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Transit Bus Automation Market Assessment

PREPARED BY

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John A. Volpe National Transportation Systems Center

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

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14. ABSTRACT

Under its Strategic Transit Automation Research (STAR) Plan, the United States Department of Transportation (USDOT) Federal Transit Administration (FTA) has conducted research on conceptual ideas, prototypes, and commercially available products related to automated vehicle technologies for transit bus operations. During that time, the development and testing of driving automation systems have received enthusiastic media coverage, and that coverage has included systems that have been applied to transit buses.

In reading about transit buses equipped with driving automation systems, however, stakeholders may not always have sufficient objective information or clearly understand the difference between conceptual ideas, prototype systems, and available products. To help align expectations with reality and assist in transit agency planning, FTA published a *Transit Bus Automation Market Assessment* report in 2019, and it provided updates to the report in the form of addenda in 2020 and 2021. For this next edition of the *Transit Bus Automation Market Assessment*, FTA is releasing a standalone report that updates the report as a single document—research for this edition was conducted throughout 2022, with some additions in early 2023.

This report attempts to convey the state of transit bus automation technology in terms of its availability, capabilities, and limitations. It aims to inform FTA, transit agencies, and other transit industry stakeholders interested in understanding the market. This market assessment considers automation at all levels and a broad definition of transit bus, including a range of passenger capacities and both traditional and novel vehicle designs.

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Under its Strategic Transit Automation Research (STAR) Plan, the United States Department of Transportation (USDOT) Federal Transit Administration (FTA) has conducted research on conceptual ideas, prototypes, and commercially available products related to automated vehicle technologies for transit bus operations. During that time, the development and testing of driving automation systems have received enthusiastic media coverage, and that coverage has included systems that have been applied to transit buses.

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Executive Summary

Driving automation systems, including those developed for transit bus applications, have received enthusiastic media coverage, but stakeholders may not have sufficient objective information or clearly understand the difference between conceptual ideas, prototype systems, and available products for transit service. To help align expectations with reality and assist in transit agency planning, this market assessment report conveys the state of transit bus automation technology in terms of its availability, capabilities, and limitations. It aims to inform the Federal Transit Administration (FTA), transit agencies, and other transit industry stakeholders interested in understanding the market.

This market assessment report follows an initial T*ransit Bus Automation Market Assessment* report that FTA first published in 2019 and later updated with addenda in 2020 and 2021. This report is a standalone document that further updates and extends the content. The updated report considers automation at all levels and a broad definition of transit bus, including a range of passenger capacities and both traditional and novel vehicle designs. The company and product names included are only for illustrative purposes and do not represent an endorsement.

To gather relevant information, research staff conducted a scan of literature and met virtually with industry representatives, including bus manufacturers, suppliers, and new entrants. These efforts helped researchers learn more about current and future products, research and commercialization activities, and commercialization challenges.

Key themes from the report include the following:

- **Development and commercialization of driving automation systems for transit bus applications is still at an early stage.**
  - **System maturity** may not be as advanced as it is sometimes portrayed in media reporting or marketing materials, and systems are likely multiple years away from commercial availability or broad revenue service deployment.
  - **Cost and price estimates** are largely unavailable, highly variable, and subject to change. Costs for mature systems may be quite different than those for prototype systems.
  - **Timing estimates** for commercialization and mass production are largely unavailable and publicly announced targets may or may not be accurate predictors of actual timelines.
- **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 low volume of bus production translates to high per-unit costs for research and development (R&D), testing, and validation though some efforts are looking to overcome this challenge through larger-scale projects or joint procurement activities.
  - **Transferability** of systems from other vehicle formats (i.e., heavy-duty trucks and light-duty vehicles) is limited due to differing use cases, vehicle architectures and control systems, and other considerations.

- **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 with light-duty vehicles and next-generation shuttles.
  - **Factory installed systems** are preferred over retrofit systems and Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) developers are partnering with bus manufacturers to better integrate their systems into transit buses.
  - **Partnerships** are 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 there are more commercially available options for many systems on the market.**
  - **Powertrain technology preferences** for buses are shifting toward electrified systems, both for manually driven buses and ADS-equipped prototypes.
  - **Sensors** (e.g., camera, infrared, lidar, radar, and ultrasonic systems) continue to improve in their availability, capability, and affordability.
  - **Connectivity** technologies can potentially augment ADS in transit buses through enabling applications such as smoother braking or providing redundant signal phase information.

- **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.
  - **Bus yard automaton systems** have received increased interest in recent years and may present a simplified ODD and address specific needs for some (but not all) transit agencies.
  - **Automated bus rapid transit (BRT)** applications may also present a simplified ODD and may be an early demonstration opportunity for transit agencies that operate service on dedicated transit lanes.
  - **Driver support features** in the form of ADAS are beginning to emerge in the market and, though few systems currently have automated actuation, bus manufacturers are partnering with firms to create new systems that include automated control.
  - **Goods movement** is an application outside of transit service, but it may be seen as a more practical, near-term use case and lead some companies to prioritize ADS investments for goods movement over transit service applications.

- **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.
  - **In-vehicle unstaffed operation** is a continued area of interest for ADS developers, but it is primarily limited to light-duty vehicles and heavy-duty trucks, and applications in transit vehicles are limited.

- **Implementing driving automation systems in transit buses is a big investment and funding may be a challenge, especially as fare collection is rare for pilots and transit agencies face resource constraints while trying to meet their core missions.**
  - **Fare collection** is still a relatively uncommon feature in transit bus automation pilots, though some services are beginning to incorporate it into operations.
  - **Competing priorities** and limited resources to meet core transit agency missions may cause some organizations to postpone or cancel driving automation systems efforts.
  - **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.

Vehicle automation is a rapidly evolving field with multiple potential paths to commercialization. As a result, new technologies may be developed and

commercialized following the publication of this report; however, it is expected that progress will generally be incremental. As more information becomes available, FTA will continue to monitor developments in this area and seek to share information to keep relevant stakeholders updated.

