendees. FTA also held a similar event at the USDOT headquarters building on June 30, 2023, where USDOT staff presented on policies and regulations applicable to transit bus automation and transit agency representatives shared their perspectives on challenges related to transit bus automation projects.

FTA created a survey for the FTA Regional Offices to determine the state of transit automation at the Regional Offices and transit agencies within the regions. The survey was conducted in February 2023 and the FTA Regional Offices provided valuable feedback on the state of transit agencies across the country. The survey found that transit agencies are experiencing common challenges, including labor shortages, reduced ridership, increased fuel costs, and funding constraints. Given the direct impact of these issues on maintaining normal service levels, it is not surprising that transit automation is not a priority for many transit agencies at this time. There is, however, general interest in the topic, with requests from the Regional Offices for the Office of Research, Demonstration, and Innovation to provide more resources, training, and technical assistance.

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[5] Federal Transit Administration. (2022). "Request for Information on Transit Bus Automation Research and Demonstrations." Federal Register Notice. https://www.federalregister.gov/documents/2022/06/02/2022-11782/request-for-information-on-transit-bus-automation-research-and-demonstrations.

In addition to collecting responses from the RFI, receiving input during listening sessions at conferences, and conducting the survey, the research team held several small group and individual interviews with both internal and external stakeholders. These meetings were held in October and November 2022 and served to gather more-detailed perspectives and identify additional topics of interest.

Broadly, many stakeholders expressed support for the STAR Plan and ongoing interest in transit bus automation research and demonstration. They gave many specific examples of areas where additional research and agency guidance are needed. These are summarized in Table 2. In addition to technical research related to vehicle performance, standards, human-machine interfaces, etc., stakeholders also identified practical concerns related to product availability, ADA compliance, Buy America compliance, etc. as presenting a challenge to advancing demonstrations to operation. This reinforces the need to translate innovation into specific FTA policies and procedures.

Table 2: ***Stakeholder Input on Topics for Future STAR Plan Work***

Broad Research Areas	Guidance, Processes, and Tools	Use Cases, Demonstrations, and Pilots
• Workforce and Labor • Accessibility and ADA • Human Factors • Cost-Benefit/Business Case • Insurance and Liability • Integration with Traditional Transit Bus Technologies • Vehicle Safety Performance	• Standards • Procurement • Bus Testing • Cybersecurity Practices • Data Sharing • Federal Requirements	• ADAS • Bus Rapid Transit • Yard Operations • Paratransit • Rural Applications • Integration with Transit Systems

Note: Topics identified by stakeholders are reflected in the research roadmap—in some cases a topic directly aligns to a single project, while in other cases, it could also be cross cutting (aligning with multiple projects), or many topics may be addressed in a single project.

Questions Addressed by STAR Plan 1.0 Research

This section provides a brief overview of the transit bus automation industry in the United States, drawing upon the findings of an ongoing study conducted by FTA through the STAR Plan 1.0. For a more-complete discussion, interested readers may consult other FTA publications, such as the Transit Bus Automation Market Assessment or Transit Bus Automation Quarterly Update, which are available on the Resources section of the FTA Transit Bus Automation website.[6]

[6] FTA. (2023). "Transit Automation Research Resources." Transit Automation Research website, Federal Transit Administration, U.S. Department of Transportation, accessed May 2023, https://www.transit.dot.gov/research-innovation/transit-automation-research-resources.

What Does the Transit Bus Market Look Like?

Driving automation systems, including both ADAS and ADS, have been applied to a range of different bus models. Transit buses come in a variety of formats, including:

- **Standard city transit buses**, which are typically 30 to 40 feet long and are used for fixed route service;
- **Cutaway buses**, which are also called "body-on-chassis" buses or minibuses, are typically around 22 ft to 25 ft long, and are often used for shuttle service, demand responsive service, or paratransit service;
- **Articulated buses**, which have separate front and rear body sections and are often 60 feet long; and
- **Motor coaches,** which are also called "intercity" or "over the road" buses and are typically used for fixed route transportation between cities.

Beyond traditional bus formats, ADS have also been applied to passenger vehicles (such as minivans and SUVs) and smaller low-speed shuttles with novel designs (which have typical maximum operating speeds of 10–12 miles per hour). While the novel-design low-speed shuttle format has not yet been commercialized, it is well represented among ADS pilots that have focused on public transportation service, and some transit agencies and companies seek to operate next-generation novel-design shuttles in the future.

Overall, the U.S. transit bus market is relatively small, with annual sales to transit agencies of approximately 10,000 buses in recent years, according to the NTD.[7] Approximately 40 percent of those vehicles are classified as city transit buses, just over 50 percent are classified as cutaway buses, and the remaining 10 percent is split roughly evenly between articulated buses and motor coaches. For comparison, annual U.S. sales of heavy-duty trucks (i.e., trucks with more than 14,000 pounds gross vehicle weight) have been between 400,000 to 500,000 units in recent years, and annual U.S. sales of light-duty vehicles (e.g., cars, vans, pickup trucks, and sports utility vehicles) have been approximately 17 million units.[8] [9]

While several new companies have moved into the transit bus manufacturing space in recent years, the industry has also seen consolidation, and a small number of companies provide the majority of new transit buses to transit agencies. With respect to the larger full-size city transit bus segment, the top

[7] In addition to the buses sold to transit agencies that report in the NTD, transit buses are sold to other organizations (e.g., cutaway buses used for hotel shuttle service), and those buses are not included in this estimate. These numbers also do not include over-the-road coaches (e.g., large buses such as those used for intercity travel or to provide tours). NTD, (2020), "2020 Annual Database Revenue Vehicle Inventory," National Transit Database, Federal Transit Administration, U.S. Department of Transportation, accessed March 2019, https://www.transit.dot.gov/ntd/data-product/2020-annual-database-revenue-vehicle-inventory.

[8] U.S. Bureau of Economic Analysis. (2022). "Motor Vehicle Retail Sales: Heavy Weight Trucks." Retrieved from FRED, Federal Reserve Bank of St. Louis. September 19, 2022. https://fred.stlouisfed.org/series/HTRUCKSSAAR.

[9] U.S. Bureau of Economic Analysis. (2022). "Light Weight Vehicle Sales: Autos and Light Trucks." Retrieved from FRED, Federal Reserve Bank of St. Louis, September 19, 2022. https://fred.stlouisfed.org/series/ALTSALES.

two manufacturers provide approximately 75–80 percent of buses to transit agencies.[10] Similarly, with respect to the smaller cutaway bus segment, the top two manufacturers provide more than 80 percent of buses to transit agencies.

Who is Developing ADAS and ADS for Transit Buses?

While much of the development of ADS has focused on light-duty vehicles and commercial trucks, some ADS developers have either focused specifically on ADS for transit buses or have adapted their ADS to apply it to transit buses. At this point, all ADS for road vehicles are better considered to be prototypes used in pilots rather than commercialized products ready for long-term or permanent deployment. While ADS testing, broadly speaking, has been occurring over the past several years, ADS testing in transit buses is much more recent, and the most high-profile pilots in the United States have begun in the past year or will only begin in the near future.

Low-speed shuttles have been used in testing, pilot, and demonstration projects for several years, with some of the earlier testing activities launching as long as five or six years ago. They also represent many more pilots and demonstrations, and such activities have occurred in several dozen locations across the country. Some companies have produced and operated novel-design automated shuttles, while other companies have applied their ADS to FMVSS 500 compliant base vehicles (e.g., small, low-speed neighborhood electric vehicles) to create automated shuttles; however, many of those efforts have ended as companies have ceased work with automated shuttles or moved on to other platforms.[11] In some cases, ADS developers shifted from shuttle platforms to light-duty vehicles, cutaway buses, or full-size city transit buses. In addition, some companies that had previously focused on low-speed shuttles have moved away from passenger applications and towards goods movement applications (e.g., ADS for small trucks at closed logistics facilities).

How is the Development of Transit Bus ADAS and ADS Changing?

The state of driving automation systems for transit buses is a rapidly evolving field with multiple potential paths to commercialization. It is expected that the field will continue to evolve, with new technologies to be developed and commercialized and new actors entering the market, partnering with existing actors, and consolidating through mergers and acquisitions or exiting the market as conditions change.

[10] Ibid NTD 2020.

[11] Past models of novel design shuttles did not comply with FMVSS requirements, and often did not comply with requirements of other laws and policies (e.g., ADA, Buy America, etc.).

In the near term, pilot and demonstration projects are choosing vehicle models for compatibility with transit service needs. In the longer term, the industry is working to evolve and improve vehicle and system designs. Bus architectures are slowly evolving and becoming more conducive to drive-by-wire integration, but many challenges remain, including the lack of commercially available components. Vehicle formats for pilots and demonstrations are shifting to traditional bus formats that meet regulatory requirements, though several companies have also announced work on next-generation shuttles. Factory installed systems are preferred over retrofit systems, and system developers are working to partner with bus manufacturers to better integrate their systems into transit buses. Publicly announced partnerships continue to become more common as ADAS and ADS developers and other suppliers seek to apply their systems to vehicles from different bus manufacturers and vice versa.

Component technologies that enable automation are maturing and, for many systems, there are more commercially available options on the market. Powertrain technology preferences for buses are shifting towards electrified systems, both for manually-driven buses and ADS-equipped prototypes. The availability, capability, and affordability of sensors (e.g., camera, infrared, lidar, radar, and ultrasonic systems) continues to improve. Connectivity technologies can potentially augment ADS in transit buses through enabling applications such as smoother braking, bus platooning, or providing transit signal priority.

While concepts for driving automation system use cases in transit operations have existed for many years, many pilot and demonstration activities are focusing on near-term applications in simplified environments. Operational design domains (ODDs) in protected and controllable environments are easier for ADS operations, and such geographically-limited areas may align with some transit services and applications. Those could include bus yard automation systems and automated bus rapid transit (BRT) systems, both of which have received increased interest in recent years and may present simplified ODDs and address specific needs for some (but not all) transit agencies. Driver support features in the form of ADAS are beginning to emerge in the market, and, though few systems have automated actuation at this time, bus manufacturers are partnering with other firms to create new systems that do include automated control.

Transit agency staff will continue to play an important part in enabling transit service, and new roles will emerge as driving automation systems for transit buses continue to mature. Workforce training and retraining on driving automation systems will be needed as technologies continue to evolve and mature, but in the near-term, staff will likely maintain roles similar to those that currently exist. Unstaffed operation is a continued area of interest for ADS developers, but it is primarily limited to pilots and demonstrations of ADS-equipped light-duty vehicles and heavy-duty trucks or may take place in highly controlled environments (e.g., private campuses and roads)—current work related to unstaffed operation of ADS-equipped transit vehicles is limited.

What is the Current State of Transit Bus Automation Demonstrations?

Transit bus automation demonstrations are challenging. In general, transit agencies' core expertise is in transit planning and operations, not research design or evaluation. Working with an emerging technology adds significant complexity. For example, procurement of innovative technologies can be an unfamiliar, slow process for public sector agencies. Many vendors active in this space are start-ups, and demonstrations have been delayed by staff turnover at vendors, and companies changing strategic direction or going out of business. This adds risk and time. In addition, sharing operational and system data can be a sensitive issue, as private sector companies often have a strong business interest in keeping certain information confidential and who may be motivated to participate in demonstrations to further prove out their systems and attract investors.

The scalability of early demonstrations is unclear. Early demonstrations have focused on highly localized and site-specific use cases. It is difficult to translate these into more generalizable applications. In practice, route flexibility and higher speeds are frequently needed. Both vendors and project sponsors may shift or concentrate resources to ensure successful operations throughout a demonstration; this is unlikely to be sustainable in the long term. It may be appropriate for future demonstrations to further explore less tailored applications.

Summary of Literature Review

The FTA transit automation research team conducted a literature review (Appendix C) to identify the current level of research and development in automated transit buses in the United States and internationally. The state-of-the-practice scan reviewed academic literature relevant to transit bus automation that has been published in the years since STAR Plan 1.0 was adopted, as well as closeout reports of recent transit bus automation pilot projects conducted in the United States.

Overall, the literature is generally optimistic that automated transit bus operations could reduce operating costs vis-a-vis a traditional fixed route bus. The literature finds few differences between rider intentions to use automated transit compared to rider intentions to use conventional transit. Research shows that the most important factors in determining an individual's intention to use an automated transit service were service frequency, speed of service, travel time, ride comfort and smoothness, and cost to ride.

Low-speed automated shuttle pilots in the United States have generally been deemed successful at introducing the concept of automated transit bus service to the public, but the longer-term business case for such projects remains uncertain.

At the current state of development, automated transit buses appear to be best suited to fixed routes in smaller service areas, but the applicability of door-to-door (D2D) services is expected to increase as automation technology matures. Additionally, there is a desire from transit agencies and automated transit vendors for future pilot projects to test automation on larger, conventional transit buses, operating at higher speeds and in a variety of road and traffic conditions.

Conclusion

The second five-year research agenda outlined in FTA's Strategic Transit Automation Research Plan will provide a framework for the transit industry to pursue transit bus automation in a safe, efficient, and economically-sound manner. Built on a foundation of stakeholder engagement, use case analysis, and an extensive literature review, STAR Plan 2.0 defines activities in the areas of Enabling Research, Integrated Demonstrations, and Strategic Engagement to explore various technical and non-technical factors. If not properly addressed, these factors could slow or stop the development and deployment of transit automation technologies. FTA developed this plan to address a range of technical, societal, institutional, and regulatory issues impacting the development, demonstration, evaluation, and, ultimately, full deployment of transit bus automation.

STAR Plan 2.0 has a continued emphasis on stakeholder engagement, knowledge transfer, and technical assistance to ensure that complementary work being done by the public sector, the private sector, and academia is effectively communicated and leveraged. By providing leadership and guidance at the Federal level while incorporating the strengths of external stakeholders and partners, the Strategic Transit Automation Research Plan will help close the gap between the transit bus industry and earlier adopters of automation technologies while continuing to maintain a safe and accessible transportation system.

Appendix A Transit Bus Automation Technology Packages and Use Cases

STAR Plan 1.0 used information gathered from a literature review and initial interviews to identify five technology packages that encompassed 14 use cases. The technology packages, which grouped use cases with similar functionalities, were selected to represent a range of near-term and long-term concepts, and to respond to interest expressed by stakeholders. They included the following:

- Transit Bus Advanced Driver Assistance Systems
- Automated Shuttles
- Maintenance, Yard, and Parking Operations
- Mobility-on-Demand Service
- Automated Bus Rapid Transit (BRT)

These technology packages and corresponding use cases were used to structure discussions in stakeholder events and to structure the analysis in a benefit-cost analysis study (see STAR Plan 1.0 Appendix C). Stakeholder engagement activities used to guide the development of STAR Plan 2.0 did not identify additional technology packages or use cases that needed to be integrated, nor did they lead to any major revisions to the existing technology packages and use cases. Table 3 summarizes the technology packages and use cases.

Table 3: *Summary of Technology Packages and Use Cases*

Technology Packages	Use Cases
Transit Bus Advanced Driver Assistance Systems (ADAS) (SAE Automation Levels 0–2)	• Smooth acceleration and deceleration • Automatic emergency braking and pedestrian collision avoidance • Curb avoidance • Precision docking • Narrow lane/shoulder operations • Platooning
Automated Shuttles (SAE Automation Level 4)	• Circulator bus service • Feeder bus service
Maintenance, Yard, Parking Operations (SAE Automation Level 4)	• Precision movement for fueling, service bays, and bus wash • Automated parking and recall
Mobility-on-Demand (MOD) Service (SAE Automation Level 4)	• Automated first-mile/last-mile • Automated ADA paratransit • On-demand shared ride
Automated Bus Rapid Transit (BRT) (SAE Automation Level 4)	• Automated BRT

Source: Adapted from the FTA STAR Plan 1.0

Transit Bus Advanced Driver Assistance Systems

The Transit Bus Advanced Driver Assistance Systems (ADAS) technology package includes partial automation technologies that can be added to a typical 40-foot bus, cutaway bus, or articulated bus. These systems can be factory installed or installed on existing buses as retrofit systems. Depending on the specific ADAS application, the technology may increase the safety of operations, provide a better and more accessible service to customers, or improve driving performance in terms of fuel economy, network efficiency, or other metrics. ADAS capabilities are generally classified as SAE Level 1 or Level 2 (L1/L2) systems when they involve partial automation of one or more aspects of vehicle control, such as longitudinal or lateral control, whereas the human operator maintains overall responsibility for the driving task. Systems that provide only momentary intervention, such as automatic emergency braking (AEB), are classified as SAE Level 0 (L0). ADAS on buses can enable a variety of applications, including:

- Smooth acceleration and deceleration to improve fuel economy, such as approaches at signalized intersections.
- Pedestrian detection and automatic emergency braking (AEB) for collision avoidance
- Precision docking at bus stops
- Curb avoidance during bus stop approaches and turns.
- Operations in narrow lanes or road shoulders (e.g., for Bus-on-Shoulder or BRT guideway)
- Bus platooning to enhance throughput in constrained corridors.

These applications could potentially be used in a variety of settings, including highways, expressways, busways, urban roads, and tunnels, depending on the specific application.

Automated Shuttles

The Automated Shuttle technology package uses a small shuttle vehicle equipped with a SAE Level 4 (L4) ADS. There have been multiple shuttle models with novel designs, but some companies have created shuttle prototypes using FMVSS-compliant vehicles as well. While a mature system would not require a human operator onboard the vehicle, demonstrations to date have included an on-board staff to serve as safety operators and manage other tasks, such as observing passengers, recording data, and answering questions. Potential applications that have been considered for automated shuttles include:

- Circulator bus service—fixed-route or flexible service between two or more points
- Feeder bus service—connections to fixed-route transit stations.