Section 1 Introduction

Driving automation systems have generated significant interest in terms of their potentially transformational role in society. Companies are actively and extensively showcasing new concept vehicles and systems at auto shows, testing prototype Automated Driving Systems (ADS) on public roads, scaling and expanding those tests, and introducing Advanced Driver Assistance Systems (ADAS) on new production vehicles. Automation is being applied to all on-road modes of transportation, including personal vehicles, taxis, commercial trucks, and transit buses. While there has been enthusiastic media coverage regarding these new technologies, stakeholders may not have sufficient objective information to understand the difference between conceptual ideas, prototypes, and available products.

Purpose

To support the development and deployment of driving automation systems in transit buses, the United States Department of Transportation (USDOT) Federal Transit Administration (FTA) developed a five-year Strategic Transit Automation Research (STAR) Plan that outlines the agency's research agenda on automation technologies.[1] As part of the research outlined in the STAR Plan, this report discusses the state of the industry in terms of which technologies are commercially available and which are in development but may become commercially available in the near future. Some of the challenges impeding development and commercialization of ADS and ADAS for transit buses are also discussed. This report is designed to provide a realistic market assessment to inform FTA and public transportation agency decision-makers, who are the primary audiences. The information is intended to help align expectations with the current state of industry and assist transit agencies in planning the timing and scope of potential demonstration and pilot activities.

Scope

This report considers transit bus automation systems across all levels of automation (SAE Levels 0–5).[2] Although it focuses on systems with automated

[1] For more information on this work and access to the Strategic Transit Automation Research Plan, visit https://www.transit.dot.gov/research-innovation/strategic-transit-automation-research-plan-report-0116.

[2] SAE International. (2021). J3016_202104: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. SAE International Standard https://www.sae.org/standards/content/j3016_202104/. SAE Level 0 systems include both systems without any automation that provide warnings to drivers (e.g., collision warning systems) and systems that provide momentary automated control of the vehicle (e.g., AEB). Systems that provide momentary automated control of the vehicle are considered within the scope for this report, though some systems that do not include automation (e.g., products from Mobileye and Protran) are also mentioned as potential precursors to automation systems..

actuation (e.g., automated braking, steering, or throttle), it also, to some extent, addresses driver warning systems with limited or no automation. On the lower end of the automation spectrum (SAE Levels 0–2), ADAS is commonly used to describe a broad range of features, from those that provide warnings and/or momentary automated intervention (SAE Level 0), such as automatic emergency braking (AEB) or lane keeping assistance, to driver support features (SAE Levels 1 and 2), which include automation of steering (lateral) systems such as lane centering, braking and acceleration/deceleration (longitudinal) systems such as adaptive cruise control (ACC), or both. On the higher end of the automation spectrum, ADS (SAE Levels 3–5) perform the entire dynamic driving task on a sustained basis and do not require supervision from a safety driver. For Level 3 systems, a safety driver (fallback-ready user) must be present and able to respond to an ADS-issued request to intervene, but for Level 4 and 5 systems, there is no assumption that a safety driver would need to be present. In practice, while ADS systems are under development and testing as prototypes, they include safety drivers regardless of SAE level.

For the purposes of FTA's STAR Plan, "bus" is defined broadly to consider a range of passenger capacities and both traditional and novel vehicle designs. Smaller vehicles can include light-duty passenger vehicles (e.g., vans) or smaller shuttle buses. Larger vehicles can include 40-foot city transit buses (the common type used in larger transit systems) and even longer articulated buses.

To provide examples of ADAS, ADS, and buses that are being used in testing and pilot projects, this report references company and product names. These are included only for illustrative purposes and do not represent an endorsement.

Methodology

Project staff conducted a scan of literature (e.g., press releases, company websites, and other publicly available materials) on commercially available technologies and commercialization timelines for prototype technologies relevant to transit bus automation. The findings are documented in this report and were used to inform an industry outreach effort through phone interviews with representatives from various organizations, including transit bus manufacturers, driving automation system developers, transit service operators, and organizations conducting pilot projects with ADS-equipped buses. Previous editions of the *Transit Bus Automation Market Assessment* report involved outreach to additional organizations, and information from those conversations is also reflected in this report.

Report Organization

Section 2, "Market Overview," discusses relevant companies and product types along with their current market availability and future outlook. Section

3, “Selected Research and Pilot Projects,” provides background on domestic and international efforts to develop and test transit bus automation systems. Section 4, “Key Themes,” presents high-level takeaways from the research, while Section 5, “Conclusions,” offers concluding remarks, a summary of the findings, and potential implications for FTA and public transportation decision-makers.

Section 2

Market Overview

This section discusses the supply side of the market, including bus manufacturers, foundational system suppliers, and ADAS and ADS developers. Existing products are identified and described at a high level. In cases where a company does not have commercialized products but is engaged in relevant activities to develop or test automation systems, those activities are described.

Transit Bus Market

Bus transit service is provided using many types of vehicles, examples of which are described below:

- **City Transit Buses** are typically used for fixed route service with the most common size being 40 feet long, holding approximately 38 seated passengers and 25 standees. Buses that are 35 and 30 feet long are also somewhat common.
- **Articulated Buses** are also used for fixed route transit and they are typically 60 feet long. They have separate front and rear body sections that are connected by a joint mechanism. They can typically hold around 55 seated passengers and 40 standees.
- **Cutaway Buses** (also called "body-on-chassis" buses) are shorter (typically around 22 to 25 feet long) and can accommodate 12–16 seated passengers. These buses use medium-duty truck chassis with the bodies manufactured separately.
- **Motor Coaches** (also called "intercity" or "over the road" buses) are typically used for fixed route transportation between cities. They have separate luggage compartments and often have restroom facilities. They are typically 40 or 45 feet long and can seat 45–55 passengers.

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 National Transit Database (NTD).[3] Approximately 40% of those vehicles are classified as city transit buses, just over 50% are classified as cutaway buses, and the remaining 10% are split roughly evenly between articulated buses and motor coaches. Of the transit buses, approximately 75% are 40 feet or longer,

[3] 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. 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 used for intercity travel or tours).

approximately 20% are between 30 and 39 feet, with the remaining buses being shorter than 30 feet.

For context on the scale of production compared to other types of motor vehicles, prior to the COVID-19 pandemic, annual U.S. sales of heavy-duty trucks (i.e., trucks with more than 14,000 pounds gross vehicle weight) were between 400,000 and 500,000 units,[4] and annual U.S. sales of light-duty vehicles (e.g., cars, vans, pickup trucks, and sport utility vehicles) were approximately 17 million units.[5] For each bus sold in the United States, there are more than 40 heavy-duty trucks sold and approximately 1,700 light-duty vehicles sold.

For buses that are 30 feet or longer, Gillig and NFI Group (parent of New Flyer) are the two largest bus manufacturers that sell to transit agencies in the United States. Together, they represent approximately 75–80% of all buses 30 feet or longer that were identified in the NTD in recent years.[6] Other manufacturers that supply buses to U.S. transit agencies include Forest River Bus (parent of El Dorado, Champion, Goshen, Starcraft, Startrans, and other brands) and Volvo (parent of Nova Bus), which each sell 200–300 buses annually that are 30 feet or longer, as well as many smaller companies (e.g., Blue Bird, BYD, Double K, Proterra, and others), which together annually sell around 200 buses that are 30 feet or longer to U.S. transit agencies.

Many of the same companies serve the market for cutaways and buses that are shorter than 30 feet. Forest River is the largest company serving that portion of the market, providing just over 60% of all cutaways and transit buses less than 30 feet long that were identified in the NTD in recent years. The next largest firm operating in this space is Coach and Equipment Manufacturing Company, which provides just over 20% of the buses in this segment. The other companies building smaller buses have relatively low market shares (i.e., 3% or less). Gillig and New Flyer produce and sell some shorter buses, but together those two companies only account for approximately 5% of sales in this segment.

Scalability of Systems for Transit Buses

Market scale becomes an issue with respect to developing or adapting technologies for transit buses. In general, suppliers are not developing new automated driving systems primarily for transit buses because the potential addressable market is so much smaller than it is for other vehicles. Instead, suppliers typically focus on developing new technologies for light-duty vehicles first, as the relatively large market means that a successful product may make it

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

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

[6] NTD 2020, *op cit.*

into tens or hundreds of thousands of vehicles each year, allowing the company to spread its R&D costs among many vehicles.[7] After developing the initial technology, a supplier might seek to adapt it for medium-duty and heavy-duty trucks, which can be challenging as the foundational systems (e.g., steering, brakes, and powertrain) for those vehicles may differ substantially from those used in light-duty vehicles. Once the system is adapted for heavy-duty commercial trucks, the supplier may then consider working with a transit bus manufacturer to further adapt the system to function in a transit bus.

Beyond the cost of adapting a system for buses, additional testing and validation is needed each time the system is modified for a new vehicle type, so adapting existing technology for buses can be costly. Supplier firms are interested in finding opportunities to implement their technologies, but if the technology requires major changes for a new vehicle platform, it may be difficult to justify the R&D investment for relatively small markets, such as transit buses. Other challenges to employing new technologies in the transit bus market include a lack of technologies applicable to transit bus service, relatively limited interest from transit agency customers, and high levels of customization requested by transit agency customers.

The high level of customization in the transit industry results from the unique features requested by transit agencies when placing bus orders; thus, bus manufacturers adapt bus designs to meet the needs of each transit agency customer rather than producing a single, standardized bus. This lack of standardization may cause issues when integrating an automation system, as placement of components or requirements for the components themselves may need to change depending on other agency requirements, potentially requiring more testing and validation and adding more costs.

Applicability of Existing Technologies

Not all existing technologies will be applicable to transit service. While some technologies may be compatible with the foundational systems of a transit bus, the applications may not be suited to the use cases that a bus encounters. In particular, many of the SAE Level 1 or Level 2 systems currently available for heavy-duty vehicles are intended to operate at high speeds on divided highways, whereas most transit buses operate at low speeds on urban roads. Adapting those technologies for use on a transit bus, if possible, may represent a substantial R&D effort, requiring time and resources to implement.

[7] With a total sales volume of 17 million vehicles sold in the United States each year, even relatively low penetration rates of a new technology can translate to many units sold. For example, if a system was applied to half of one percent of all vehicles, it would sell more than 80,000 units for that year.

Customer Interest

Many industry representatives noted that they have heard little interest from transit agency customers regarding automation systems for transit vehicles, although a few noted a growing interest in AEB systems to help prevent collisions with other vehicles or pedestrians. The high cost of production combined with limited customer interest means that suppliers and bus manufacturers are hesitant to proactively design and introduce automation technology for transit buses. Demonstration of transit agency customer demand is needed to justify company investments. Even then, interested transit agencies may not be able to commit to a large number of equipped buses or may have a limited ability to pay for automation systems.

Technology Roadmaps

While bus manufacturers may not be installing driving automation systems in their buses yet (at least not outside of small pilot projects to test new technologies), they are talking to ADAS developers, ADS developers, and other suppliers to assess when relevant automation systems will be available. Most manufacturers are also developing or have developed internal roadmaps for future technology. These roadmaps often do not contain firm dates due to the uncertainty regarding the evolution of the technology. Compounding this uncertainty, some systems require the development and implementation of other systems before commercialization and scaling will be feasible; for example, development of an electronically actuated braking system is a prerequisite for a transit bus AEB system.