Automated shuttles may be suitable for providing service in areas such as parking lots, campuses, downtown districts, retirement communities, and business parks, and/or connecting these areas to fixed-route transit.

Maintenance, Yard, and Parking Operations

The Maintenance, Yard, and Parking Operations technology package would use a L4 ADS that could be added to a range of different bus formats, including city transit buses, cutaway buses, or articulated buses. In this technology package, the ODD for the vehicles comprises transit agency maintenance facilities and bus yards. While outside of the ODD, the vehicles would still require a human operator, but within the ODD, they would be capable of operating without staff in the vehicle. This technology package is designed primarily to increase efficiency in transit agency facilities, but it could also potentially have implications for safety of operations within the yard. Applications in this technology package include:

- Precision docking and maneuvering for bus wash, disinfection, service bay, refueling/recharging, and other yard or maintenance operations.
- Fully automated driving for parking and recall

These applications can be used only within the ODD and may require precision mapping of the facilities or, in some cases, reconfiguration of the infrastructure at the facility. Precision docking and maneuvering applications could include automated driving operations for some maintenance and service activities, such as pulling through a bus wash or into a service bay. Maintenance staff would still be needed to perform some daily operations and maintenance activities.

Mobility on Demand Service

The Mobility-on-Demand (MOD) Service technology package uses an L4 ADS in a small- to medium-size vehicle (such as a light-duty passenger vehicle or a minibus on a cutaway van chassis, although new designs may emerge) to provide on-demand service between any two addresses within a defined service area. Use cases identified for the MOD service include:

- Automated ADA paratransit
- Automated first/last-mile service
- On-demand shared ride

This MOD concept is similar to the automated shuttle technology package; however, it is not restricted to predefined routes and stops, and users can request pick-ups and drop-offs rather than being restricted to scheduled service. In addition, rather than operating only in dense, high-demand areas, the MOD service can provide rides to users in neighborhoods and other less-dense locations, such as suburban and rural regions. The automated first/last-mile service concept would provide connections between a fixed-route transit stop (e.g., BRT or rail transit) and user specified locations, such as shopping centers, business parks, and residences. The on-demand shared ride concept would provide rides between user specified locations within a designated service area. The automated ADA paratransit concept would provide similar service as the on-demand shared ride concept, but it would also focus on providing rides to persons with disabilities, and therefore, may need an on-board attendant, specialized equipment, or other design features.

Automated Bus Rapid Transit (BRT) Service

The automated Bus Rapid Transit (BRT) Service technology package uses a full-size or articulated bus equipped with a L4 ADS to provide BRT service without a driver on board the vehicle. BRT systems use buses to provide fast, efficient, and cost-effective service at metro-level capacities by including features similar to a light or heavy rail system. BRT service may include dedicated lanes, busways, traffic signal priority, off-board fare collection, elevated platforms, enhanced stations, and operating in mixed traffic. BRT systems also typically have longer distances between stops compared to regular bus service. These features focus on eliminating causes of delay that typically slow regular bus services (e.g., being stuck in other road traffic and on-board payment for passengers).

An automated BRT bus operating on a fixed guideway equipped with a mature L4 ADS would not require an onboard human operator, although such a system has yet to be demonstrated. Some work has already been done or is being done to test automated features on BRT systems, including applications such as platooning, lane centering, and precision docking at boarding platforms, although individually, those applications would be considered ADAS.

Appendix B Lessons Learned from STAR Plan 1.0

Introduction

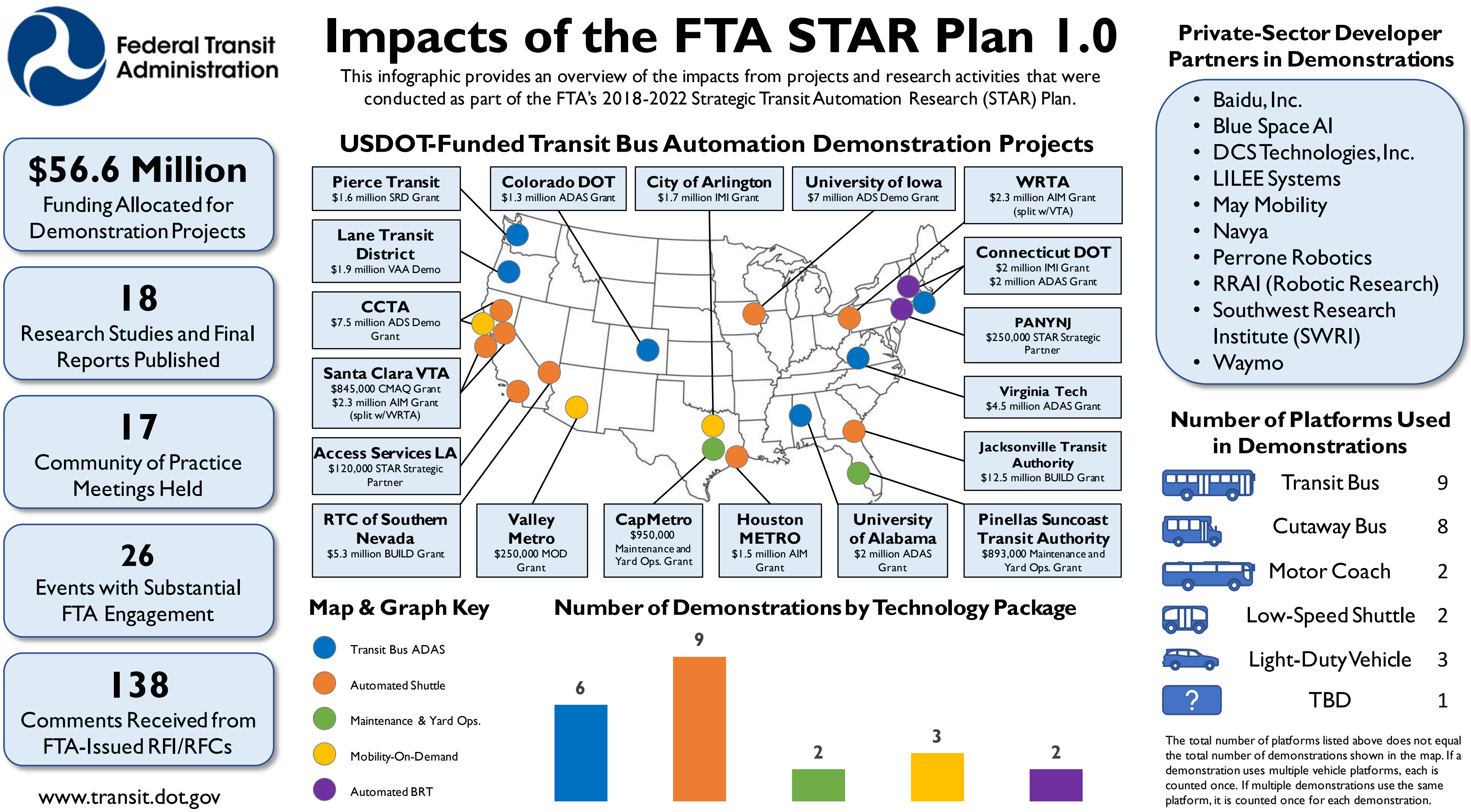
FTA published the STAR Plan 1.0 in January 2018, with the goal of providing research and policy guidance to help transit agencies make informed deployment decisions regarding transit bus automation. The plan was prepared by a team of FTA staff and researchers from the Volpe National Transportation Systems Center, with input from numerous stakeholders through workshops, interviews, and webinars. The research objectives of STAR Plan 1.0 were to improve safety, including the deployment of automated vehicles and integration of automated technologies; to increase the efficiency and productivity of transit operations; and to enhance customer experience and satisfaction through improved service frequency and flexibility.

The key components of STAR Plan 1.0 were to conduct enabling research, identify and resolve barriers to deployment, leverage technologies from other sectors, demonstrate market-ready technologies, and transfer knowledge to the transit stakeholder community, with the ultimate goal of establishing a research and demonstration framework to move the transit industry forward.

Outputs and impacts of the work conducted under STAR Plan 1.0 are summarized in the Figure 2 infographic. It includes information on the published studies and reports, as well as engagement and knowledge transfer with stakeholders through meetings, event participation, and formal public comment processes. With respect to demonstrations and strategic partnerships, it includes a range of information on the location of projects, the funding they received, the technology packages they address, vehicle types tested, and private-sector partners involved.

This appendix provides an overview of the lessons learned from the projects and research activities that were conducted as part of STAR Plan 1.0 to share the research findings with a broad audience. Further, this compilation of findings and lessons was used to provide input to and inform STAR Plan 2.0.

Figure 2: *Infographic Overview of the 2018 - 2022 FTA STAR Plan*



What We Learned

The transit industry professionals, technology developers, local governments, and researchers brought together through the STAR Plan-related work to date have contributed to a new body of knowledge regarding transit bus automation research in the United States. This section summarizes principal findings and research needs from across the program. In the subsequent sections, more detailed findings are presented by project or work area.

Key findings identified from work conducted under STAR Plan 1.0 included the following:

- Many transit agencies are interested in automation technologies.
- The limited number of buses sold annually and the limited transferability of driving automation systems from other modes and vehicle types has slowed the introduction of driving automation systems to transit buses.
- Development and commercialization of driving automation systems for transit bus applications is still at an early stage, and transit-specific research and development will take time.
- Implementing driving automation systems in transit buses will be a substantial investment, and funding it may be a challenge, especially with limited revenue streams and resource constraints.
- Federal investment in transit bus automation research is critical to creating outcomes that meet public policy goals.

Research and data needs identified from work conducted under STAR Plan 1.0 included the following:

- Better data on benefits and costs are needed to inform agency decisions with respect to implementation of transit bus automation systems.
- Additional work is needed to translate innovation into Federal policy and guidance
- Research gaps related to transit bus automation still exist on the topics of unstaffed operations, labor and workforce, and human factors.
- Better data is needed to support standards and procurement of transit bus automation systems.

Impacts of STAR Plan 1.0 on Transit Industry

Enabling Research

STAR Plan 1.0 and the subsequent reports under the enabling research category were widely reviewed and used by other transit bus automation stakeholders. FTA transit bus automation reports were also used as references for a number of other studies and reports, as evidenced by their citations in other media, including:

- Trade associations, such as APTA
- Academic and transportation journals
- News media and industry blogs
- Studies, reports, and white papers
- Government memos and reports

The citations referenced above were confirmed using available bibliographic tools. It is likely that FTA-produced content on transit bus automation also informed other research efforts, even if not included in formal citations. Moreover, a number of other research reports and journal articles were found that cite the works from those above, which in turn cited FTA research. The research team did not take on the task of building a full citation tree to document these secondary impacts, but it is clear that FTA's transit bus automation research directly and indirectly supported the emerging literature on this topic.

Integrated Demonstrations and Strategic Partnerships

FTA has funded and managed many different transit bus automation demonstrations and pilots in the United States. FTA has funded demonstration and pilot projects with approximately $32.6 million and it has provided more than $600,000 to support evaluation of externally funded work. In addition, other U.S. Department of Transportation (USDOT) grant programs have funded approximately $32.4 million for transit bus automation projects that FTA manages. Table 4 lists the various projects in these categories along with information on Federal funding amounts for each.

Table 4: ***FTA-Funded and Managed Transit Bus Automation Projects***

FTA-Funded and Managed Projects	• Western Reserve Transit Authority (WRTA) and Santa Clara Valley Transportation Authority (VTA) Accelerating Innovative Mobility (AIM) demonstration ($2.3M) • Metropolitan Transit Authority of Harris County (Houston METRO) AIM demonstration ($1.5M) • Connecticut Department of Transportation (CTDOT) Integrated Mobility Innovation (IMI) demonstration ($2.0M) • Arlington, TX IMI demonstration ($1.7M) • VTA Congestion Mitigation and Air Quality (CMAQ) pilot ($845K) • Pierce Transit Safety Research and Demonstration (SRD) Program demonstration ($1.6M) • Lane Transit District (LTD) Vehicle Assist and Automation (VAA) demonstration ($1.9M) • Colorado Department of Transportation (CDOT) Advanced Driver Assistance Systems (ADAS) for Transit Buses Demonstration Program ($1.3M) • CTDOT ADAS for Transit Buses Demonstration Program ($2.0M) • University of Alabama ADAS for Transit Buses Demonstration Program ($2.0M) • Virginia Polytechnic Institute and State University (VTTI) ADAS for Transit Buses Demonstration Program ($4.5M) • Capital Metropolitan Transportation Authority (CapMetro) Automated Transit Bus Maintenance and Yard Operations Demonstration Program ($950K) • Pinellas Suncoast Transit Authority (PSTA) Automated Transit Bus Maintenance and Yard Operations Demonstration Program ($893K)
FTA-Funded Strategic Partners	• Access Services of Los Angeles ($120K) • Valley Metro Regional Public Transportation Authority (Valley Metro) ($250K) • Port Authority of New York and New Jersey (PANYNJ) ($250K)
FTA Managed Projects with Other USDOT Funding	• Contra Costa Transportation Authority (CCTA) ADS Demo Grant ($7.5M) • University of Iowa ADS Demo Grant ($7.0M) • Regional Transportation Commission (RTC) of Southern Nevada Better Utilizing Investments to Leverage Development (BUILD)[12] project ($5.3M) • Jacksonville Transportation Authority (JTA) BUILD project ($12.5M)

Source: USDOT 2022

Much of the work related to using ADS-equipped vehicles for passenger transportation has focused on using light-duty passenger vehicles or novel-design, low-speed automated shuttles. Outside of those shuttle pilots, there are some efforts using traditional transit bus formats, though they are relatively limited in number. To the extent that they exist, **FTA has funded or managed the majority (70 percent) of domestic projects using ADS-equipped transit buses** (e.g., transit vans, cutaways, city transit buses, and motor coaches). FTA focused its efforts on these conventional vehicle designs because of their prevalence and compliance with relevant regulations. Table 5 provides lists of transit bus automation projects using conventional vehicle formats, including those with Federal funding and those without Federal funding.

[12] In 2021, the BUILD discretionary grant program was renamed as the RAISE grant program, and prior to 2018, it had been known as the TIGER grant program.

Table 5: ***Transit Bus Automation Projects Using Conventional Vehicle Formats***

Demonstrations with USDOT Funding (FTA managed): Recipient & Automated Vehicle (AV) Provider
• Access Services & LILEE Systems • CapMetro & Perrone Robotics • CDOT & ADAS provider TBD • CTDOT & RRAI (Robotic Research) • CTDOT & ADAS provider TBD • Houston METRO & Perrone Robotics • LTD & California Partners for Advanced Transportation Technology (PATH) • PANYNJ & Southwest Research Institute (SwRI) • Pierce Transit & DCS Technologies, Inc. • PSTA & Blue Space AI • University of Alabama & Perrone Robotics • University of Iowa & Baidu • VTA & Perrone Robotics • VTTI & ADAS provider TBD • WRTA & Perrone Robotics
Demonstrations without USDOT Funding (Externally managed): Recipient & AV Provider
• Hawaii Department of Transportation (HIDOT) & Perrone Robotics • JTA & Perrone Robotics • Michigan State University (MSU) & ADASTEC • Southeastern Pennsylvania Transportation Authority (SEPTA) & Perrone Robotics • SwRI (with a SwRI ADS) • University of Virginia & Perrone Robotics

Source: USDOT 2022.

Knowledge Transfer, Stakeholder Engagement, & Technical Assistance

To support knowledge transfer among USDOT recipients, FTA formed the Transit Bus Automation Community of Practice. For its first 1.5 years, the group had 14 members and met bimonthly, for a total of nine meetings. For 2022, the group had 12 members and met quarterly, for a total of four meetings. For 2023, the group is on track to meet four times and will expand to include additional FTA grantees; it plans to meet with a similar meeting quarterly cadence moving forward. In addition, FTA and the Shared Use Mobility Center (SUMC) convened a similar group of FTA-funded recipients (including some with transit bus automation projects) as part of the Mobility Innovation Collaborative (MIC) program. The MIC has held regular meetings with the goal of increasing awareness about developments in mobility innovation projects, facilitating knowledge exchange, and fostering a community for transit agencies. FTA, its representatives, and recipients also participated in many other activities, as outlined later in the document.

FTA also worked with the Intelligent Transportation Systems Joint Program Office (ITS JPO) Professional Capacity Building (PCB) Program’s Talking Technology and Transportation (T3) Webinar series to host two webinars:

- “Introducing FTA’s Strategic Transit Automation Research (STAR) Plan”

(December 2017)
- "FTA Transit Automation Research: Transit Bus Automation Market Assessment" (November 2019)

The webinars had 435 and 193 attendees respectively and served to share details and results about the respective efforts with external audiences. FTA also provided technical support to transit bus automation stakeholders, in particular, transit agencies planning, operating, and evaluating transit bus automation demonstrations and pilots. Activities included reviewing and providing feedback on planning documents, survey tools, evaluations, and final reports.

STAR Plan 1.0 Activities by Work Area

STAR Plan 1.0 outlined three complimentary work areas: Enabling Research, Integrated Demonstrations, and Strategic Partnerships. Those work areas served as the foundation for the FTA transit bus automation projects and activities undertaken during the 2018 through 2022 timeframe. The following sections highlight the activities within these three work areas and provide information for each activity. Project titles in parentheses are the original project names identified in STAR Plan 1.0.

Enabling Research

Through research, FTA investigated basic questions with regard to technology availability, business case, policy, human factors, and safety to sharpen the research focus of the demonstrations and help resolve policy and technical issues that affect their viability.