Collaboration and Partnerships

Industry coordination is in a relatively nascent stage, although some bus manufacturers are working with suppliers, transit agencies, or researchers at universities or other institutions. Relationships between bus manufacturers, suppliers, and ADAS and ADS developers are critical to testing and deployment. While companies have been quietly coordinating and collaborating for years, they have recently begun publicly announcing their partnerships. For instance, Robotic Research OpCp, LLC (RRAI), has partnerships with New Flyer and Gillig to develop and test ADAS and ADS for its buses.[8] Similarly, other bus

[8] New Flyer. (2019, May 15). *New Flyer announces Robotic Research partnership to revolutionize public transit using automated bus technology* [Press release]. https://www.nfigroup.com/news-releases/news-release-details/new-flyer-announces-robotic-research-partnership-revolutionize; and Gillig. (2022, January 10). *GILLIG and RR.AI to Partner on Next Generation Automated Vehicle Technology* [Press release]. https://www.gillig.com/post/gillig-and-rr-ai-to-partner-on-next-generation-automated-vehicle-technology.

manufacturers such as GreenPower, Phoenix Motorcars, Rampini, and Lightning eMotors have partnered with Perrone Robotics.[9]

One industry representative noted that fostering relationships with progressive transit agencies could enable more experimentation and progress. Other industry representatives suggested that greater manufacturer and supplier involvement in automation system standards through participation in committees could be beneficial for developing automation systems for transit buses, and some companies are beginning to engage in these activities through organizations such as the American Public Transportation Association (APTA).

Systems and Components Market

While some vehicle manufacturers develop certain systems in-house, much system development occurs at supplier firms, which then sell those systems to the manufacturers. These suppliers typically provide the same or similar products to multiple vehicle manufacturers, taking advantage of economies of scale and spreading fixed costs (e.g., R&D or factory tooling) across many units. Many of these suppliers offer systems and components to both light-duty (passenger cars, pickup trucks, sport utility vehicles, and vans) and heavy-duty vehicles (commercial trucks and buses). With respect to automation, most of the research, development, and commercialization activity has focused on light-duty vehicles. Multiple interviewees attributed this focus to the large market size (approximately 17 million units in recent years prior to COVID-19). At that scale, a supplier may be able to get its new system or component in a fraction of that total and sell tens or hundreds of thousands of units annually. Suppliers can provide a range of different systems, including ADAS, sensors, brake systems, and steering systems. The following subsections discuss companies offering these different systems and components.

Driver Assistance System Firms

Many firms provide ADAS for vehicles, including Aptiv, Bosch, Continental, Denso, Hella, Hitachi, Magna, Mobileye, Valeo, Veoneer, ZF, and others. ADAS can include driver warnings and alerts, such as lane departure warning (LDW), forward collision warning (FCW), and blind spot monitoring (BSM), as well as low-level automation features, such as ACC, AEB, lane keep assistance (LKA), and automated parking assistance. Some of these systems are only compatible

[9] GreenPower Motor Company. (2021, November 8). *GreenPower Motor Company Announces OEM Agreement with Autonomous Vehicle Technology Provider Perrone Robotics.* PR Newswire. https://www.prnewswire.com/news-releases/greenpower-motor-company-announces-oem-agreement-with-autonomous-vehicle-technology-provider-perrone-robotics-301418121.html; and *Lightning eMotors. (2022, May 9). Lightning eMotors Partners with Perrone Robotics to Offer Fully Autonomous Vehicle Option to Zero-Emission Fleet Customers*. [Press release]. https://lightningemotors.com/lightning-emotors-partners-with-perrone-robotics-to-offer-fully-autonomous-vehicle-option-to-zero-emission-fleet-customers/.

with light-duty vehicles, but some companies have adapted their systems for heavy-duty vehicles as well. For instance, ADAS that provide warnings from companies such as Mobileye and Protran have been installed on buses. In addition, some ADS developers may offer options for ADAS modes of operation for vehicles equipped with their ADS technology.

Sensor Firms

The types of sensors needed to support ADAS and ADS for transit buses may not differ from those used in other vehicles. Depending on the system and approach, a system could use a variety of sensors, potentially including camera, infrared, lidar, radar, and ultrasonic sensor technologies. A broad range of companies produce sensor units, and some sensors are relatively mature commodities, while others are being developed, improved, and scaled. Although the sensors may be the same, their number and placement will likely vary due to the different size and shape of the vehicle envelope, use cases addressed (e.g., lower speeds in more urban environments), and considerations unique to transit bus operations (e.g., interior sensors may be needed to monitor status, location, and intent of passengers and additional sensors may be needed to monitor non-driving tasks such as accessibility ramp deployment).

There are many companies developing sensors—some develop multiple types of sensors and some also integrate the sensors into commercialized ADAS or into prototype ADS used in testing and pilots. The list below describes how various sensors found in ADAS and ADS work and what they are used for, along with examples of suppliers that provide them.

- **Cameras** are one of the most common sensors used in ADAS and ADS. Camera systems can distinguish shapes and colors and quickly classify objects based on that information. Cameras work well in rainy conditions, but they may not work well in low-visibility conditions such as fog, snow, low-light, or glare. Within ADAS, they can enable features such as ACC, AEB, LDW, and LKA. Some systems use multiple cameras positioned in the front, sides, and rear of the vehicle, enabling a "360-degree view" that can be useful for LKA, lane centering, parking assistance, and BSM. Some firms offering camera systems include Aptiv, Bosch, Continental, FLIR Systems, Magna, Mobileye, and Valeo.
- **Radar** units are also commonly used in both ADAS and ADS. These systems emit radio waves that reflect off other objects and return to the sensor. The information on the time the wave takes to return is used to calculate distances. Radar systems are good at detecting dynamic and stationary objects, but they are not good at object classification. They are relatively unaffected by weather and operate to a good degree in snow, rain, and fog. Within ADAS, the radar unit is the default sensor for AEB, and it can enable

features such as ACC, BSM, FCW, and pedestrian detection. Some firms offering radar systems include Aisin Seiki, Analog Devices, Aptiv, Bosch, Continental, Denso, Texas Instruments, Valeo, Veoneer, and ZF.

- **Lidar** systems are less common in ADAS, but they are included in almost all ADS sensor suites. The system emits laser lights that reflect off other objects and return to the sensor. The information on the time the light takes to return is used to calculate distances. Compared to cameras, lidar performance is less affected by environmental conditions or ambient lighting, though in some cases, conditions such as precipitation, fog, smoke, or dust clouds may degrade performance. Lidar systems are good at high-definition three-dimensional (3D) modeling and can be used for object classification, but unlike cameras, they are unable to detect colors or interpret sign text. Lidar systems require a significant amount of computing power to accurately model the environment compared to other sensor types and they are relatively expensive, though the cost of a lidar unit has been decreasing over the years. Some firms offering lidar systems include Aeva, AEye, Velodyne, Cepton, Ibeo, Innoviz, Luminar, Ouster, Sense Photonics, and Quanergy.
- **Ultrasonic** sensors can be found in both ADAS and ADS sensor suites. The system emits sound that reflects off other objects and returns to the sensor. The information on the time the sound takes to return is used to calculate distances. Ultrasonic sensors are relatively inexpensive and they are unaffected by weather or lighting conditions. They work well for detecting peripheral objects (both moving and stationary) within short distances. Ultrasonic sensors have relatively short operating ranges; therefore, they are often used for object detection at low speeds (e.g., parking assistance features). Some firms offering ultrasonic sensor systems include Bosch, Continental, Denso, Hella, Panasonic, Texas Instruments, and Valeo.

Brake Firms

While brake supplier firms have focused on developing products for other vehicle formats rather than producing automated braking systems specifically designed for transit buses, some work has been done to adapt systems originally designed for heavy-duty trucks to apply them to motor coaches and transit buses. As heavy-duty vehicles, transit buses have brake systems that differ from those used in light-duty vehicles. While light-duty passenger vehicles primarily use hydraulic braking systems, transit buses use pneumatic braking systems, so automated braking systems for light-duty vehicles are not directly transferable to buses. Heavy-duty commercial trucks (i.e., Class 8 tractor-trailer vehicles) also use pneumatic braking systems, so automated braking systems designed for those vehicles may be more transferable to transit buses. However, some issues may remain such as sudden, harsh braking may create new hazards

for transit bus applications, particularly for unrestrained passengers and standees. One bus manufacturer noted that while some systems are available in Europe, electronic braking systems are not currently an option for buses in North America.

Several suppliers of brake systems for heavy-duty commercial trucks have been developing ADAS systems that include automated braking. While not all of those systems have been adapted for transit buses, some have been and they could be a starting point for transit bus AEB or other more advanced features that include automated braking functionality. Firms with commercialized automated braking systems for commercial trucks include Bendix (Wingman), Detroit Diesel (Detroit Assurance), and ZF (OnGuard):

- **Bendix** (a Knorr-Bremse subsidiary) purchased the VORAD collision warning system from Eaton in 2009 and has since developed multiple systems of its own, including Wingman Active Cruise with Braking, Wingman Advanced, and Wingman Fusion.[10] These systems combine data inputs from radar, camera, and brake systems to enable applications such as driver alerts and warnings, ACC, AEB, and other collision mitigation features. Motor Coach Industries (MCI) introduced Bendix Wingman systems in its J-Series motor coach models, enabling ACC, AEB, LDW, and traffic sign recognition features.[11]
- **Detroit Diesel** (a Daimler Truck subsidiary) has a system called Detroit Assurance, which is a radar-based (with optional windshield-mounted camera) system that interfaces with brake, engine, and transmission systems.[12] Features include AEB (full or partial braking), active side guard assist (prevents merging into vehicles in the right-hand lane on highways or turning into pedestrians or cyclists during low-speed, right turn maneuvers), ACC (down to a full stop), lane centering, LKA, and various driver warnings. The system can provide SAE Level 2 functionality in some conditions. Daimler has added some of the warning features to Mercedes-Benz and Sentra buses and motor coaches,[13] and the company is working to debut AEB and ACC in the Mercedes-Benz OC 500 bus in the second half of 2022.[14]

[10] Bendix. (2022). "Products." Accessed September 2022. http://www.bendix.com/en/products/products_1.jsp.
[11] MCI. (2022). "Advanced Driver Assistance Systems." Accessed September 2022. https://www.mcicoach.com/tools-tech/adas/.
[12] Detroit Diesel. (2022). "Detroit Assurance." Accessed September 2022. https://demanddetroit.com/assurance/.
[13] Automotive World. (2020). "Safety for all: Mercedes-Benz and Setra offering sideguard assists as retrofit solutions for both trucks, buses and coaches." Accessed May 2023. https://www.automotiveworld.com/news-releases/safety-for-all-mercedes-benz-and-setra-offering-sideguard-assists-as-retrofit-solutions-for-both-trucks-buses-and-coaches/.
[14] Mercedes-Benz Bus. (2022, April). *Extensive upgrade for the Mercedes-Benz OC 500 bus chassis: Cutting-edge technology with comprehensive safety and comfort features*. https://www.mercedes-benz-bus.com/en_CY/brand/news/2022/extensive-upgrade-mercedes-benz-oc-500-cutting-edge-technology.html

- **ZF** acquired the brake system supplier WABCO in 2020,[15] along with its family of driver assistance systems under the OnGuard brand (OnGuardACTIVE and OnGuardMAX).[16] Its products include features such as AEB (for both moving and stationary vehicles and pedestrians), ACC, and LKA, as well as warning systems for lane departure, following distance, excessive speed, and impending collisions. ZF has a collision mitigation system for city buses that builds on the OnGuardMAX system and offers performance tailored to city bus applications.[17] The system combines camera and radar inputs to enable FCW and AEB features to prevent collisions with vehicles, bicyclists, and pedestrians.