Transit Bus Applications of Light and Commercial Vehicle Automation Technology

Summary:

This project examines the feasibility of transferring 13 current automated systems technologies from light-duty vehicles and commercial trucks to 40-foot diesel transit buses. It explores the associated technical and safety challenges of implementing those systems in transit buses and ways to overcome some of the identified barriers to implementation. The transferability of each system was given a grade of "red," "yellow," or "green," with "green" indicating most ready to be transferred.

High-Level Results:

Transferring existing automation systems from other vehicle formats will generally require modification, replacement, or redesign of components and systems on the bus. Sensors are relatively mature and should be able to be adapted to buses without modification. To enable other automation systems, however, the transit bus industry will need to implement foundational and interfacing systems that can support electronic actuation.

Findings:

- Beyond the minor adjustments needed to install an automation system on a new vehicle model (e.g., modifying the number and placement of sensors to accommodate a new vehicle footprint), transferring these systems to buses requires modification, replacement, or redesign of components and systems on the bus.
- To enable automation systems, the transit bus industry will need to implement foundational and interfacing systems that can support electronic actuation.
- Modifications to powertrain systems in support of automation should be made more easily than modifications to other foundational systems (i.e., steering and braking).
- Bus steering systems may require more modification, but heavy-duty vehicle steering solutions exist to enable automation and may not require extensive changes.
- With respect to technologies currently found in light-duty vehicles and commercial trucks, automated steering applications may be easier to transfer to transit buses than automated braking applications.
- Implementation of electronic control of a transit bus brake system appears to be a major challenge, as pneumatic brakes found in buses are less conducive to automation and more extensive design changes may be needed.
- Automated applications, especially those requiring a braking component, may require a new communication system architecture with bandwidth to carry numerous complex signals reliably.
- Buses will require new human-machine interfaces to control automation systems, although these should be relatively easy to design and implement.
- Sensors are relatively mature and should be able to be adapted to buses without modification.

Report:

Transit Bus Automation Project: Transferability of Automation Final Report (Report 0125) | FTA (dot.gov)

Test Facility Requirements for Automated Transit Vehicles

Summary:

FTA conducted research on guidelines for test facility requirements to support automated transit vehicle testing and demonstration projects. Stakeholders, including Federal agencies, universities, transit agencies and operators, test facilities, and industry representatives, were consulted and, based on those conversations, a list of requirements was compiled in the areas of test facility features, functionality and performance, safety, environmental resilience, human factors, and data collection and management. These requirements were classified as "mandatory," "optional," and "not applicable" with respect to 14 use cases that have been organized into five technology packages—Transit Bus ADAS; Automated Shuttles; Maintenance, Yard, Parking Operations; Mobility-on-Demand Service; and Automated BRT.

High-Level Results:

A variety of organizations may be interested in performing or otherwise participating in automated transit bus research and development tests and pilot demonstrations to assess the ability of these vehicles to meet performance, safety, and economic goals. The report lists 91 requirements that provide a resource and reference for selecting facilities with the appropriate and necessary characteristics in terms of infrastructure, equipment, and personnel for the testing of automated transit buses for all levels of automation. The requirements are divided into the categories of Test Facility Features, Functionality and Performance, Safety, Environmental Resilience, Human Factors, and Data Collection and Management.

Findings:

- The document may be used as a guide or resource for identifying requirements and considerations for testing the capabilities of automated transit buses, and it may have multiple audiences and serve a variety of purposes.
- Outside of the common mandatory requirements, most requirements listed in this report are only mandatory for certain technology packages and use cases (e.g., physically simulating a bus yard for Maintenance, Yard, Parking Operations) or they are considered optional depending on the specific goals of a test or demonstration.
- The requirements listed in this report are intentionally left as broad categories to provide flexibility in defining the operating domain of the automated vehicle and thus the testing program. Requirements for testing automated transit buses for actual demonstration pilots and deployments should contain specific and measurable statements that are precise and quantifiable.
- Depending on the organization conducting the testing, product being considered, or use case being tested, users may identify additional requirements beyond those included in this document. Users may opt to take requirements from this document, adapt them, or add additional requirements as needed.

Report:

Determining Requirements for Automated Transit Bus Test Facilities: Considerations for Practitioners (Report 0131) | FTA (dot.gov)

Transit Bus Automation Policy – Frequently Asked Questions (part of Automation Policy Review)

Summary:

As the transit industry begins to explore the use of automated transit buses, many stakeholders have questions about the impact of new technologies on transit agencies, employees, riders, and the general public. In response, FTA has developed Transit Bus Automation Policy FAQs for key areas of interest:

- Transit bus automation in relation to U.S. Department of Transportation (DOT) requirements.
- Transit bus automation in relation to FTA requirements.
- Transit bus automation in relation to other considerations.

Report:

Transit Bus Automation Policy FAQs | FTA (dot.gov)

Transit Bus Automation Market Assessment (Market Analysis for Automated Transit Buses and Supporting Systems)

Summary:

The market assessment depicts the current state of the industry, including the availability, capabilities, and limitations of automated transit bus technologies. The research results are intended for use as a resource for identifying commercially available automation technologies and providing context related to automated transit bus prototype research. The original edition was first published in 2019, followed by subsequent updated editions.

High-Level Results:

Stakeholders may not clearly understand the difference between conceptual ideas, prototype systems, and available products related to the emerging automated transit bus market. Currently, no commercially available products exist, and current pilot and demonstration work uses ADAS and ADS protypes. Other factors, such as the COVID-19 pandemic, show shifts away from transit bus automation to meet more immediate demands.

Findings:

- Media coverage and marketing materials may overstate the capabilities and market readiness of the technology, which is still in the pilot testing stage.
- Technology costs are unknown and estimates that do exist vary from pilot project to pilot project; to the extent that it exists, currently available cost information reflects prototype systems only, as there are no commercial products.
- There is a limited ability to leverage technology across modal use cases.
- The limited market scale of transit buses (which have low production volumes

and are highly customized) makes it difficult for the private sector to justify technology development investments.
- There is significant uncertainty and development needed with respect to human factors (pedestrians, occupants, and drivers) aspects of transit bus automation systems.
- Transit vehicle manufacturers are striving to be “tech ready” and developing partnerships with system developers and other suppliers.
- Demonstrations are vital to advancing technology development and deployment.

Report:
Transit Bus Automation Market Assessment (Report 0255) | FTA (dot.gov)

Considerations for Evaluating Automated Transit Bus Programs (Evaluation Guidance for Integrated Demonstrations)

Summary:

Given the potential of transit bus automation, it is critical to evaluate the benefits and challenges from early implementations. This effort produced guidance for transit agency consideration in designing and evaluating deployments of transit bus automation technologies. The guide that was developed highlights important, general principles that can be applied to evaluations of various transit-automation projects and recommends and discusses the steps for designing and implementing an evaluation.

High-Level Results & Findings:

- A well-designed evaluation can quantify societal benefits such as reductions in travel time, improvements to mobility, and increases in transit ridership.
- In designing evaluations, transit agencies and other stakeholders should identify program goals and audiences affected by the technology; develop a logic model that maps project inputs, activities, and outcomes; choose an appropriate evaluation design; and collect and analyze data on key performance indicators related to their program goals.

Report:
Considerations for Evaluating Automated Transit Bus Programs (Report 0149) | FTA (dot.gov)

Transit Bus Automation: State and Local Policy Scan (part of Automation Policy Review)

Summary:

This project included research, largely through stakeholder interviews, on State and local policies with a focus on those that may pose challenges to, or require revision in light of, the deployment of transit bus automation technologies by U.S. transit agencies. Through this process, insight was also gained on State- and local-level perspectives regarding barriers and challenges that are relevant at the Federal level.

High-Level Results:

Federal policy issues are the primary issues identified by stakeholders and are generally within USDOT's jurisdiction to address, whereas State and local governments typically can resolve local issues if there is political will to move forward.

Findings:

- Assess opportunities to address identified Federal barriers.
- Continue the dialogue with stakeholders. As transit grantees explore bus transit automation further, they are likely to encounter new issues. Some of those issues may be candidates for FTA-sponsored research, which could help inform development of local policies and programs. Regular communication among States, localities, FTA Regions, and FTA Headquarters could help stakeholders keep abreast of emerging issues.
- Leverage planned research and programs to better address State and local issues. Through STAR Plan 1.0, FTA has outlined several key activities focused on the topics noted in the previous section.

Report:

Transit Bus Automation: State and Local Policy Scan (Report 0162) | FTA (dot.gov)

Hazard and Safety Analysis of Automated Transit Bus Applications

Summary:

This research applied hazard analysis techniques to identify potential high-level hazards and top-level safety goals for a generic 40-ft transit bus system equipped with SAE Level 0, 1, or 2 driving automation systems, such as entering/exiting bus stops and embarking/disembarking passengers. It also developed generic risk mitigation functions that may facilitate the safe deployment of automated transit buses.

High-Level Results:

Although this study found that many of the same basic hazards exist for transit buses as for other vehicles, specific aspects of transit bus operations resulted in additional hazards and associated functional safety measures. The results of this research provide a useful reference for manufacturers on the application of hazard analysis and risk assessment concepts in the context of transit bus applications and for comparison of the results from internal system-specific hazard and safety analyses.

Findings:

- The majority of vehicle-level hazards and functional safety measures for Level 0 to Level 2 driving automation systems would be similar for light vehicles, heavy trucks, and transit buses. In general, this will facilitate transfer of these technologies to transit buses.
- Unique vehicle-level hazards exist for Level 0 to Level 2 driving automation systems in transit buses based on transit bus-specific operations, such as embarking and disembarking passengers. System-specific hazard analyses should be performed when transferring these systems to transit buses to ensure that any transit bus-specific hazards are identified.
- For hazards common to both light vehicles, heavy trucks, and transit buses, additional safety-relevant design considerations specific to transit buses exist—for instance, new safety measures may be needed to protect standing and unrestrained passengers. As with the hazard analysis, a system-specific safety analysis should be performed to identify these additional safety-relevant design considerations.

Report:
Hazard and Safety Analysis of Automated Transit Bus Applications (Report 0161) | FTA (dot.gov)

Transit Providers' Internal Business Case for Transit Bus Automation (Business Case for Transit Automation)

Summary:

This project explored how transit providers make capital investment decisions and how they assess their internal business case for transit bus automation. The research included an extensive literature review and interviews with transit agencies and other organizations pursuing transit automation, and it aims to inform transit industry stakeholders on how early adopters are approaching transit bus automation decisions.

High-Level Results:

Transit agencies often approach automation projects the same way they would other capital investments, but they often have to rely on qualitative measures to assess the fast-moving world of transit bus automation. The ability of agencies to assess their business case for automation is limited by data availability and a lack of knowledge on regulatory issues as well as uncertainty over operational changes, customer acceptance, and the applicability of findings from various pilot projects.

Findings:

- It is important to start with a clear agency consensus about the intended goals of the automation project and whether a quantitative business case is needed.
- Transit agencies should ensure that a comprehensive list of benefit and lifecycle cost impacts is considered.
- Transit agencies can use scenarios and sensitivity testing to address uncertainties in a quantitative benefit-cost analysis.
- Transit agencies should connect with agencies with more experience in automation to share data.
- Transit agencies can review the latest FTA publications and research findings on bus automation.

Report:
[Assessing Transit Providers' Internal Business Case for Transit Bus Automation (Report 0187) | FTA (dot.gov)]

Insurance and Liability for Automated Transit Buses (part of Automation Policy Review)

Summary:

This project examined the state of the practice of insuring automated transit buses, as informed by insurance industry representatives and stakeholders with recent experience regarding automated transit bus pilots and demonstration projects. Insurance is available for automated transit buses, but it may require a significant up-front investment of time to determine insurance requirements and identify a broker—and ultimately an insurance provider—that are a good fit for the project. The goal of this project was to understand the insurance considerations transit agencies or other organizations should consider when planning an automated transit bus pilot.

High-Level Results:

Interviewees generally suggested that insurance should not be a barrier to the deployment of automated transit bus projects. They were also optimistic that insurance for automated transit bus projects will be increasingly mainstreamed over time.

Findings:

- Insurance is available but not routine. In general, insurance coverage is widely available for ADAS-equipped vehicles. However, although multiple insurance firms do provide coverage for ADS-equipped vehicles, including some in automated transit bus pilot applications, not all insurers are in this market. Transit agencies may need to invest effort to find a firm willing to insure their project.

- Multiple aspects of the implementation will affect insurability. The details of the implementation and the ODD will inform insurance requirements and costs as well as the complexity of insuring the project. Factors that interviewees identified as relevant are the duration of pilots and demonstrations; the role of operators; vehicle mass, value, and passenger capacity; ADS; and operator and passenger presence.
- Vehicle ownership and operation arrangements inform which parties are insured, and how. Transit agencies may purchase or lease vehicles, or an operator or technology developer may provide vehicles as part of a contract. These arrangements will influence the specific insurance coverage for each party.
- State and local laws and regulations will influence insurance needs. Workers' compensation requirements vary from state to state. Some agencies may have local requirements to work with a firm based in their state.

Report:
Insurance and Liability for Automated Transit Buses: State of the Practice Review (Report 0192) | FTA (dot.gov)

Survey Research for Automated Shuttle Pilots: Issues and Challenges (part of Evaluation Guidance for Integrated Demonstrations)

Summary:

This project involved a scan of survey development approaches used by recent projects. It discusses considerations for the development of future surveys across three key areas: survey population, survey approach, and questionnaire design. The goal of the project was to understand how survey design choices can elicit useful data as part of a transit agency's overall evaluation approach.

High-Level Results:

Well-designed user surveys can be part of a robust demonstration and evaluation program. They can provide insight into user and non-user experiences and elicit qualitative details that complement other sources of data.

Findings:

- As with many emerging technologies, automated shuttles typically have characteristics that present evaluation challenges, particularly in testing phases where prototype vehicles may be imperfect proxies for future services.
- In some cases, these issues can be addressed through survey design choices, as discussed above and in the four example surveys cited.
- Projects exploring technologies with multiple novel aspects will benefit from carefully identifying survey objectives to elicit useful data as part of their overall evaluation approach.

Report:
Survey Research for Automated Shuttle Pilots: Issues and Challenges (Report 0193) | FTA (dot.gov)

Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research (part of Accessibility Analysis)

Summary:

The project reviewed 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 goal of this project was to understand how transit bus automation could improve accessibility needs for passengers.

High-Level Results:

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.

Findings:

- 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.

Report:
Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research (Report 0228) | FTA (dot.gov)

Considerations for Partnering on Emerging Public Transportation Technology Projects (part of Automation Policy Review)

Summary:

This research project identified challenges and lessons learned from public sector interactions with private sector technology companies on transit vehicle automation pilots and demonstrations conducted between 2018 and 2022. It explored the partnerships between public agencies and private sector companies that have been part of transit automation research, demonstrations, and deployments, with the goal of helping transit agencies apply the lessons learned and recommendations to improve future transit automation projects.

High-Level Results:

Many agencies have reported having successful and mutually beneficial relationships with their private sector partners, but other agencies have experienced numerous challenges. As transit providers continue to explore new opportunities to improve transit service, partnerships for these pilot demonstrations are likely to become more common.

Findings:

Lessons identified from the literature and by public sector interviewees regarding experiences in working with private sector partners on pilots and demonstrations of emerging technologies, include the following advice for transit agencies:

- Have realistic expectations for the technology performance, by engaging with industry, reaching out to peers, and seeing operations in a realistic environment.
- Select the most appropriate procurement strategy for the project.
- Plan for the possibilities of personnel, partner, or vendor changes.
- Understand all applicable Federal, State, and local requirements in advance.
- Plan for how data from pilots will be used and clearly establish data requirements, formats, and specifications up front.
- Understand where agency goals align—or do not align—with the partner's goals, including on branding and marketing.
- Identify priorities among goals in advance.
- Understand partners' experiences and roles in transportation operations vis-à-vis technology.
- Hold regular project partner coordination meetings.

Report:
Considerations for Partnering on Emerging Public Transportation Technology Projects (Report 0245) | FTA (dot.gov)

Interactive PowerPoint Training to Improve Safety Driver Awareness while Operating a Transit Vehicle Equipped with Driving Automation Features (part of Transit Automation User Acceptance Study and Human Factors Research)

Summary:

This research effort sought to understand whether a low-cost tool could be developed to maintain and improve driver awareness as transit agencies pilot test new technologies. With input from a transit agency, four scenarios were identified as well as three specific human factors concern areas for each scenario.

These three concern areas, referred to as modules in the training, included hazard anticipation, hazard mitigation, and attention maintenance. An interactive training program, developed in Microsoft PowerPoint, was created to test these scenarios.

High-Level Results:

Participants who piloted the interactive training program achieved a larger improvement in driver awareness after training than the control group in every module and scenario. In all scenarios, a larger gain in improvement was found for the experimental condition and no single scenario showed a noticeably larger or smaller effect, indicating that the effect of training was not dependent on a specific scenario.

Findings:

- Widely available software was used for this research effort, which transit agencies could use to easily include scenarios specific to their needs.
- The module with the largest improvement gains was the attention maintenance module.
- The overall benefit of the training was not specific to any particular module or to any particular.

Report:
Interactive PowerPoint Training to Improve Safety Driver Awareness while Operating a Transit Vehicle Equipped with Driving Automation Features (Report 0248) | FTA (dot.gov)

Integrated Demonstrations, Strategic Partnerships, and Other FTA-Sponsored Demonstrations

STAR Plan 1.0 identified multiple integrated demonstrations to explore the use cases identified. Several projects were funded across USDOT programs. Table 6 below summarizes the status of transit bus automation projects either funded or managed by FTA, as of June 2023.