In general, applications for commercial trucks include warnings for following distance and collisions as well as automated actuation for ACC and AEB. Each system supports different types of warnings and operates within different parameters. The currently available systems have minimum speed limitations (e.g., 15 or 20 mph). These limits may need to be adjusted for some bus applications, which depending on the use case being considered may need braking functionality at lower speeds. Early adaptations of these systems from truck to bus platforms have focused on motor coaches, which generally operate in environments similar to those of heavy-duty commercial trucks (i.e., higher-speed highways) and may not have standees. Additional work may be necessary to further adapt these systems to city transit buses, though that transition is already beginning for some systems.

Steering Firms

Companies have developed automated steering systems that can be used in transit buses, but due to the limited durability and reliability of currently available systems, they may not meet bus manufacturer requirements for commercialized products. As with brake systems for heavy-duty commercial trucks, steering systems in heavy-duty vehicles differ from those in light-duty vehicles. Heavy-duty vehicles such as transit buses and commercial trucks use hydraulic steering systems because current electric power steering systems cannot provide adequate torque on larger vehicles. Several suppliers such as Bosch, Knorr-Bremse (including acquisitions of Bendix, tedrive, and R.H. Sheppard Co.),[18] Nexteer, and ZF (including acquisitions of WABCO and TRW) have commercialized

[15] ZF. (2020, May 29). *ZF Completes WABCO Acquisition*. [Press release]. https://press.zf.com/press/en/releases/release_16832.html.

[16] ZF. (2022). "OnGuard Collision Mitigation System." Accessed September 2022. https://www.zf.com/products/en/cv/products_64563.html.

[17] ZF. (2022, April 25). *Advancing City Safety: ZF Presents New Collision Mitigation System for City Bus Applications*. [Press release]. https://press.zf.com/press/en/releases/release_37952.html.

[18] Knorr-Bremse. (2016, September 12). *Entering the steering systems business: Knorr-Bremse completes takeover of tedrive Steering*. [Press release]. https://www.knorr-bremse.com/remote/media/documents/press/press_releases/2016_1/25_2016_tedrive_closing/KB_262016_tedrive_closing_e.pdf; and Knorr-Bremse. (2020, June 2). *Knorr-Bremse completes acquisition of R.H. Sheppard Co., Inc.: The acquisition is a major step towards becoming a leading global manufacturer of steering systems for commercial vehicles*. [Press release]. https://www.knorr-bremse.com/remote/media/documents/press/press_releases/2016_1/25_2016_tedrive_closing/KB_262016_tedrive_closing_e.pdf. https://www.knorr-bremse.com/en/media/press-releases/knorr-bremse-completes-acquisition-of-r-h-sheppard-co-inc-the-acquisition-is-a-major-step-towards-becoming-a-leading-global-manufacturer-of-steering-systems-for-commercial-vehicles.json

steering products to create electro-hydraulic power steering systems, which allow the electronic actuation of heavy-duty vehicle steering systems. The proposed solutions range from adding a torque overlay on the steering column or on the large hydraulic gear to electronically manipulating the rotary valve with a motor or electro-magnetic actuator. These systems are used in medium- and heavy-duty trucks to provide ADAS features such as lane keep assistance and lane centering. As with automated braking systems, the currently available heavy-duty vehicle solutions are geared toward higher-speed use cases and may not be applicable to some of the lower-speed use cases of transit buses.

Automation Systems Market

Development of driving automation systems for transit buses has been gradual and while ADAS with low levels of automation are becoming available, they are not widely installed. ADS that are capable of providing higher levels of automation are not yet commercially available and to the extent that they currently exist, they can be considered to be prototypes. The following subsections discuss the state of ADAS and ADS for buses, low-speed shuttles, and light-duty vehicles intended for transit service.

Transit Bus ADAS

The transit bus ADAS that are currently commercialized provide warnings and alerts but do not include automated control of foundational systems (e.g., steering, acceleration, deceleration, and braking).[19] To the extent that ADAS with automated control of foundational systems have been applied to buses, they are largely based on similar systems previously developed for and installed in other heavy-duty vehicles (i.e., commercial trucks). Most commonly, those systems enable features such as ACC, AEB, and lane keeping. When adapting those systems for buses, companies have started with motor coach and school bus formats.

While a few commercialized transit bus ADAS features exist in the United States (e.g., driver warning and alert features), they do not include automated actuation of foundational systems. One such system, Mobileye Shield+, provides audio and visual alerts to warn the driver to react quickly to avoid a collision.[20] Another similar ADAS, Protran Blind Spot Awareness, provides audio and visual warnings to the bus driver when an object is detected in the blind spot area of the bus.[21] Protran also offers Safe Turn Alert 2.0, which provides audio and visual alerts to pedestrians and cyclists at crosswalks when a bus is making

[19] One industry representative noted that components for automated steering that meet bus manufacturer requirements for buses are not yet available in the United States.
[20] Mobileye. (2022). "Mobileye Shield+." Accessed October 2022. https://www.mobileye.com/us/fleets/products/mobileye-shield-plus/.
[21] Protran Technology. (2022). "Bus Safety." Accessed October 2022. https://www.protrantechnology.com/bus-safety.

visual alerts to pedestrians and cyclists at crosswalks when a bus is making a turn. Lytx also offers its DriveCam system, which provides audio alerts for following distance and lane departure.[22] Warning systems such as those offered by Mobileye, Protran, and Lytx have been piloted by transit agencies and are commercially available.

Outside of city transit buses and cutaway buses, Bendix Wingman Fusion system, which has largely been used in commercial trucks, has been applied to motor coaches.[23] That system includes features such as adaptive cruise control with braking, braking for avoidance of collisions with stationary vehicles, collision mitigation, and alerts for following distance, stationary objects, and lane departure.

In Europe, ADAS features for transit buses have begun to be commercialized. For instance, ZF has announced its Collision Mitigation System for city bus applications.[24] The system has active braking to help avoid head-on crashes with other road users, including vehicles, bicycles and pedestrians. The ZF press release notes that the system also helps counteract the negative impacts of sudden braking on passengers. MAN also offers ADAS features for motor coaches including adaptive cruise control, driver behavior monitoring and alerts, emergency automated braking, and driver alerts for lane keeping.[25]

As with ADAS for other vehicle formats, driver monitoring systems (or driver attentiveness systems) are important in ensuring that drivers remain alert and engaged in the driving task. Such systems have been improving in their capabilities, though they may need further development and customization to be adapted for transit bus operations.