Table 6: ***USDOT-Funded Transit Bus Automation Projects***

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
University of Alabama	Operation of automation technologies for large transit buses using a lab simulation environment and	Tuscaloosa, AL	$2,000,000	ADAS for Transit Buses Demonstration Program	Smooth acceleration and deceleration, AEB, precision docking, and narrow lane operations	In Planning

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
	real-world tests to demonstrate cost-effectiveness and service impacts.					
Valley Metro Regional Public Transportation Authority (Valley Metro)	Operation of an on-demand service for ambulatory paratransit users and seniors aged 65 and over for Valley Metro's RideChoice program using Waymo's Chrysler Pacifica models. Project partners include Arizona State University and Waymo.	Chandler, AZ	$250,000	Mobility on Demand (MOD) Sandbox	On-demand shared ride	Complete
Contra Costa Transportation Authority (CCTA)	Operation of automated vehicles through three real-world demonstration projects (a low-speed automated shuttle service in the Rossmoor community, an on-demand, wheelchair-accessible automated shuttle service to a regional medical center, and installation of infrastructure along a two-mile segment of the I-680 corridor). Project partners include County Connection, Verizon, AAA, Nissan, and Navya.	Contra Costa County, CA	$7,500,000	Automated Driving System (ADS) Demonstration Grants	Feeder bus service & on-demand shared ride	In Planning
Santa Clara Valley Transportation Authority	Operation of an automated bus in Mahoning Valley, OH, and Santa	Santa Clara County, CA	$2,300,000 (shared with WRTA)	Accelerating Innovative Mobility (AIM) Grant	Feeder bus service	In Planning

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
(VTA)	Clara Valley, CA using a purpose-built, common-specification prototype accessible automated electric vehicle. Project partners include WRTA, CALSTART, Transdev, and Perrone Robotics.					
Santa Clara Valley Transportation Authority (VTA)	Operation of a Local Motors Olli low-speed automated shuttle on the Veterans Affairs Palo Alto Health Care System campus.[13]	Santa Clara County, CA	$845,000	Congestion Mitigation and Air Quality (CMAQ) Improvement Program	Circulator	On Hold
Access Services of LA	Operation of an automated Dodge ProMaster van along a route in mixed traffic between a light rail station and health facility. Project partner includes LILEE Systems.	Los Angeles County, CA	$120,000	STAR Strategic Partner	Feeder bus service	Complete (Report Pending)
Colorado Department of Transportation (CDOT)	Demonstration of ADAS technology in three retrofitted vehicles (including a cutaway bus and two motor coaches) that serve critical rural transit routes.	Rural Interstate 70 and U.S. Highways 50/550 in CO	$1,253,952	ADAS for Transit Buses Demonstration Program	Smooth acceleration and deceleration, automatic emergency braking and pedestrian collision avoidance, and narrow lane/shoulder operations	In Planning
Connecticut Department of Transportation (CTDOT)	Operation of bus rapid transit service with three electric New Flyer Xcelsior CHARGE 40-foot buses on	New Britain to Hartford, CT	$2,000,000	Integrated Mobility Innovation (IMI)	Automated BRT service; platooning; precision docking	In Planning

[13] Local Motors is out of business as of January 2022.

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
	the CTfastrak dedicated busway (9 miles, 11 stations, 5 intersections) with applications including bus platooning and precision docking. Project partners include CTE, New Flyer, Robotic Research, the University of Connecticut, Edge Case Research, and the Capitol Region Council of Governments.					
Connecticut Department of Transportation (CTDOT)	Expansion of an existing FTA-sponsored transit automation program along the CTfastrak bus rapid transit corridor. The project will incorporate ADAS features to enhance safety and accessibility throughout the CTfastrak local bus network.	New Britain to Hartford, CT	$2,000,000	ADAS for Transit Buses Demonstration Program	Collision avoidance, precision docking assist, and other ADAS features	In Planning
Jacksonville Transportation Authority (JTA)	Operation of automated vehicles and other ITS systems along Bay Street in Jacksonville. The 12-15 vehicles to be used for the project are to be determined.	Jacksonville, FL	$12,500,000	Better Utilizing Investments to Leverage Development (BUILD) ($25M total, split into two parts)	Feeder bus service	In Planning
Virginia Polytechnic Institute and State University (VTTI)	Demonstration of ADAS features to enhance safety for buses.	Jacksonville, FL	$4,541,630	ADAS for Transit Buses Demonstration Program	AEB, pedestrian collision avoidance, and other ADAS features	In Planning

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
Pinellas Suncoast Transit Authority (PSTA)	Operation of a bus to perform routine bus yard tasks to be done more efficiently. The agency will implement automated parking and recall to improve bus yard operations and reallocate driver time.	Pinellas County, FL	$892,609	Automated Transit Bus Maintenance and Yard Operations Demonstration Program	Maintenance and Yard Operations	In Planning
University of Iowa	Operation of an automated Starlite Transit bus (Ford Transit 350 HD Cutaway Cab chassis) on a 47-mile rural fixed-route loop from Iowa City through rural areas and small towns. Project partners include the University of Iowa, Iowa Department of Transportation, AutonomouStuff, and Mandli Communications.	Johnson County, IA	$7,000,000	ADS Demo Grant	Circulator	Complete (Report Pending)
Regional Transportation Commission (RTC) of Southern Nevada	Operation of an automated circulator shuttle in the Las Vegas Medical District. The vehicles to be used for the project are to be determined.	Las Vegas, NV	$5,300,000	BUILD	Circulator	In Planning
Port Authority of New York and New Jersey (PANYNJ)	Pilot of motor coach buses equipped with ADAS in the Lincoln Tunnel Exclusive Bus Lane (XBL), with applications including lateral lane-keeping,	New York Metropolitan Area (NY and NJ)	$250,000	STAR Strategic Partner	Platooning and narrow lane operations	Complete

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
	merging and bus platooning. Project partners include New Jersey Department of Transportation, New Jersey Turnpike, New Jersey Transit, Southwest Research Institute, AutonomouStuff, Coach USA, and Greyhound.					
Western Reserve Transit Authority (WRTA)	Operation of an automated bus in Mahoning Valley, OH, and Santa Clara Valley, CA using a purpose-built, common-specification prototype accessible automated electric vehicle. Project partners include Santa Clara VTA and CALSTART.	Mahoning County, OH	$2,300,000 (shared with VTA)	AIM	Feeder bus service	In Planning
Lane Transit District (LTD)	Operation of an automated 60-foot articulated New Flyer bus on a 1.5-mile segment of LTD's Emerald Express Bus Rapid Transit route, with applications including lateral lane-keeping and precision docking.	Lane County, OR	$1,900,000	Vehicle Assist and Automation (VAA) Demonstration	Precision docking, narrow lane operation	Complete
Metropolitan Transit Authority of Harris County (METRO)	Operation of an electric, wheelchair-accessible cutaway bus, on a fixed-route connecting the Third Ward community and Texas Southern	Harris County, TX	$1,500,000	AIM	Feeder bus service	In Planning

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
	University to Metro buses and light rail to address first and last-mile connections. Project partners include AECOM, Phoenix Motorcars, and Perrone Robotics.					
City of Arlington, TX	Operation of four automated Lexus RX 450h SUVs and one automated wheelchair-accessible Polaris GEM e6 in an on-demand shared ride service in downtown Arlington and the University of Texas at Arlington (UTA) campus. Project partners include Via Transportation, May Mobility, and UTA.	Arlington, TX	$1,700,000	IMI	On-demand shared ride	Complete
Capital Metropolitan Transportation Authority (CapMetro)	Integration of vehicle automation in an advanced yard management system and completing heavy-duty vehicle demonstrations at an operations facility. The project includes a bus automation workforce analysis to address how bus yard automation may impact existing roles and create demand for new positions.	Austin, TX	$949,500	Automated Transit Bus Maintenance and Yard Operations Demonstration Program	Maintenance and Yard Operations	In Planning
Pierce Transit	Operation of 30 New Flyer transit buses equipped	Pierce County, WA	$1,600,000	Safety Research and Demonstration	AEB and Pedestrian Collision	Complete

Lead Agency	Project Description	Location	Funding	Funding Program	Use Case	Status
	with DCS Technologies' automated emergency braking Pedestrian Avoidance Safety System (PASS).			(SRD) Program	Avoidance (AEB not activated)	

Project and Evaluation Reports

This section captures the final project reports and evaluations to come out of the integrated demonstrations, strategic partnerships, and other FTA-sponsored demonstrations. As many of the integrated demonstrations are still active, this section only captures the final reports and evaluations from projects that have been completed.

Vehicle Assist and Automation Demonstration Report

Summary:

This project aimed to demonstrate the technical merits and feasibility of vehicle assist and automation (VAA) applications in bus revenue service. The VAA Demonstration project was carried out through the four phases of design, development, deployment, and operational tests. In the design phase, the system architecture and requirements were finalized, and test plans were generated for four levels of testing. All hardware and software components were installed on a 60-ft articulated bus during the development phase. In the deployment phase, system performance and reliability testing were conducted, first at a test track and then on an operational route in Eugene, Oregon. After operational testing without passengers, revenue service at Lane Transit District commenced.

High-Level Results:

Data from revenue service operations showed that the VAA system met its performance goals, specifically that lateral deviation was substantially smaller under automated operations than it was under manual driving.

Findings:

- Redundancy is central to the safety and reliability of the VAA system. It is critical to adopt safety standards in the design, development, and deployment process of a bus VAA system to ensure that the system is as safe as possible.
- Distinctive warning tones and dashboard lights should be utilized to warn of system failures.
- Sufficient resources must be available to develop and deploy such a system, both financially and in the way of support from management and decision-makers.
- The customer (e.g., transit agency) must be willing to provide its operational

experience, facilities for testing, and support for deploying such a system.

Report:
Vehicle Assist and Automation Demonstration Report | FTA (dot.gov)

Vehicle Assist and Automation Demonstration Evaluation Report

Summary:

The goal of this project was to present the results of an independent evaluation of the Vehicle Assist and Automation (VAA) Demonstration. The project demonstrated a proof-of-concept VAA system in revenue service operations, which included lateral control and precision docking capabilities on a segment of Lane Transit District's Emerald Express Bus Rapid Transit (BRT) system. The VAA system was evaluated in six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including customer surveys, driver surveys and focus groups, accident reports, maintenance reports, and lane position data from the VAA on-board computer system.

High-Level Results:

The VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The VAA system was widely praised by the bus operators and passengers for its precision docking at the station platforms.

Findings:

- The VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform.
- Lateral acceleration was consistently higher on several of the lane segments when the steering was under automated control.
- The Global Positioning System (GPS) was not precise enough to be used as a control technology for precision docking. Therefore, the project only included magnetic maker sensing as the primary controller, and GPS was used as a backup source of measurement and location referencing.
- Training is an important element of demonstration programs, as is incorporating feedback from operators and instructors.
- Understanding liability and indemnification requirements at the onset of a project, as well as having flexibility in procurement rules for technology research, are critical to the success of a demonstration project.

Report:
Vehicle Assist and Automation Demonstration Evaluation Report | FTA (dot.gov)

Pierce Transit Automated Collision Avoidance and Mitigation Safety Research and Demonstration Project

Summary:

The project goal was to research and facilitate the development of collision avoidance warning system (CAWS) and automatic emergency braking (AEB) system for transit buses. The project scope was revised during the project to include five parallel research tracks:

- Quantifying Contributing Factors to Transit Bus Casualty and Liability Expenses Using the NTD
- Commercialization Potential for Transit Bus Automated Collision Avoidance Warning and Emergency Braking Systems
- Developing and testing a 2D Flash Lidar Transit Bus Collision Avoidance Warning System
- Evaluating the Accuracy of Transit Bus Collision Avoidance Warning Systems
- Analyzing Unrestrained Passenger Motion During Transit Bus Braking

High-Level Results:

The report recommended that continued research and development funding for CAWS/AEB be provided by sponsoring agencies and that bus original equipment manufacturers (OEMs) and technology suppliers continue to research and develop the technology.

Findings:

- The project was not able to provide a conclusive evaluation of a CAWS/AEB system due to a number of complicating factors. Thirty CAWS/AEB systems were installed on buses but operated in a data-collection mode only.
- Lessons learned include the need for test procedures and protocols, bus OEM participation, and continued transit environment research.
- Statistical analysis of NTD data showed a reduction of 100 collisions with motor vehicles could result in a decrease in casualty and liability expenses of $4.42 million, and a decrease of 100 collisions with persons could result in a decrease of $16.7 million.
- An analysis of Washington State Transit Insurance Pool data found that 45 percent of $59.9 million in liability claims and 38 percent of injuries could potentially be mitigated if a fully tested and operational CAWS/AEB system were to be implemented and adopted. Break-even costs for CAWS/AEB ranged between $3,000 and $17,000 per vehicle.

Report:

Pierce Transit Automated Collision Avoidance and Mitigation Safety Research and Demonstration Project | FTA (dot.gov)

An Evaluation of the Valley Metro–Waymo Automated Vehicle RideChoice Mobility on Demand Demonstration

Summary:

This project developed a report of Valley Metro's pilot that used Waymo ADS-equipped vehicles as a part of Valley Metro's RideChoice program, a subsidized curb-to-curb individual mobility service (via taxi or ride-hailing services) for paratransit-certified people under the ADA and for older adults aged 65 and over living in Greater Phoenix, Arizona.

High-Level Results:

A majority of participants expressed positive feelings about the introduction of ADS-equipped vehicles, both for RideChoice services and more generally on the roads. Their expectation was that ADS-equipped vehicles would increase safety on the roads.

Findings:

- Participants felt safe, found the ADS-equipped vehicle services more convenient than typical RideChoice options, and engaged in more out-of-home activities (i.e., made new trips) as a result of the ADS-equipped vehicle option.
- Participants indicated a willingness to ride alone in ADS-equipped vehicles and to ride with family or friends. Riding with strangers in an ADS-equipped vehicle was considered the least desirable option.
- Their ratings of wait time, travel time, convenience, and comfort of the ADS-equipped vehicle option were in all cases higher than for traditional options available through RideChoice.

Report:
An Evaluation of the Valley Metro–Waymo Automated Vehicle RideChoice Mobility on Demand Demonstration | FTA (dot.gov)

Arlington Rideshare, Automation, and Payment Integration Demonstration

Summary:

This report presents the results of the Arlington Rideshare, Automation, and Payment Integration Demonstration (RAPID) project. This project integrates a shared, dynamically routed AV fleet into an existing public rideshare system in Arlington, Texas.

High-Level Results:

Over the one-year RAPID demonstration, a total of 28,140 rides were provided with no safety incidents or accidents, successfully demonstrating that an AV service could be seamlessly integrated into an existing on-demand rideshare service and that the public would accept automated rides. Customer feedback showed that riders felt safe and that they enjoyed the service. Autonomy performance improved over the course of the year as the project team and AV technology learned and adapted to the demonstration area.

Findings:

- Autonomy performance improved over the course of the year as the project team and AV technology learned and adapted to the demonstration area.
- Communication and education to riders and the public was robust, but additional outreach could have strengthened messaging to more members of the public.

Report:
Arlington Rideshare, Automation, and Payment Integration Demonstration (RAPID) (Report 0244) | FTA (dot.gov)

Lincoln Tunnel Exclusive Bus Lane Connected Automated Bus Proof-of-Concept Demonstration Project

Summary:

The Port Authority of New York and New Jersey (PANYNJ) implemented a connected automated bus proof of concept demonstration project. The goal of the project was to improve the operation of the contraflow Lincoln Tunnel exclusive bus lane (XBL) along NJ Route 495, which connects the New Jersey Turnpike and NJ Route 3 to the Lincoln Tunnel and the Port Authority Midtown Bus Terminal (MBT) in New York City.

High-Level Results:

The XBL demonstration project demonstrated the effects of connectivity and automation to determine what improvements on safety and throughput could be achieved with the application of technology on buses. Three decommissioned NJ TRANSIT MCI Coach D-45 buses were retrofitted with braking, steering, and throttle control capability to enable automated lane keeping, cooperative adaptive cruise control, and automated merging. The final report summarizes the approach, test results, the perspective of the operator, simulation modeling findings, and lessons learned.

Findings:

- The project successfully tested and demonstrated effective ADS technologies to enhance the safety, reliability, and effective capacity of the XBL.
- The three retrofitted buses were able to safely merge, maintain headway, and

keep within the lane, all while allowing the operator to switch between ADS and manual modes as needed.

Report:
Lincoln Tunnel Exclusive Bus Lane Connected Automated Bus Proof-of-Concept Demonstration Project (Report 0258) | FTA (dot.gov)

Stakeholder Engagement and Knowledge Transfer

Internal FTA Automation Research Engagements

The FTA Office of Research, Demonstration, and Innovation (TRI) engaged with numerous internal stakeholders throughout STAR Plan 1.0 implementation. This included participation in both the FTA Automated Vehicle Transit Grant Eligibility Workgroup and the USDOT Cross-Modal Automation Working Group. TRI also coordinated across modes, including the Federal Highway Administration (FHWA), ITS JPO, National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA), and Office of the Secretary of Transportation (OST), on topics related to transit automation. Further, TRI also briefed the FTA Policy Council when appropriate on the STAR Plan 1.0 work and the state of transit automation research, and it coordinated with the newly developed USDOT Highly Automated Systems Safety Center of Excellence (HASS COE) in the Office of the Assistant Secretary for Research and Technology as it relates to data.

External FTA Automation Research Engagements

Transit Bus Automation Community of Practice

FTA developed the Transit Bus Automation Community of Practice to convene pioneering agencies on the topic of transit automation to exchange best practices, lessons learned, and provide a safe space for discussion. These quarterly virtual meetings included relevant news updates, project updates, and topical presentations. The Community of Practice was composed of different agency and project types, including varying types of vehicles and expertise.

Transit Automation Research Website

An external website (Transit Automation Research | FTA (dot.gov)) was developed to share reports, case studies, fact sheets, funding opportunities, and other relevant transit bus automation information with the public. Additionally, a dedicated transit automation email address (transitautomation@dot.gov) was created for FTA to receive and respond to various inquiries and requests.

Transit Bus Automation Quarterly Updates

This publication, updated and released quarterly, highlights publicly available information on transit bus automation pilot projects, demonstrations, tests, and other activities, with a main focus on testing activities in the United States. It includes information on pilot and demonstration projects supported by USDOT funding or with external funding and transit agency participation. The Transit Bus Automation Quarterly Update publications are available at https://www.transit.dot.gov/research-innovation/transit-automation-research-resources.

Transit Automation Public Engagements

A total of 26 public engagements took place from January 2017 through July 2023 as part of STAR Plan 1.0 and its implementation. Table 7 provides the year, month, and a brief description of those engagements.

Table 7: ***FTA Transit Bus Automation-Related Public Engagements***

Year	Month	Brief Description
2017	January	Held "Transit Automation Stakeholder Workshop #1" at USDOT Headquarters following the TRB Annual Meeting
2017	June	Held "Transit Automation Stakeholder Workshop #2" webinar
2017	July	Presented preliminary research at the Automated Vehicles Symposium
2017	November	Presented research at Florida Automated Vehicle Summit
2017	December	Held webinar introducing the Strategic Transit Automation Research (STAR) Plan
2018	January	Presented preliminary research at TRB; Issued RFC on Automated Transit Buses Research Program; and Issued RFC on Removing Barriers to Transit Bus Automation
2018	May	Presented research at the APTA Bus and Paratransit Conference
2018	July	Presented research at the Automated Vehicles Symposium
2018	October	Presented research at a CALSTART Connected and Automated Transit Users Forum webinar
2018	November	Presented at an APTA Webinar on "Preparing for the Future of Transportation: AV 3.0"
2019	June	Presented research at the ITS America Annual Meeting
2019	July	Presented research at the Automated Vehicles Symposium

Year	Month	Brief Description
2019	November	Held T3 Webinar on the Transit Bus Automation Market Assessment report
2020	January	Presented research at AV America Conference on Impact of Autonomous Vehicles on public Transport
2020	July	Presented research at the Automated Vehicles Symposium
2020	August	Presented research at APTAtech 2020 Virtual Conference
2020	September	Moderated the Automated Vehicle Roundtable at the Texas Mobility Summit
2020	November	Presented research at APTA Technologies for Vehicle Automation Connectivity (TVAC) virtual subcommittee meeting
2021	January	Presented research at APTA Technologies for Vehicle Automation and Connectivity (TVAC) webinar
2021	July	Presented research at Southwest Transit Association University; Grantee presentations at TRB Automated Road Transportation Symposium (ARTS21) and AV America's conference on Autonomous Vehicles and Public Transport
2021	September	Provided recorded opening remarks and Grantee presented at Midwest Transit Conference
2022	July	Presented on "Enhancing Mobility with Automated Shuttles and Buses" and held a stakeholder listening workshop at the Automated Road Transportation Symposium (ARTS22)
2022	August	Held a stakeholder session at APTAtech
2022	November	Provided support and grantees presented at a SHOW (SHared automation Operating models for Worldwide adoption) automation and accessibility webinar hosted by UITP (Union Internationale des Transports Publics)
2023	June	Held an FTA Transit Bus Automation Convening event at USDOT Headquarters
2023	July	Hosted an Automated Road Transportation Symposium (ARTS23) breakout session on transit bus automation

Status of STAR Plan 1.0 Projects

This section lists the status of each project identified in the STAR Plan, as of April 2024, and it provides links to relevant publications, where available.

Project Name	Status	Publication (if applicable)
Automation Policy Review	Completed January 2023	Transit Bus Automation Policy FAQs, Transit Bus Automation: State and Local Policy Scan Final Report, and Considerations for Partnering on Emerging Public Transportation Technology Projects
Transit Bus Applications of Light and Commercial Vehicle Automation Technology	Completed September 2018	Transit Bus Automation Project: Transferability of Automation Technologies Final Report
Market Analysis for Automated Transit Buses and Supporting Systems	Completed October 2019, updated July 2020, September 2021, and September 2023	Transit Bus Automation Market Assessment
Transit Automation User Acceptance Study and Human Factors Research	Completed September 2022	Interactive PowerPoint Training to Improve Safety Driver Awareness while Operating a Transit Vehicle Equipped with Driving Automation Features
Hazard and Safety Analysis of Automated Transit Bus Applications	Completed April 2020	Hazard and Safety Analysis of Automated Transit Bus Applications
Test Facility Requirements for Automated Transit Vehicles	Completed February 2019	Determining Requirements for Automated Transit Bus Test Facilities: Considerations for Practitioners
Evaluation Guidance for Integrated Demonstrations	Completed December 2019	Considerations for Evaluating Automated Transit Bus Programs and Survey Research for Automated Shuttle Pilots: Issues and Challenges
Transit Automation Consortium Solicitation	Not started	
Integrated Demonstration 1: Automated ADAS for Transit Buses	In progress	
Automated Transit Labor Impacts Assessment	Not started	
Automation Policy Implementation	In progress	
Business Case for Transit Automation	Completed February 2021	Assessing Transit Providers' Internal Business Case for Transit Bus Automation
Integrated Demonstration 2: Automated Shuttles	In progress	

Project Name	Status	Publication (if applicable)
Accessibility Analysis	In progress	Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research
Integrated Demonstration 3: Automation for Maintenance and Yard Operations	In progress	
Finance Options for Automated Transit Investments	Not started	
Stakeholder Guidance Updates	Not started	
Standards Assessment and Coordination	Not started	
Integrated Demonstrations 4a, 4b, 4c: Automation for Mobility on Demand	Demo 4a: Not started Demo 4b: Not started Demo 4c: Completed July 2023	Arlington Rideshare, Automation, and Payment Integration Demonstration (RAPID)
Integrated Demonstration 5: Automated Bus Rapid Transit	In progress	
Security and Customer Acceptance Implications of Automated Transit Buses	Not started	
Transition Costs and Planning for Automated Transit Bus Deployment	Not started	
Impact on Service Patterns and Users	Not started	
Strategic Partnership: Valley Metro Regional Public Transportation Authority (Valley Metro)	Completed August 2021	An Evaluation of the Valley Metro–Waymo Automated Vehicle RideChoice Mobility on Demand Demonstration
Strategic Partnership: Port Authority of New York and New Jersey (PANYNJ)	Completed September 2023	Lincoln Tunnel Exclusive Bus Lane Connected Automated Bus Proof-of-Concept Demonstration Project
Strategic Partnership: Access Services of Los Angeles	Complete (Report Pending)	
Knowledge Transfer	In progress	Work products include the Transit Bus Automation Quarterly Updates available at Transit Automation Research Resources | FTA (dot.gov)

Conclusion

Transit bus automation research in the United States has progressed significantly since the publication of STAR Plan 1.0 in early 2018, due in part to the role of federally funded research. FTA was able to address fundamental research questions that:

- Addressed policy related questions from the industry;
- Assessed the transit bus automation market;
- Analyzed the business case for deploying transit bus automation;
- Provided evaluation guidance; and
- Helped the domestic transit bus automation market to grow through demonstration investments (e.g., number of bus OEM participants increased, number of ADS developers with transit bus applications increased).

Progress in the driving automation industry generally has been slower than initially anticipated and to some extent delays in the transit industry can be attributed to the pandemic and resulting labor, supply chain, and agency priority changes. Further research is needed to understand how these technologies can benefit public transportation in the United States and where operational or process changes may be needed in the future.

Appendix C

Literature Review

Introduction

An essential step in developing a research plan is understanding the current state of the practice. The research team conducted a literature review to identify the current level of research and development in automated transit buses in the United States and internationally. This appendix is divided into two sections: a short summary of the literature related to transit automation pilots and demonstrations and an annotated bibliography that reviews literature on the state of the practice.

The state-of-the-practice scan reviewed academic literature relevant to transit bus automation that has been published in the years since STAR Plan 1.0 was adopted. Search terms in academic journals included *transit*, *public transportation*, *shared mobility*, *Advanced Drive Assistance Systems* (ADAS), *Automated Driving Systems* (ADS), *automation*, *accessibility*, and *workforce*. The articles were selected based on their applicability to bus transit applications that do not require a fixed guideway. While the scope includes systems operating BRT service on fixed guideways, it intentionally excludes automated transit networks (ATN) and rail applications, since these do not align with the research plan goals.

Overview

- Overall, the literature is generally optimistic that automated transit bus operations could reduce operating costs vis-a-vis a traditional fixed route bus.
- The literature finds few differences between rider intentions to use automated transit compared to rider intentions to use conventional transit. Research shows that the most important factors in determining an individual's intention to use an automated transit service were service frequency, speed of service, travel time, ride comfort and smoothness, and cost to ride.
- Low-speed automated shuttle pilots in the United States have generally been deemed successful introducing the concept of automated transit bus service to the public, but the longer-term business case for such projects remains uncertain.
- At the current state of development, automated transit buses appear to be best suited to fixed routes in smaller service areas, but the applicability of door-to-door (D2D) services is expected to increase as automation technology matures.
- There is a desire from transit agencies and automated transit vendors for future pilot projects to test automation on larger, conventional transit buses, operating at higher speeds and in a variety of road and traffic conditions.

Summary of Literature

The academic literature which has been published about transit bus automation since the release of the FTA STAR Plan 1.0 can be classified into a few broad categories. Approximately one-third of the research articles summarized in the

Annotated Bibliography can be categorized as "intention-to-use" studies that attempt to gauge public acceptance of future automated transit services, while another one-third of the literature consists of hypothetical service models which attempt to demonstrate the benefits and viability of fully automated transit bus operations. The remaining one-third of the literature consists of transit automation business cases, industry surveys, and articles which summarize "lessons learned" from recent automated transit projects.

The literature review also includes closeout reports of recent transit bus automation pilot projects conducted in the United States. The majority of automated transit projects conducted in the United States since the release of STAR Plan 1.0 have consisted of pilots with low-speed shuttles operating on closed campuses or short routes on public streets or ADS-equipped light-duty vehicle used to provide shared mobility services. The final reports that have been released about these pilots after project closeout offer valuable lessons learned from low-speed automated transit vehicle pilots in the US context. The academic literature also contains studies related to pilot projects in Europe, where transit agencies have recently begun to deploy automated buses in mixed traffic.

Key Findings

The literature identified common factors that influence an individual's intention to utilize automated transit, including age, income, access to a private vehicle, and familiarity with the technology. Major service factors that potential riders consider when judging the usefulness of an automated transit service included:

- Service frequency
- Speed of service
- Travel time
- Ride comfort
- Smoothness of automated operation (e.g., braking)
- Cost to ride

The literature shows a repeated interest in cost comparison studies between fixed route and on-demand service models, but it is unclear how useful these comparisons are given the lack of cost data, as commercialized automated transit buses are not available in the marketplace.

Many studies focused on other aspects of traditional transit service that the authors assume are related to automation, such as crowding discomfort and unpredictable travel times. Riders were attracted to new automated transit services if they perceived the available information about the new service to be sufficient but were demotivated to continue using the service if the comfort was worse, frequency was lower, or travel time was longer than expected in comparison to traditional transit. In general, survey respondents that were male and who did not have access to private vehicles tended to be more likely to answer that they would regularly ride an automated shuttle and feel safe doing so than survey respondents who were female or who had access to private vehicles.

Overall, the literature indicates a positive potential for automated buses to provide first-mile/last-mile transit connections at a significantly reduced cost compared to the traditional services that operate today. However, some researchers raised accessibility concerns about the prospect of transit buses that may no longer have a human driver onboard. Respondents to several of the intention-to-use surveys in this review also stated that due to accessibility and personal security concerns, they would be reticent to use an automated transit bus service if a transit agency employee were no longer present on board the vehicle.

The reports that have been published about low-speed automated shuttle pilots in the United States detail several technical and regulatory challenges that agencies must address to implement such projects. A major hurdle is the fact that the most widely available purpose-built vehicle models do not meet Federal Motor Vehicle Safety Standards (FMVSS), because they lack required features common to most passenger vehicles (such as a steering wheel or rearview mirrors), and/or have not been evaluated for crash readiness. Thus, many pilots elected to operate only on closed campuses or private road systems (such as office parks, universities, and parking lots). However, an increasing number of shuttle pilots have been planned or implemented on public roadways in recent years, which required an FMVSS exemption.

The research consensus seems to be that automated transit buses are best suited to fixed routes in smaller service areas, which is expected to remain the case until automation technology reaches a higher degree of development. The applicability of door-to-door services will significantly increase as ADS technology matures, although D2D models will still be most effective under specific circumstances, such as serving shorter distance trips within a small service area. Although the potential road safety benefits of transit bus automation are promising, there remains relatively little published research about the potential effects of automation on the transit workforce. Automation may significantly change the transit workforce structure, but any prospective effects at this point in the development of automation technology are speculative.

Regarding the future of transit bus automation research, the literature shows a desire for future pilot projects to test automation on larger, conventional transit buses operating at higher speeds in a variety of road and traffic conditions. Although several such pilots are currently in the planning stages in the United States, they have thus far only been represented in a small subsection of the academic literature drawing from European pilots. Case studies from Europe indicate that automated transit bus developers should prioritize fitting shuttles into the existing traffic environment, rather than attempting to adapt the road infrastructure and surroundings (e.g., trimming of greenery or removal of snow) to enable the smooth operation of automated shuttles.

Annotated Bibliography

Anund, A., Ludovic, R., Caroleo, B., Hardestam, H., Dahlman, A., Skogsmo, I., Nicaise, M., & Arnone, M. (2022). "Lessons learned from setting up a demonstration site with autonomous shuttle operation—based on experience from three cities in Europe." *Journal of Urban Mobility* (Vol. 2).
This paper is based on lessons learned from setting up automated shuttle operations in three different areas in Europe: Brussels (Belgium), Linköping (Sweden), and Turin (Italy). The authors conclude that further development of these automated shuttles is vital to ensure that they operate smoothly in complex traffic situations, considering lane and road width, shared spaces, snow, dust, rain, leaves, birds, and other extant factors. Adapting the road infrastructure to enable the shuttles to run in the automated mode should be avoided; instead, the shuttle development should prioritize fitting into the existing traffic environment and ecosystem. For example, rather than needing to continuously clear moderate seasonally occurring obstruction such as snow and leaves from the roadway environment to ensure that shuttles can easily operate, the authors recommend to further develop the shuttle technology and work towards a solution that can teach shuttles not only to identify that an object is ahead, but also what the object is and whether it is necessary to act on it or carry on. To this end, artificial intelligence (AI) may be a powerful tool to be incorporated into shuttles. The paper identifies mitigation areas covering road infrastructure, weather dependent operation, season dependent operation, improvement of localization, digital infrastructure, design and working conditions, and user experience.

Badia, H., & Jenelius, E. (2021). "Design and operation of feeder systems in the era of automated and electric buses." *Transportation Research Part A: Policy and Practice* (Vol. 152, pp. 146–172).
This paper assesses the impact of vehicle automation and electrification on feeder transit design. Two operating strategies (fixed routes versus door-to-door trips) are compared, with variations of the cost structure of the service defining different scenarios of study. Automation presents the main impact on the applicability of door-to-door trips—currently, the applicability of door-to-door trips is limited due to their high operating costs, but the reduction of these costs derived from technological advancements in automation provides an opportunity to extend the implementation of this type of on-demand service. The authors conclude that automation has the potential to make door-to-door services more competitive than fixed routes under specific conditions, even for high demand densities. However, these changes would mainly occur for small areas close to transit stations where high speeds are allowed, for populations of high-income users, limited walking speeds, or a negative perception of access cost. The reduction in transit operating costs due to automation has the potential to moderate the current main limitation of door-to-door trips and improve the level of service, resulting in shorter waiting times and route lengths. However, improvements to the level of service would also occur in fixed routes via higher frequencies and wider spatial coverage, reducing the main distinctive cost of this type of operation. Thus, the authors conclude that significant impacts from transit automation will require mature technologies, small service areas, and high values of time.

Badia, H., & Jenelius, E. (2020). "Feeder Transit Services in Different Development Stages of Automated Buses: Comparing Fixed Routes versus Door-to-Door Trips." Transportation Research Procedia (Vol. 47, pp. 521–528).
This paper compares fixed-route versus door-to-door transit services to supply first/last-mile solutions in suburban areas. The results show that fixed routes remain the most efficient alternative, unless the new technology reaches a certain degree of development that allows a major reduction in operating costs. The applicability of door-to-door services will significantly increase under certain circumstances: small areas of service, short-distance trips, and high values of time.

Chee, P. N. E., Susilo, Y. O., & Wong, Y. D. (2020). "Determinants of intention-to-use first-/last-mile automated bus service." *Transportation Research Part A: Policy and Practice* (Vol. 139, pp. 350–375).
The data analyzed in this study was collected from a survey conducted in February and March of 2018 in Stockholm, Sweden, during a trial operation of a first-/last-mile automated transit bus service. The survey indicated that frequency is critical to intention-to-use a last-mile automated bus service, and that ride comfort due to technical performance is vital to keep returning users. Age, income, current travel modes, and tech awareness all influenced intention-to-use.