A transit bus manufacturer identified lack of performance information for insurance purposes as a challenge to adopting transit bus ADAS. It noted that demonstrating the capability of ADAS to reduce the number of accidents, damage to property, and liability could allow for reduced insurance rates.

Transit Bus ADS

While much of the ADS development has focused on light-duty vehicles and commercial trucks, some developers have either focused specifically on ADS for transit buses or have adapted their ADS to apply it to transit buses. Although some systems are used on public roads in limited operations, all

[22] Lytx. (2022). "Intelligent fleet safety solutions powered by video." Accessed November 2022. https://www.lytx.com/en-us/fleet-management/fleet-safety.
[23] MCI, *op cit*.
[24] ZF Group. (2022, April 25). *Advancing City Safety: ZF Presents New Collision Mitigation System for City Bus Applications*. [Press release]. https://press.zf.com/press/en/releases/release_37952.html.
[25] MAN. (2022). "Increased Safety on the Road with MAN Assistance Systems." Accessed October 2022. https://www.man.eu/de/en/bus/assistance-systems/overview/man-assistance-systems-overview.html.

ADS for road vehicles are better considered as prototypes in pilots rather than commercialized products 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 more recent. The highest profile pilots in the United States have either begun in the past year or will begin in 2023 or later.

Examples of ADS developers working to test and pilot ADS-equipped buses in the United States include ADASTEC, Perrone Robotics, RRAI, and Southwest Research Institute (SwRI). RRAI announced partnerships with both New Flyer and Gillig to develop ADS and ADAS for 40-foot transit buses.[26] Perrone Robotics is working to install its ADS on shorter buses from GreenPower Motor Company, Lightning eMotors, Phoenix Motorcars, and Rampini. ADASTEC has applied its ADS to buses from Karsan,[27] which are designed for European markets. The company has received a waiver from the National Highway Traffic Safety Administration (NHTSA) to import and test one of the buses in Michigan. It is also in the process of identifying a domestic bus manufacturing partner to provide buses that comply with all relevant regulations for operating the United States. SwRI has applied its ADS to motor coaches [28] and to a 14-passenger cutaway bus.[29]

All ADS-equipped buses operated in the United States have used an onboard safety operator. Operations to date have not included charging fares to riding customers, although there are plans to operate ADS-equipped transit buses in revenue service soon as part of pilots currently planned.

A transit bus manufacturer identified a lack of minimum safety performance standards or best practices for ADS as a challenge. Such resources could help align expectations among project partners. Currently, various stakeholders may have different expectations leading up to the launch of pilots and demonstrations, which could cause confusion or miscommunication.

[26] RRAI. (2021, February 1). *New Flyer unveils its automated bus. A cooperation with Robotic Research*. https://rr.ai/news/new-flyer-unveils-its-automated-bus-a-cooperation-with-robotic-research; and Allinson, M. (2022, January 11). *Gillig and Robotic Research partner to develop autonomous buses*. Robotics & Automation News. https://www.gillig.com/post/gillig-and-robotic-research-partner-to-develop-autonomous-buses.

[27] Karsan. (2021, November 19). *The US Expansion of Karsan Continues with Autonomous E-ATAK!* [Press release]. https://www.karsan.com/en/press/current-news/the-us-expansion-of-karsan-continues-with-autonomous-e-atak-en.

[28] Port Authority NY NJ. (2019, December 12). *Port Authority Board Approves Demonstration Program to Test Groundbreaking Technology for Increasing Bus Capacity in the Lincoln Tunnel Exclusive Bus Lane*. [Press release]. https://www.panynj.gov/port-authority/en/press-room/press-release-archives/2019_press_releases/port-authority-board-approves-demonstration-program-to-test-grou.html.

[29] Wessling, B. (2022, August 10). *SwRI deploys autonomous shuttle for campus tours*. The Robot Report. https://www.therobotreport.com/swri-deploys-autonomous-shuttle-for-campus-tours/.

Low-Speed Shuttles ADS

In addition to traditional transit buses, smaller automated shuttles are becoming more widely available for early pilot testing and demonstrations. Although numerous demonstrations and pilot projects feature these new types of vehicles, they are not currently produced at scale and many models do not comply with federal requirements such as the Federal Motor Vehicle Safety Standards (FMVSS) and the Americans with Disabilities Act (ADA). In addition, most automated shuttles are limited to carrying relatively few occupants and operating at low speeds (with typical maximum operating speeds of 10–12 miles per hour), which may preclude many transit use cases. As a result of these challenges, most automated shuttle customers to date have purchased or leased vehicles for research purposes rather than to operate a service to meet an existing transportation need. While some companies have exited this space, others are doubling down to create new shuttle models that address the challenges faced by previous designs.

Companies that have produced and operated novel design automated shuttles include 2getthere, Aurrigo, EasyMile, Local Motors, and Navya. However, some of these companies have either reduced pilot activities or ceased operations altogether. Some have also applied their ADS to small, low-speed electric vehicles (called "low-speed vehicles" in FMVSS No. 500) to create automated shuttles, such as Auro Robotics, May Mobility, Optimus Ride, Perrone Robotics, and RRAI. However, most of those efforts have ended as the companies have ceased work with automated shuttles (Auro Robotics and Optimus Ride) or moved on to other platforms (May Mobility and RRAI). Perrone Robotics still works with Waev GEM shuttles[30] and Tropos Motors electric vehicles, although it is also working with other larger bus platforms.