Chee, P. N. E., Susilo, Y. O., & Wong, Y. D. (2021). "Longitudinal interactions between experienced users' service valuations and willingness-to-use a first-/last-mile automated bus service." *Travel Behaviour and Society* (Vol. 22, pp. 252–261).
During a first-/last-mile automated bus service trial in Stockholm, Sweden, results from 185 survey respondents were available for analysis. The judging criteria of service adopters changed with increasing ride experiences. Adopters were first concerned about safety and travel time reliability, but ride comfort (e.g., braking speed and smoothness of ride) became a dominant concern to adopters with increasing ride experiences. Service expectations are differentiated along socio-demographic lines.

Coyner, K., Blackmer, S., Good, J., Lewis, P., & Grossman, A. (2021). "Low-Speed Automated Vehicles (LSAVs) in Public Transportation." *National Academies of Sciences, Engineering, and Medicine* (Transit Cooperative Research Program Report 220).
This report aims to provide public transit agencies and communities with guidance about the deployment of low-speed automated vehicles (LSAVs) as a new public transportation service and a step toward automated mobility on demand. The authors present use cases for LSAVs based on recent pilot projects in the United States and provide a checklist for planning and implementing such projects. Through a literature review, interviews, and project assessments, the authors develop practical guidance for public transit agencies on emerging LSAV technology, lessons learned from early implementations, and considerations for LSAV projects in public transportation. The report surveys a broad range of issues related to LSAVs, including current global and U.S. interest in the technology; objectives for planning and implementing LSAV services; considerations for the management, oversight, and funding of LSAV services; and current and future accessibility considerations.

Epting, S. (2021). "Ethical requirements for transport systems with automated buses." *Technology in Society* (Vol. 64).
This paper identifies areas of concern for implementing automated buses in cities. The author argues that unlike personal vehicles, buses provide some users with more than just mobility: they provide care and community, aspects of transportation that may be under-appreciated. The author advances studies on the moral dimensions of automated transit buses and employs care ethics to address mobility challenges. The author concludes that transit agencies should not fully automate all buses, because vulnerable populations require care from bus drivers to mitigate dangers that stem from some cities' designs. In turn, the author employs care ethics to advocate for the view that some human drivers should be retained because they serve in care positions that should not be replaced with fully automated systems.

Etminani-Ghasrodashti, R., Ketankumar Patel, R., Kermanshachi, S., Rosenberger, J. M., & Foss, A. (2022). "Modeling Users' Adoption of Shared Autonomous Vehicles Employing Actual Ridership Experiences." *Transportation Research Record*.
This study aims to fill gaps in current methodology by analyzing data collected from a users' survey of an automated shuttle piloted downtown and on a university campus in Arlington, Texas. Data analyses indicated that individuals with limited access to a private vehicle, low-income people, young adults, university students, males, and Asians were more likely to ride this new service. The study also highlighted the role of trip waiting time, trip purpose, and trip frequency on shared automated vehicle (SAV) adoption. The results suggested that

participants with greater access to a private vehicle were strongly interested in using private vehicles and less likely to use the ridesharing alternative, consequently they less frequently used the piloted SAV.

Goldbach, C., Sickmann, J., Pitz, T., & Zimasa, T. (2022). "Towards autonomous public transportation: Attitudes and intentions of the local population." ***Transportation Research Interdisciplinary Perspectives*** **(Vol. 13).**
This paper presents the results of an extensive online survey of students at the Rhine-Waal University of Applied Sciences (Kleve, Germany) prior to implementation of automated buses. Trust and experience had a major impact on the stated intention to ride an automated bus. The Unified Theory of Acceptance and Use of Technology (UTAUT) factors were also relevant for intention to use automated transit buses. Survey results varied with the level of oversight by an employee, although that majority of respondents' stated preference was to have a transit employee on board monitoring vehicle operations and providing customer service (even if they were not sitting in a driver's seat).

Guo, J., Susilo, Y., Antoniou, C., & Pernestål, A. (2021). "When and why do people choose automated buses over conventional buses? Results of a context-dependent stated choice experiment." ***Sustainable Cities and Society*** **(Vol. 69).**
This paper examines travelers' preferences for automated buses compared to conventional buses, using a context-dependent choice experiment model. This experiment measured the effects of context variables (such as trip purpose, travel distance, time of day, weather conditions and travel companion) on the choice of automated buses versus conventional buses. The influence of choice attributes does not vary greatly when choosing to use automated buses or choosing to use conventional buses. The results show that poor weather conditions may lower the quality and reliability of public transport service, and the probability of choosing an automated bus over a conventional bus is reduced due to such disruptions. In addition, passengers travelling for work purposes, covering long distances, or travelling with companions are more likely to choose conventional buses than automated buses.

Gurumurthy, K. M., Kockelman, K. M., & Zuniga-Garcia, N. (2020). "First-Mile-Last-Mile Collector-Distributor System using Shared Autonomous Mobility." ***Transportation Research Record*** **(Vol. 2674, Issue 10, pp. 638–647).**
Results from a simulation in Austin, Texas, show that SAVs have the potential to help solve first-mile / last-mile (FMLM) transit problems when fare benefits are provided to transit users. The first scenario uses SAVs to serve D2D trips only, and it aims to assess the impact of SAVs and demand changes on the transit system under current conditions. The second scenario uses SAVs as a collector-distributor system for Austin's transit system and provides reduced fares to incentivize usage. The last scenario combines both D2D and FMLM trips. The results of the simulation found that SAVs generally competed with traditional transit in D2D service scenarios. Restricting SAV use for FMLM trips increases transit coverage, lowers average access and egress walking distance, and shifts demand away from park-and-ride and long walk trips. When SAVs are available for both D2D use and FMLM trips, high SAV fares help maintain transit demand (indicating the need for policies to regulate SAV fares). If SAVs are widely available for D2D trips with a reduced fare, transit service demand may reduce significantly, affecting the service quality of the existing transit system.

Han, M., Dean, M. D., Maldonado, P. A., Masungi, P., Srinivasan, S., Steiner, R. L., & Salzer, K. (2019). "Understanding Transit Agency Perceptions about Transportation Network Companies, Shared Mobility, and Autonomous Transit: Lessons from the United States." ***Transportation Research Record*** **(Vol. 2673, Issue 5, pp. 95–108).**
The authors surveyed staff members from 50 transit agencies in the United States. Of the agencies surveyed, few governing boards had directed the agency to study automated transit (AT) systems (22 percent), and only three responding agencies are testing or working on bringing an automated vehicle to their locality. Further, only 24 percent of agencies had reported receiving public pressure to move toward automation. 40 percent of agencies

were aware of concerns about AT from their transit unions and drivers. A lower percent of agencies believe AT will have a negative impact on their operations than transportation network companies (TNCs) (6 percent as compared with 45 percent). Although 50 percent or more of all transit agencies, regardless of size, were considering adopting new technology because of influences of TNCs, only large agencies met the same threshold when considering how planning for AT systems had influenced them to adopt or consider adopting new technology. For small agencies, 81 percent of transit agency boards have not directed the agency to study the use of AT systems compared with 59 percent and 71 percent for medium and large agencies, respectively. The majority of agencies reported that before anticipated benefits such as attracting new riders, expanding service area, or improving peak hour service with AT systems could occur, the agency must first wait for the technology to mature to prove reliability and safety performance, and for costs of the technology to fall within an accepted range.

Haque, A. M., & Brakewood, C. (2020). "A synthesis and comparison of American automated shuttle pilot projects." ***Case Studies on Transport Policy*** **(Vol. 8, Issue 3, pp. 928–937).**
Automated shuttles have been piloted in at least 19 locations in the United States. The case study method was used to identify deployment trends. Locations of deployments varied, but six types of locations were identified. Common service characteristics were low speeds, short routes, and free fares.

Hatzenbühler, J., Cats, O., & Jenelius, E. (2020). "Transitioning towards the deployment of line-based autonomous buses: Consequences for service frequency and vehicle capacity." ***Transportation Research Part A: Policy and Practice*** **(Vol. 138, pp. 491–507).**
This paper provides a practical planning framework for automated buses operating on fixed line networks, encouraging a shift towards higher service frequency when operating automated buses. The framework is applied to a real-world pilot study in Kista, Stockholm, Sweden, and examines both simultaneous and sequential deployment scenarios for automated buses. Deployment solutions are assessed in terms of both total operator and user cost. The decision variables are vehicle capacity per line, service frequency per line, and vehicle technology per line (either manually driven or fully automated buses). The paper concludes that automated bus service has the potential to attract passengers through improved service provision.

Heikoop, D. D., Nuñez Velasco, J. P., Boersma, R., Bjørnskau, T., & Hagenzieker, M. P. (2020). "Automated bus systems in Europe: A systematic review of passenger experience and road user interaction." ***Advances in Transport Policy and Planning*** **(pp. 51–71).**
By means of a systematic review, this paper provides an overview of current state-of-the-art knowledge on the interaction between automated bus systems and riders. Results of these studies are described and discussed, and implications are made regarding future policies to be applied in this domain to safeguard safe interaction with automated bus systems.

Hub, F., Oehl, M., Hesse, T., & Seifert, K. (2023). "Supporting user experience of shared automated mobility on-demand through novel virtual infrastructure: Making the case for virtual stops." ***International Journal of Human-Computer Studies*** **(Vol. 176).**
In pick-up scenarios of shared automated mobility on-demand (SAMOD), the new concept of virtual stops (vStop) improves control and planning, and the human-machine interface (HMI) associated with it aims to increase usability for users. The authors write that a vStop goes beyond traditional ad hoc drop-off / pick-up locations for passengers and vehicles; instead, it represents a new digital organizing element which deliberately predicts, plans and controls traffic and on-demand mobility in pick-up scenarios. This paper introduces the concept of vStops and presents two user-centered online-interview studies. The objectives were to capture users' information requirements when using SAMOD and evaluate an early stage vStop HMI prototype in terms of user experience. Results show that the HMI prototype's high pragmatic quality corresponds to the user's desire for distinctive information, which becomes especially valuable to users when picked up at unfamiliar traffic locations.

Conclusions from both studies lead to initial design guidelines for a vStop HMI, which could be implemented using mobile augmented reality. The authors conclude that this paper is a starting point for user-centered HMI development for vStops, and it contributes to widespread deployment of SAMOD in the future and fosters the change towards more sustainable mobility solutions.

Johansson, M., Ekman, F., Karlsson, M., Strömberg, H., & Jonsson, J (2022). "ADAS at work: assessing professional bus drivers' experience and acceptance of a narrow navigation system." ***Cognition, Technology & Work*** **(Vol. 24, pp. 625–639).**
This study aims to develop knowledge of professional bus drivers' acceptance and experience of ADAS systems, which can greatly improve the ease and efficiency of docking at stops along a bus's route. The study was conducted on a public route in an industrial area with five different bus stops, and it allowed ten professional bus drivers to use a narrow navigation system (NNS) that could dock automatically at stops. The participants indicated high levels of trust and acceptance of the NNS, and they felt that it had multiple benefits in terms of cognitive and physical ergonomics, safety, and comfort. However, the relatively slow docking process was also expected to negatively affect transit timetables, possibly degrading headways and resulting in higher stress levels for operators. Thus, the researchers conclude that it is important to consider acceptance in terms of the operation, use, and work system levels when investigating users' experiences with ADAS in a work context.

Jung, S., Seyedi, M., & Rashid, M. (2022). "Safety Assessment of the Interaction Between the Autonomous Shuttle Bus and Vulnerable Road Users." ***National Academies of Sciences, Engineering, and Medicine*** **(Transit IDEA Project 98).**
The objectives of this research project were to identify potential safety issues regarding interactions between LSAVs and vulnerable road users (VRUs), and to evaluate the performance of LSAVs to provide practical recommendations on improving VRU safety. The project included closed-track tests of automated shuttle buses and a qualitative/quantitative analysis of the resulting data to build a safety risk assessment framework and improve the basic vehicle model; vehicle and pedestrian models to represent the motion of the vehicle and crossing pedestrian; and a field crash data analysis and safety assessment of LSAVs. The main lessons learned in this research were as follows. First, the driver must have minimum interaction with the vehicle for a fully automated low-speed vehicle. This means that the vehicle must be able to operate safely in most traffic situations without requiring driver assistance. Second, for safe operation of LSAV, sufficient knowledge and data on pedestrians are necessary—far beyond what is covered in this research. This may require inter-jurisdictional collaboration amongst State DOTs and other transit agencies. The knowledge and data can be shared to obtain critical information about the safety performance of different LSAV types in different edge case scenarios and understand the important key aspects of their ODD. Third, how road users feel safe when interacting with LSAV has a subjective nature. For example, how far away an LSAV should stop when a pedestrian is crossing in front of the vehicle highly depends on how closeness can affect the perception of comfort and safety for that specific road user. This is a challenging aspect that the developers of these technologies must address. While road users may not experience actual accidents, they can form negative opinions on LSAVs if they do not feel safe.

Lee, J., & Kockelman, K. M. (2022). "Access Benefits of Shared Autonomous Vehicle Fleets: Focus on Vulnerable Populations." ***Transportation Research Record*****.**
This paper attempts to estimate the access benefits of making SAVs available to residents of residents of Dallas-Fort Worth Metroplex. The model found that with a $0.50/mi SAV fare, private car/truck mode share would be reduced from 92.4 percent to 40.3 percent, while SAVs would take 55.8 percent of the share. Results suggest that the access benefits of SAVs will be higher in locations/neighborhoods housing more vulnerable populations, but some vulnerabilities (e.g., those over age 65) result in lower levels of access improvement.

Mahmoodi Nesheli, M., Li, L., Palm, M., & Shalaby, A. (2021). "Driverless shuttle pilots: Lessons for automated transit technology deployment." ***Case Studies on Transport Policy*** **(Vol. 9, Issue 2, pp. 723–742).**
This paper aims to synthesize the state of the art and practice in driverless shuttles. Despite numerous automated shuttle pilot programs being deployed around the world, there is a lack of comprehensive guidelines for ensuring the effectiveness of such programs in attaining reliable outcomes and insights. The objective of this paper is to synthesize lessons from automated shuttle pilot programs worldwide and develop a planning framework that will help policymakers and transit agencies facilitate the incorporation of driverless shuttles into transit systems. Over 25 completed or ongoing driverless shuttle deployments were reviewed and critiqued to identify what constitutes a successful pilot program. The authors summarize the lessons learned from previous shuttle pilot deployments and propose a planning framework for different driverless shuttle use cases. From the selected case studies, the authors deduced that the technology is still in its infancy, and they recommend that future programs consider various operating traffic and environmental conditions, as well as different route layouts and speed and headway levels, to more realistically evaluate the viability of replacing conventional buses with driverless shuttles.

Mo, B., Cao, Z., Zhang, H., Shen, Y., & Zhao, J. (2021). "Competition between shared autonomous vehicles and public transit: A case study in Singapore." ***Transportation Research Part C: Emerging Technologies*** **(Vol. 127).**
This study examines a competitive perspective in which both automated vehicle and public transit (PT) operators are profit-oriented with dynamic adjustable supply strategies in a first-mile market, to examine whether shared automated vehicles can supplement the public transportation system or compete with it. Five scenarios with different regulation levels are tested, considering factors such as whether the automated vehicle operator is allowed to change the fleet size, or whether the PT operator is allowed to adjust headways. The simulation demonstrated that supplies of automated vehicles and PT tended to concentrate both spatially and temporally, with PT services spatially concentrating to shorter routes feeding directly to the subway station and temporally concentrated to peak hours. On average, the competition reduced the travel time of passengers but increased their travel costs. However, the generalized travel cost is reduced when incorporating the value of time. In terms of system efficiency, the bus supply adjustment increased the average vehicle load and reduced the total vehicle kilometers traveled as measured by the passenger car equivalent (PCE), while the automated vehicle supply adjustment does the opposite. The results suggest that public transit should be allowed to optimize its supply strategies under specific operation goals and constraints, and automated vehicle operations should be regulated to reduce their system impacts—including potentially limiting the number of licenses, operation time, and service areas—to makes shared automated vehicles operate in a manner more complementary to the public transit system.

Mouratidis, K., & Cobeña Serrano, V. (2021). "Autonomous buses: Intentions to use, passenger experiences, and suggestions for improvement." ***Transportation Research Part F: Traffic Psychology and Behaviour*** **(Vol. 76, pp. 321–335).**
This paper focuses on the use of recently established automated shuttles running along a regular public transport line in a residential area of Oslo, Norway. Intention to use automated buses was high among study participants. Users were satisfied with the additional departures offered by automated buses. Feelings of safety during travel by automated bus were generally high, although suggestions for improvement focused on higher speeds and softer braking. Automated buses seem more applicable for areas with low speeds and low traffic.

Nemoto, E.H., Korbee, D., Jaroudi, I., Viere, T., Naderer, G., & Fournier, G. (2023). "Integrating automated minibuses into mobility systems—Socio-technical transitions analysis and multi-level perspectives." ***Technological Forecasting and Social Change*** **(Vol. 188).**
Automated driving, along with other mobility innovations, is expected to entail socio-technical changes in mobility systems. In this study, the authors analyze automated vehicles and, more specifically, automated minibuses integrated into mobility systems as a breakthrough technology through the perspective of different

stakeholder groups and citizens. Their research approach builds upon conceptual mapping and semi-structured interviews with major stakeholder groups and a large-scale survey with citizens of four European cities. The study addresses the main drivers and barriers to steering the deployment of automated minibuses to meet the mobility needs of citizens and the aims of cities towards sustainable mobility, and it identifies five main mechanisms to help pave the way to a mobility transition with automated minibuses integrated into mobility systems. The authors conclude that automated minibuses integrated into public transport and mobility as a service (MaaS) system, coupled with other niche innovations and policy instruments, can be part of the solution to pave the way towards a socio-technical transition to a new mobility paradigm.

Ng, M. T. M., & Mahmassani, H. S. (2022). "Autonomous Minibus Service with Semi-on-Demand Routes in Grid Networks." ***Transportation Research Record*****.**

This paper investigates the potential of automated shuttles that take on-demand directional routes for pick-up and drop-off in a grid network of wider areas with low density, followed by fixed routes in areas with greater demand. Mathematical formulation for generalized costs demonstrates its benefits, with indicators proposed to select existing bus routes for conversion with the options of zonal express and parallel routes. Simulations on modeled scenarios and case studies with bus routes in Chicago, Illinois show reductions in both passenger costs and generalized costs compared with existing fixed-route bus services between suburban areas and the central business district.

Nguyen-Phuoc, D.Q., Zhou, M., Chua, M.H., Alho, A.R., Oh, S., Seshadri, R., & Le, D (2023). "Examining the effects of Automated Mobility-on-Demand services on public transport systems using an agent-based simulation approach*. Transportation Research Part A: Policy and Practice* (Vol. 169).

This paper models the potential impact of shared AVs, or Automated Mobility-on-Demand (AMOD), on the public transit network in Singapore using the microsimulation platform SimMobility. Two AV adoption scenarios were simulated: "Partial Automation" in which AMOD is introduced alongside existing modes, and "Full Automation" in which the use of private human-driven vehicles is prohibited upon the implementation of AMOD. The authors found that compared to the base case in which there is no AMOD, the share of public transit usage decreased significantly in the Partial Automation scenario but increased in the Full Automation scenario. While the overall congestion level was reduced in the Full Automation scenario, the road network tended to suffer from high travel demand in the Partial Automation. The authors conclude that the temporal and spatial analyses of public transit demand between scenarios have useful implications for transportation planners on the implementation of AMOD.

Oldbury, K., & Isaksson, K. (2021). "Governance arrangements shaping driverless shuttles in public transport: The case of Barkarbystaden, Stockholm." ***Cities*** **(Vol. 113).**

Based on an understanding of automation as various technological and organizational configurations in the making, this article aims to deepen insights into the governance arrangements shaping the way that automation is being introduced in public transport. The authors analyze the introduction of automated shuttle buses in Barkarbystaden, Stockholm, Sweden, using participant observation and qualitative interviews to explore the governance arrangement forming transit automation in this case. The article's findings demonstrate how the governance arrangement transferred existing roles and responsibilities in public transit provision to the collaboration involving driverless shuttles, something which gives the bus operator a new and influential role in smart mobility in public transport. The authors conclude that there is a need for more clearly articulated policy and planning agendas clarifying the long-term public stance regarding automation in infrastructure planning, transportation planning, and smart mobility.

Patel, R. K., Etminani-Ghasrodashti, R., Kermanshachi, S., Rosenberger, J. M., & Foss, A. (2022). "Exploring willingness to use shared autonomous vehicles." *International Journal of Transportation Science and Technology*.
This study aims to identify the factors affecting the user's willingness to ride SAVs based on the data collected from a comprehensive survey distributed among users and non-users of an on-demand service pilot project using ADS-equipped SUVs called RAPID (Rideshare, Automation, and Payment Integration Demonstration) in Arlington, Texas. Using structural equation modeling (SEM), the authors identify the effects from vehicle ownership, RAPID usage, existing modes of transportation, RAPID service attributes (comfort and safety), and sociodemographic variables on individuals' willingness to use SAVs in the future. Results indicate that most riders of the RAPID service are young Asian individuals and students from low-income households with limited or no access to a private vehicle. Furthermore, SEM results show that RAPID usage directly impacts willingness to use SAVs, implying that people start developing trust for the technology with an increase in the frequency of using the service.

Peirce, S., Cregger, J., Burkman, E., Richardson, H., Machek, E., Mortensen, S., & Mahavier, K. (2019). "Assessing the Transit Agency Business Case for Partial and Full Automation of Bus Services." *Transportation Research Record* (Vol. 2673, Issue 5, pp. 109–118).
This assessment concludes that at current cost levels, ADAS capabilities such as smooth acceleration and braking, AEB, and narrow lane/shoulder operation all have favorable investment profiles. As there is overlap in the equipment required for each use case, transit agencies may find that implementing these capabilities as a package is more cost effective than any single application. Calculations for the automated maintenance yard operations use cases also showed the potential for a positive return on investment, based on the prospect of reducing labor requirements. Automated shuttle vehicles, paratransit, and BRT all have the potential for large cost savings relative to conventional service with human operators but only in scenarios without an onboard attendant.

Räth, Y.M., Balac, M., Hörl, S., & Axhausen, K.W. (2023). "Assessing service characteristics of an automated transit on-demand service." Journal of Urban Mobility (Vol. 3).
With the introduction of automated vehicles, new operating regimes for public transport services will become possible. With this in mind, the authors of this paper posit that a station-based Automated Transit on Demand service could be an attractive alternative to the current modes of transportation. In this paper, the impact of this kind of service on the modal share for the city of Zurich, Switzerland, and its surrounding area is modeled using an agent-based approach. Different scenarios regarding the operating area, pricing scheme, and a cordon charge were tested on their potential to make use of the benefits of the new service while preventing an overflow of automated vehicles in the urban core. Results showed that if left unconstrained, the proposed service could substantially impact the demand for public transit. A pricing scheme that bases the pricing of the new service relative to the accessibility of the current public transit service is a promising solution to increase the accessibility of the rural areas while maintaining a high modal share for public transit in the city center. The authors also contend that the cost coverage of the proposed transit service is potentially much higher in comparison to current public transport services.

Sadrani, M., Tirachini, A., & Antoniou, C. (2022). "Optimization of service frequency and vehicle size for automated bus systems with crowding externalities and travel time stochasticity." *Transportation Research Part C: Emerging Technologies* (Vol. 143).
This paper attempts to develop a total cost minimization model to optimize service frequency and vehicle size for automated bus systems. Crowding discomfort externalities, time-dependent demand, denied boardings, and stochastic travel times are modeled, and extensive experiments are performed for two real-life case studies in Germany and Chile, with numerical results are analyzed. The authors conclude that in the presence of crowding discomfort externalities, the frequency is increased at a higher rate for automated bus fleets than for human-

driven bus fleets. The deployment of automated bus systems can significantly mitigate crowding-related problems for users.

Sipetas, C., Roncoli, C., & Mladenović, M. (2023). "Mixed fleets of automated and human-driven vehicles in public transport systems: An evaluation of feeder line services." ***Transportation Research Interdisciplinary Perspectives*** **(Vol. 18).**
This study focuses on the transitioning period of operating mixed fleets of both automated and human-driven vehicles for public transit services. The type of service investigated here is flexible, including elements of both fixed route and on-demand systems. The operation of the mixed fleet is optimized with analytical methods leading to models for optimal service headway and stop spacing for the two types of vehicles. The authors also derive analytical models for optimal passenger capacity per vehicle and required fleet size for each type of vehicle. Four operational strategies are considered, referring to whether the two types of vehicles operate jointly or independently in terms of optimal service headway and stop spacing within the mixed fleet. Numerical analyses indicate that automated vehicles operate optimally with less frequent vehicle dispatches and more fixed stop locations compared to human-driven vehicles. They also require greater fleet size and similar passenger capacity per vehicle. The four operational strategies perform similarly in terms of total generalized costs for the input values considered. However, sensitivity analyses showed that the operational characteristics of the two types of vehicles in a mixed fleet and the performance of the four operational strategies depend significantly on the percentage of total demand that each type of vehicle serves, as well as on the automated vehicles' speed and in-vehicle travel time cost for users. The mixed fleets represent the transitioning period towards transit fleets of automated vehicles only, and the authors conclude that this will be the costliest period for both users and operators.

Tian, Q., Lin, Y. H., & Wang, D. Z. W. (2020). "Autonomous and conventional bus fleet optimization for fixed-route operations considering demand uncertainty." ***Transportation*** **(Vol. 48, Issue 5, pp. 2735–2763).**
The authors apply a mixed-integer stochastic programming approach to consider the integration of automated vehicles into bus transit systems, and they propose a modeling framework to determine the optimal bus fleet size and its assignment onto multiple bus lines in a bus service network considering uncertain demand. Numerical results demonstrate the benefits of introducing automated buses as they are flexible to be assigned across different bus service lines, especially when demand uncertainty is more significant. The introduction of automated buses would enable further reduction of the required fleets and total cost.

Villadsen, H., Lanng, D.B., & Hougaard, I. (2023). "Automated shuttles and 'negotiation in motion'—A qualitative meta-synthesis of spatial interactions with human road users." ***Transport Policy*** **(Vol. 137, pp. 23-31).**
Since automated vehicles (AVs) were first introduced in the public imagination, the stated goal of developers has been to develop vehicles that would eventually operate in diverse contexts like any other vehicle. To understand what this entails in real-life traffic, the authors extracted data regarding interactions from three separately run trials of automated shuttles in low-speed contexts with human road users in Denmark from 2018 to 2021, using a qualitative meta-synthesis approach. The underlying data consists of field observations, interviews with road users, geo-localized event registrations, video tracking data, and responses to open-ended surveys. The synthesis in this report suggests that dynamic negotiation of space and timing, handling of situational and traffic system ambiguity, and human road user learning go beyond what should simply be attributed to a transitory immaturity of the technology. Road users expect other road users to engage in a deeply social negotiation of space and timing. When AVs fail to negotiate, traffic flow is interrupted, and road users express confusion and impatience until they develop strategies to move around the shuttles.

Walk, M., Hwang, J., Kuzio, J., Sener, I., Zmud, J., Elgart, Z., Tan, S., & Davis, M. (2022). "The Impacts of Vehicle Automation on the Public Transportation Workforce." *National Academies of Sciences, Engineering, and Medicine* (Transit Cooperative Research Program Report 232).
Advancements in the automation of transit vehicles will likely have significant impacts on all aspects of transit operations. However, the possible effects of automation on the public transportation workforce are largely unknown. This is due partly to the fledgling state of transit vehicle automation, and partly to the significant amount of uncertainty about how and when automated transit services will become more prevalent. This research estimated the potential workforce effects of five transit automation use cases on five directly affected operations jobs in the transit industry: operators, dispatchers, supervisors, mechanics, and service persons. The five use cases were (1) bus automation for maintenance and yard operations, (2) automated low-speed shuttles, (3) automated bus rapid transit (BRT), (4) automated mobility on demand (MOD), and (5) automated local bus transit. Workforce effect estimates were calculated for all five use cases using a workforce effect calculator that factored in the possible changes in job tasks that would be caused by the adoption of automated transit services. Within each use case, workforce effect estimates were calculated for both a remote and in-person operational model for automated services and the partial or full adoption of the use case. Key findings included that potential job count and job description changes for bus operators (and the supervisory and training staff who work with them) will be driven largely by whether a human is kept on board every automated vehicle, while automation also has the potential to increase both the number of jobs in maintenance positions and the qualifications and technical expertise required for maintenance personnel. Front-line transit employees (e.g., operators and mechanics) had significant concerns about transit vehicle automation and were highly skeptical about potential benefits.

Young, S., & Lott, J.S. (2022). "Safe and Efficient Automated Vehicle Fleet Operations for Public Mobility." *National Renewable Energy Laboratory* (NREL) Technical Report NREL/TP-5400-83276.
This second edition of the *Automated Mobility District Implementation Catalog* provides a status update on 10 early AV technology deployment sites around the United States to assess common trends of technology development and deployment, and to document the natural maturing of the AV technology industry. This second edition also reports on the framework of "cardinal principles" that the research team defined for the safest and most efficient application of AV technology in managed fleet deployment within automated mobility districts (AMDs) of the future. The report details recent trends in the development of AV deployment for passenger service, provides updated observations and assessments of the 10 early deployment projects, and presents the authors' conclusions on the primary lessons learned and the overall principles to be applied to future implementations of AMDs.

Zhang, W., Jenelius, E., & Badia, H. (2019). "Efficiency of Semi-Autonomous and Fully Autonomous Bus Services in Trunk-and-Branches Networks." *Journal of Advanced Transportation* (Vol. 2019, pp. 1–17).
This paper proposes a cost model of bus operations considering automation technology. Generalized cost (the sum of waiting, riding, operating, and capital cost) is modeled for conventional, semi-automated, and fully-automated bus services on a generic trunk-and-branches network. In the model, semi-automated buses achieved reduced unit operating cost through automated platooning on the corridor. Results show that fully automated buses exhibit great potential through reduced operating and waiting costs, even if the additional capital cost is high, while advantages of semi-automated buses are weaker and most prominent in networks with low demand along a long corridor such as interurban networks. However, a commercial speed comparable to conventional vehicles is crucial for both levels of automation. The gains in the operating and waiting cost can be easily canceled out by the current speed level of 6 km/hour, whereas the minimum commercial speed required for successful implementation is around 12 km/hour. The results suggest that services with platooning semi-automated vehicles are of most interest in interurban rather than intraurban settings.

Zhao, X., Susilo, Y. O., & Pernestål, A. (2022). "The dynamic and long-term changes of automated bus service adoption." *Transportation Research Part A: Policy and Practice* (Vol. 155, pp. 450–463).
This paper aims to add knowledge on user acceptance of automated buses in public transport based on empirical evidence in a real-life deployment context (Barkaby, Stockholm, Sweden), using structural equation modeling to analyze the data. Initially, people were attracted to use the service if they perceived the information describing the service to be sufficient, but they were demotivated to continue using the service if the comfort was worse, frequency was lower, or travel time was longer than expected. The results show that previous experience of adopting automated buses has impacts on different attitude variables. In order to promote individuals' continued use of automated buses, the public transport authorities and operators should work closely to increase the comfort of vehicles and frequency of the service.

Zoellick, J. C., Kluy, L., Rössle, S., Witte, J., Schenk, L., Kuhlmey, A., & Blüher, S. (2021). "I'm curious, I'm open to it, I test it, I trust it! A focus groups study to understand a-priori trust in automated buses." *Transportation Research Part F: Traffic Psychology and Behaviour* (Vol. 81, pp. 55–64).
The objectives of this study are to contrast participants' naïve concepts of trust with theory and to identify underlying factors influencing a-priori trust in automated buses. Results show that focus group participants use different strategies to familiarize themselves with the new technology of automated buses, e.g., comparisons with familiar technologies, fundamental tendencies to approach or avoid, additional information seeking, or anthropomorphizing These strategies largely support existing theories on trust (development) in technology.

Transit Automation Example Projects – Final Report Summaries

City of Arlington, Texas (2018). "Milo Pilot Program Closeout Report"
The Milo pilot was conducted in partnership with EasyMile from August 2017 to August 2018. Shuttles had a maximum speed of 15 miles per hour, were wheelchair accessible, and had a capacity of up to 12 ambulatory passengers (or 10 passengers and 1 wheelchair). Although Milo ran fully autonomously, a certified operator was always on board. Rides were free of charge and operated on a pre-programmed route along off-street trails during 110 individual stadium, ballpark, and demonstration events. The lease with EasyMile for two vehicles for one year cost a total of $265,213, including vehicle set up, route programming, and operator training. The program was funded through the City of Arlington's Convention and Event Services account using tourism-based revenues.

FTA (2021). "An Evaluation of the Valley Metro–Waymo Automated Vehicle RideChoice Mobility on Demand Demonstration: Final Report"
In 2016, the Valley Metro Regional Public Transportation Authority (Valley Metro) of the Greater Phoenix (Arizona) metropolitan area was awarded a grant as part of the Federal Transit Administration (FTA) Mobility on Demand (MOD) Sandbox program. Through the grant, Valley Metro and Waymo partnered to pilot the use of Waymo automated vehicles as certified vehicles for Valley Metro's RideChoice program, a subsidized curb-to-curb individual mobility service (via taxi or ride-hailing services) for paratransit-certified people under the Americans with Disabilities Act (ADA) and for older adults aged 65 and over living in Greater Phoenix. The six-month demonstration project operated from September 15, 2019 to March 15, 2020, in a geo-fenced area of about 100 square miles. Automated vehicle rides with origins and destinations within the operational territory were offered at a $3.00 fixed fare to enrolled participants, regardless of trip length. Key findings were that participants felt safe, found the automated vehicle services more convenient than typical RideChoice options, and engaged in more out-of-home activities (i.e., made new trips) as a result of the automated vehicle option. Participants indicated a willingness to ride alone in AVs and to ride with family or friends. Riding with strangers in an automated vehicle mobility future was the least desirable option. Their ratings of wait time, travel time, convenience, and comfort of the automated vehicle option were in all cases higher than for traditional options available through RideChoice. A majority of participants expressed positive feelings about the introduction of

automated vehicles, both for RideChoice services and more generally on the roads. Their expectation was that automated vehicles would increase safety on the roads.

FTA (2022). “Pierce Transit Automated Collision Avoidance and Mitigation Safety Research and Demonstration Project Final Report”
The goal of the FTA/Pierce Transit Automated Collision Avoidance and Mitigation Safety Research and Development project was to research and facilitate development of collision avoidance warning systems/automated emergency braking (CAWS/AEB) for transit buses. The project team conducted research on five parallel tracks to address some of the challenging issues facing transit agencies, bus original equipment manufacturers (OEMs), and technology developers seeking to bring collision avoidance technology to the transit bus industry. The five parallel tracks of the project were (1) Quantifying Contributing Factors to Transit Bus Casualty and Liability Expenses Using the National Transit Database, (2) Commercialization Potential for Transit Bus Automated Collision Avoidance Warning and Emergency Braking Systems, (3) Developing and Testing a 2D Flash Lidar Transit Bus Collision Avoidance Warning System, (4) Evaluating the Accuracy of Transit Bus Collision Avoidance Warning Systems, and (5) Analyzing Unrestrained Passenger Motion During Transit Bus Braking. Research partners on these tracks included the University of Washington (UW), Veritas Forensic Accounting and Economics, DCS Technologies, Inc, and the Virginia Tech Transportation Institute (VTTI). The project did not provide a conclusive evaluation of CAWS/AEB, but it does document lessons learned and provides evidence for its applicability and potential for return on investment.

Minnesota Department of Transportation (2018). “MnDOT Autonomous Bus Pilot Project Testing and Demonstration Summary”
The Minnesota Department of Transportation (MnDOT) authorized testing and demonstration of an automated vehicle in February of 2017. MnDOT’s research into previous automated vehicle efforts in other states indicated that testing had not been completed in winter weather conditions. MnDOT also wanted to address the lack of exposure to the automated vehicle technology within the State, while increasing Minnesota’s influence in automated vehicle development nationally. MnDOT tested an automated shuttle bus supplied by EasyMile at the MnROAD facility in December 2017 and January 2018 under the direction of MnDOT staff with support from project consultants. The main demonstration took place on a closed low-volume loop, and it tested how the shuttle dealt with a variety of weather conditions, pavement conditions, and in simulated interactions with pedestrians and cyclists. Public demonstrations were also held around the state in February and April 2018. The findings of the winter weather testing indicated that the automated shuttle bus operated well under dry pavement conditions with no precipitation. The vehicle kept a safe operating distance from other vehicles, pedestrians, bicycles and other roadway obstructions on the track, performing slowdowns and stops as needed. Daytime and nighttime light conditions did not impact the shuttle performance. However, falling snow, blowing snow, or loose snow on the track was often detected as obstructions by vehicle sensors, causing the vehicle to slow down or stop to avoid a collision. Snowbanks alongside the vehicle routes also caused issues with pre-programmed paths, and compacted snow and patches of ice or slush on the track caused the wheels to slip. As the core temperature of the battery dropped significantly, automated shuttle bus operations were negatively impacted. Charging times during colder temperatures increased compared to charging times during warmer temperatures.

National Park Service (2022). “Automation in Our Parks: Automated Shuttle Pilots at Yellowstone National Park and Wright Brothers National Memorial”
In 2021, the National Park Service (NPS) launched the first-ever automated, electric shuttle pilots on any U.S. recreational public lands. These demonstrations, at Yellowstone National Park and Wright Brothers National Memorial, allowed the NPS to test the suitability of ADS on public lands and in remote locations, with long-term aims of enhancing access and encouraging visitors to take green, car-free trips to these NPS units.

The first NPS automated shuttle pilot launched at Wright Brothers National Memorial in Kill Devil Hills, North Carolina on April 20, 2021, and ran through mid-July 2021. The NPS partnered with the North Carolina Department of Transportation (NCDOT) to deploy a third-generation electric EasyMile EZ10 shuttle—named the "Connected Autonomous Shuttle Supporting Innovation" (CASSI)—to transport visitors between the Wright Brothers Visitor Center and Wright Brothers Monument. The NPS also piloted two electric Local Motors Olli shuttles at Yellowstone National Park as part of the "The Electric Driverless Demonstration in Yellowstone" (TEDDY), from early June 2021 through the end of August 2021. While the two pilots took place at different NPS sites, had different vendors, used different shuttle models, and operated on different types of routes, they had similar goals—chief among them to test and demonstrate the use of automated shuttle technologies for public use in novel operating environments, including rural/remote areas and/or recreational settings in mixed vehicle traffic movement areas, and assess how those outcomes could be applied to other Federal lands. Challenges included the need to modify the boarding areas (and the vehicles themselves) for wheelchair accessibility and modifying signage and roadway geometry to ensure smooth automated operations. Additionally, GPS and internet connectivity limitations hindered data collection and transfer in Yellowstone National Park, an issue that could also apply to many other park settings. When the technology is sufficiently advanced, NPS hopes that the use of ADS can help provide new services to visitors, especially in remote park settings where staffing is limited.

Texas Southern University (2020). "Texas Southern University Automated Vehicle Final Report"
The Texas Southern University (TSU) Automated Shuttle operated for eight months along a 0.5-mile route on the Tiger Walk, a pedestrian promenade on the campus of TSU in Houston. The automated vehicle pilot program, utilizing an EasyMile Gen 2 vehicle, commenced on June 5, 2019, and operated through February 25, 2020. The goals of the pilot were to gain insight into the operational characteristics of the automated vehicle during fair and inclement weather, acquire knowledge of battery capabilities during temperature variations (especially in the hot summer months), and assess the perspectives of riders and vehicle attendants. Service was suspended on February 25, 2020, when NHTSA issued an emergency stop on a similar EasyMile automated shuttle in Columbus, Ohio, that slightly injured a passenger. NHTSA required each automated vehicle operation to submit a safety plan prior to reauthorization of operations. Before that could occur, the City of Houston and Harris County issued stay-at-home orders on March 18, 2020, due to COVID-19 threats. TSU suspended in-person classes for the duration of the spring semester. The general findings of the automated vehicle pilot included that vehicle performance was fine during fair weather and in light rain; however, it was unable to maintain operations during heavy rain. Battery life was significantly impacted by extreme hot or cold weather that engaged the air conditioner or heater, and by use of USB ports provided within the vehicle. Acceptance from the student, faculty and staff, and visitor populations were enthusiastic, and people were generally not intimidated by the automated nature of the vehicle.

Rhode Island Department of Transportation (2022). "A Rhode Trip: Lessons for the future of mobility from the Little Roady autonomous microtransit pilot"
The Little Roady shuttle pilot was coordinated by the Rhode Island Department of Transportation (RIDOT) using vehicles provided by May Mobility, and consisted of a free daily shuttle service operated from May 2019 through June 2020 along a twelve-stop, 5.3-mile loop along the Woonasquatucket Corridor in Rhode Island. According to ridership data provided by May Mobility, the project served 42,206 unique rider trips from May 15, 2019, to March 13, 2020, averaging 141 riders per day. However, the data available under the contract signed between RIDOT and May Mobility was limited. The research team requested access to additional data needed for analysis, but ultimately no changes were made to the application programming interface (API) and changes to the monthly reports did not include sharing of additional machine-readable data. Operational challenges plagued the pilot in its early months, but reliability improved over time. Incidents were infrequent, generally not serious, and often unrelated to the AV, but RIDOT found them difficult to interpret due to data sharing challenges with the project's partners. For example, as a result of the lack of actual automated vehicle mode disengagement data from May

Mobility, RIDOT's research design relied on observations to ascertain how frequently disengagements occurred as well as the observable cause of disengagements. Automated vehicle mode reliability and use appeared to improve over the course of the pilot, but many questions remain (again due to limited data sharing from the shuttle operator). Following May Mobility's decision to end Little Roady shuttle operations in March 2020, Rhode Island Public Transit Authority (RIPTA) resumed services on the Little Roady route and continued operations in place of May Mobility until the end of the originally planned pilot period in June 2020. Ridership on the RIPTA-operated conventional shuttle was starkly lower than the May Mobility automated shuttles, averaging 176 weekly riders compared to 959 under May Mobility. RIDOT's report indicates that trialing automated vehicle technology as a form of transit in a complex urban setting may not be as easy as it is portrayed by media and by operators, and that diverging interests and perspectives call for close attention to how public-private partnerships are structured if automated transit bus deployments are to serve a public good (especially in relation to data sharing, uniformity, and transparency).

University of Michigan (2020). "Mcity Driverless Shuttle: What We Learned About Consumer Acceptance of Automated Vehicles"

The Mcity Driverless Shuttle ran from June 4, 2018, to December 13, 2019. The vehicles, manufactured by French firm Navya, are Level 4 AVs as defined by SAE. Mcity driverless shuttles were deployed on publicly operated University of Michigan roadways, enabled by an exemption from NHTSA and new Michigan automated vehicle laws. Two shuttles operated simultaneously on a one-mile loop, and they would not operate during snow and heavy rain. Riders' and non-riders' experience with the shuttle positively impacted their thinking about personal ADS-equipped vehicles, generating more interest in the technology as a result of riding in the shuttle or seeing it in operation. Riders and non-riders cited the shuttle's slow speed (10 mph on average) as a negative factor. Interestingly, the low speed appealed to some riders because they perceived the risk was lower, yet it worked against the shuttle as a practical solution to daily transportation challenges. Increasing the speed of travel was the highest-rated improvement solution for both riders and non-riders, followed by improving the route, convenience, and quantity of the stops.

US Ignite (2022). "Lessons Learned from the AV Shuttle Pilot at Fort Carson"

US Ignite deployed an automated shuttle at Fort Carson, Colorado, to advance the Department of Defense's (DoD) understanding of the latest private-sector transportation and technology solutions and how they may address safety, budgetary, and operational challenges on the post. Using a combination of AVs, smart transportation sensors, and data analytics, the project provided valuable insight on how to scale these technologies. The Mountain Express automated shuttle provided transportation services to four station stops over a 3.1-mile fixed route within the central cantonment area of the post. The pilot ran from September 16, 2020 to March 15, 2021, and served 204 passengers. The "shuttles-as-a-service" model utilized by US Ignite provides straightforward pricing options for customers and speeds up the implementation of the automated vehicle technology. While the shift towards this type of automated vehicle service creates a more viable business model for service providers, it may also result in the need for a more considerable investment from clients. Therefore, communities and DoD bases interested in deploying automated shuttles for transportation services should prepare budgets, capacity, and plans accordingly while remaining observant of ongoing automated vehicle industry trends.

Utah Department of Transportation (2021). "Utah Autonomous Shuttle Pilot Final Report"

The Utah Autonomous Shuttle Pilot, a collaboration between the Utah Department of Transportation (UDOT) and the Utah Transit Authority (UTA), provided passenger service at eight locations across Utah over a 17-month project period using a Gen2 vehicle leased from EasyMile. Each location was served for varying periods of time, ranging from a few days up to eight weeks. Operational and performance data were collected at each site, as were ridership numbers and passenger feedback. The goals of the Utah Autonomous Shuttle Program included exposing the public to connected and automated vehicle (CAV) technology, assessing the viability of the shuttle as a potential solution to creating first/last mile connections, and testing the capability and readiness of the automated shuttle to communicate with traffic signal infrastructure using vehicle-to-infrastructure (V2I) communication. Testing sites include convention centers, universities, a mixed-use development, state office complexes, and the Utah Driver's License Test Track. Having the automated shuttle at different locations throughout the State allowed 6,878 riders to experience the technology firsthand, in addition to countless others who saw or interacted with the shuttle but did not ride. Riders were also asked to take a survey. Based on the 822 survey responses, nearly all riders (98 percent) felt safe on board. In addition, 95 percent stated that they think automated shuttles could complement public transit, and 95 percent had a more positive attitude toward automated vehicle technology after riding. Challenges included securing the necessary government approvals, balancing the needs and priorities of many project stakeholders, overcoming the limitations related to CAV technology itself, and getting real-time data on the vehicle's location. There was one notable incident when a passenger was injured due to an abrupt stop by the vehicle. There were also challenges with service availability due to maintenance issues with the shuttle because there was only one vehicle available for the project. The project team learned that given the current state of the technology, the most suitable operational characteristics of a permanent shuttle route would be a dedicated right-of-way with nearby storage and charging stations. For this project, a staff member was always on board the shuttle, but for a permanent deployment to be financially viable, operations with remote staff monitoring would be needed.

Virginia Tech Transportation Institute (2022). "Automated Last Mile Connectivity for Vulnerable Road Users—Real-World Low Speed Autonomous Vehicle Deployment"

This report chronicles the deployment of an EasyMile EZ10 LSAV on a route between the VTTI campus and a nearby bus transit stop to study prospective user attitudes and acceptance regarding trust in technology, system safety, and personal security. The LSAV operated on this route within normal travel lanes and interacted with mixed public traffic that included the full range of transportation users from pedestrians to heavy vehicles. The findings of this deployment work are shared in a lesson-learned format in the hope that the knowledge gained through this research and technology deployment will inform future LSAV implementations and provide insights into how automation should be applied and regulated considering real-life usage aspects. Lessons learned for potential LSAV operators include how to manage expectations for the new technology, how to deal with operator/attendant issues, and important considerations such as rider safety, traffic impacts, data acquisition, and potential regulatory issues related the ever-evolving technology of shared automated vehicles.

City of Arlington, Texas (2018). "Milo Pilot Program Closeout Report"

The Milo pilot was conducted in partnership with EasyMile from August 2017 to August 2018. Shuttles had a maximum speed of 15 miles per hour, were wheelchair accessible, and had a capacity of up to 12 ambulatory passengers (or 10 passengers and 1 wheelchair). Although Milo ran fully autonomously, a certified operator was always on board. Rides were free of charge and operated on a pre-programmed route along off-street trails during 110 individual stadium, ballpark, and demonstration events. The lease with EasyMile for two vehicles for one year cost a total of $265,213, including vehicle set up, route programming, and operator training. The program was funded through the City of Arlington's Convention and Event Services account using tourism-based revenues.

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List of Acronyms

ADA: Americans with Disabilities Act

ADAS: Advanced Driver Assistance Systems

ADS: Automated Driving Systems

AIM: Accelerating Innovative Mobility

AMD: Automated Mobility District

AMOD: Automated Mobility-on-Demand

APTA: American Public Transportation Association

Arlington RAPID: Arlington Rideshare, Automation, and Payment Integration Demonstration Project

ARTS: Automated Road Transportation Symposium

AT: Automated Transit

ATN: Automated Transit Networks

AV: Automated Vehicle

BRT: Bus Rapid Transit

BUILD: Better Utilizing Investments to Leverage Development grant program

CASSI: Connected Autonomous Shuttle Supporting Innovation

CAV: Connected and Automated Vehicle

CAWS/AEB: Collision Avoidance Warning Systems/Automated Emergency Braking

CCTA: Contra Costa Transportation Authority

CDL: Commercial Driver's License

CIG: Capital Investment Grants Program

CMAQ: Congestion Mitigation and Air Quality

CTDOT: Connecticut Department of Transportation

D2D: Door-to-Door

DBE: Disadvantaged Business Enterprise

DoD: Department of Defense

FHWA: Federal Highway Administration

FMCSA: Federal Motor Carrier Safety Administration

FMLM: First-Mile / Last-Mile

FMVSS: Federal Motor Vehicle Safety Standards

FTA: Federal Transit Administration

HASS COE: Highly Automated Systems Safety Center of Excellence

HMI: Human-Machine Interface

Houston METRO: Metropolitan Transit Authority of Harris County

IMI: Integrated Mobility Innovation

ITS: Intelligent Transportation Systems

ITS JPO: Intelligent Transportation Systems Joint Program Office

JTA: Jacksonville Transportation Authority

LSAV: Low-Speed Automated Vehicle

LTD: Lane Transit District

MaaS: Mobility as a Service

MIC: Mobility Innovation Collaborative

MnDOT: Minnesota Department of Transportation

MOD: Mobility on Demand

MPO: Metropolitan Planning Organization

MSU: Michigan State University

NCDOT: North Carolina Department of Transportation

NHTSA: National Highway Traffic Safety Administration

NNS: Narrow Navigation System

NPS: National Park Service

NTD: National Transit Database

ODD: Operational Design Domain

OEM: Original Equipment Manufacturer

OST: Office of the Secretary of Transportation

PANYNJ: Port Authority of New York and New Jersey

PCB: Professional Capacity Building

PCE: Passenger Car Equivalent

PT: Public Transit

PTASP: Public Transportation Agency Safety Plans

R&D: Research and Development

RFI: Request for Information

RIDOT: Rhode Island Department of Transportation

RIPTA: Rhode Island Public Transit Authority

RTC: Regional Transportation Commission of Southern Nevada

SAMOD: Shared Automated Mobility on-Demand

SAV: Shared Automated Vehicle

SEM: Structural Equation Modeling

SEPTA: Southeastern Pennsylvania Transportation Authority

SHOW: UITP SHared automation Operating models for Worldwide adoption webinar

SRD: Safety Research and Demonstration program

STAR Plan: Strategic Transit Automation Research Plan

SUMC: Shared Use Mobility Center

T3: Talking Technology and Transportation webinar series

TAM: Transit Asset Management

TEDDY: The Electric Driverless Demonstration in Yellowstone

TIGER: Transportation Investment Generating Economic Recovery grant program

TNC: Transportation Network Company

TRB: Transportation Research Board

TRI: FTA Office of Research, Demonstration, and Innovation

TSU: Texas Southern University

TVAC: APTA Technologies for Vehicle Automation Connectivity subcommittee

UDOT: Utah Department of Transportation

UITP: Union Internationale des Transports Publics

UM: University of Michigan

USDOT: U.S. Department of Transportation

UTA: The University of Texas at Arlington

UTAUT: Unified Theory of Acceptance and Use of Technology

UW: University of Washington

V2I: Vehicle to Infrastructure

VAA: Vehicle Assist and Automation

VRU: Vulnerable Road User

vStop: Virtual Stop

VTA: Santa Clara Valley Transportation Authority

VTTI: Virginia Tech Transportation Institute

WRTA: Western Reserve Transit Authority

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