While shuttle developers occasionally staff and operate automated shuttle pilots, they often contract with other companies to plan service, map operating environments, conduct operations, and perform shuttle service and maintenance. Companies that have filled this role include Beep, Transdev, First Transit, Keolis, RATP Dev, and Via.[31] As with ADS-equipped buses, ADS-equipped shuttles providing rides to the public in the United States have used onboard safety operators, though some unstaffed testing has occurred in closed test environments. In Europe, some shuttle services offer unstaffed

[30] In January 2022, Polaris Inc. sold its GEM brand to Waev Inc.

[31] In October 2022, Transdev signed an agreement to purchase First Transit and the acquisition was completed in March 2023. Transdev. (2022, October 26). *Transdev to Acquire First Transit to Deliver Safe, Sustainable, and More Innovative Solutions to Communities*. Newsroom. https://transdevna.com/news/2022/10/26/transdev-to-acquire-first-transit-to-deliver-safe-sustainable-and-more-innovative-solutions-to-communities/; and Transdev. (2023, March 7). *Transdev Completes Acquisition of First Transit to Become Leading Private Operator of Transportation in the U.S*. Newsroom. https://transdevna.com/news/2023/03/07/transdev-completes-acquisition-of-first-transit-to-become-leading-private-operator-of-transportation-in-the-u-s/.

service to riders. Few if any low-speed shuttle pilots have charged fares to riding customers.

During the past year, the automated shuttle landscape has begun transitioning. Some companies have exited the market and while new shuttle projects are still being announced, pilot and demonstration announcements are occurring less frequently. In addition, some companies have transitioned from shuttle formats to more traditional vehicle formats. Examples of recent changes include:

- **Exiting the market:** In January 2022, Local Motors shut down[32] and Optimus Ride discontinued its shuttle operations as part of an acquisition deal with Magna.[33]
- **Announcing fewer shuttle projects:** Some of the high-profile EasyMile shuttle pilots have concluded,[34] but there have been few new U.S. EasyMile shuttle activities announced.
- **Transitioning to traditional vehicles:** May Mobility previously worked with Polaris GEM shuttles but has largely transitioned to Lexus RX450h models[35] and is now transitioning to Toyota Sienna models. It had retained a few Polaris GEM shuttles as a wheelchair-accessible option, but May Mobility transitioned to Toyota Sienna models in 2022 for wheelchair-accessible rides.[36]

At the same time, multiple companies have announced efforts to create a new generation of novel design shuttles. Those new models will comply with some of the regulatory requirements (e.g., FMVSS, ADA, and Buy America) that have proven challenging for previous automated shuttles. In February 2022, Benteler, Beep, and Mobileye announced an effort to develop automated electric shuttles designed to meet automotive industry and safety standards,[37] with plans to

[32] Bellan, R. (2022, January 13). *Local Motors, the startup behind the Olli autonomous shuttle, has shut down*. Tech Crunch. https://techcrunch.com/2022/01/13/local-motors-the-startup-that-created-the-olli-autonomous-shuttle-has-shutdown/.

[33] Magna. (2022, January 11). *Magna Adds More Than 120 Engineers, Strengthens ADAS Capabilities*. [News release]. https://www.magna.com/docs/default-source/2022-press-and-news-releases/magna-news-release__optimusride-final_.pdf?sfvrsn=9bf7f3c8_2.

[34] WSP. (2021). *Utah Autonomous Shuttle Pilot*. Final Report. http://www.avshuttleutah.com/pdfs/UtahAutomatedShuttle_FinalReport_1-3-2022.pdf; Colorado Smart Cities Alliance. (2022). "Autonomous Vehicles in Colorado." Accessed September 2022. https://www.avco.city/; and Cregger, J., K. Mahavier, A. Holub, E. Machek, T. Crayton, R. Patel, and S. Suder. (2022). *Automation in Our Parks: Automated Shuttle Pilots at Yellowstone National Park and Wright Brothers National Memorial*. National Park Service. https://www.nps.gov/subjects/transportation/upload/NPS-Automated-Shuttle-Pilots-Evaluation-Report.pdf.

[35] May Mobility. (2021, January 19). *May Mobility launches Lexus-based shuttle*. [Press release]. https://maymobility.com/may-mobility-launches-lexus-based-shuttle/.

[36] May Mobility. (2022, April 21). *May Mobility advances AV accessibility, leads industry with development of first ADA-compliant Toyota Sienna Autono-MAAS*. [Press release]. https://maymobility.com/may-mobility-advances-av-accessibility-leads-industry-with-development-of-first-ada-compliant-toyota-sienna-autono-maas/.

[37] Intel. (2022, February 14). *Autonomous Movers Set for US Launch in 2024*. [Press release]. https://www.intel.com/content/www/us/en/newsroom/news/autonomous-movers-set-for-us-launch-in-2024.html#gs.d4f464.

begin production in 2025 under the new brand, Holon (shown in Figure 2-1).[38] Beep also partnered with ZF and plans to begin production of a novel design shuttle in 2025 (shown in Figure 2-2).[39] Both Holon and ZF vehicles aim to be accessible and capable of higher speeds than previous novel design shuttles. Both companies also plan to build the shuttles in the United States. In July 2022, May Mobility announced it would work to integrate its ADS into the Toyota e-Palette shuttle in coming years.[40] Also in July 2022, Zoox announced that it had self-certified its purpose-built, automated, electric shuttle vehicle as complying with FMVSS requirements.[41]

Figure 2-1 *Concept images of Holon shuttles*
Photo Credit: Beep

[38] Benteler. (2023, January 4). *The Autonomous Mover for Everyone: World Premiere of Holon Vehicle at CES 2023*. [Press release]. https://www.benteler.com/en/press-media/news-and-press-releases/detail/The%20autonomous%20mover%20for%20everyone:%20World%20premiere%20of%20HOLON%20vehicle%20at%20CES%202023/.
[39] ZF. (2023, January 4). *ZF announces partnership with mobility provider Beep to bring new-generation autonomous Level 4 shuttle to U.S. market*. [Press release]. https://press.zf.com/press/en/releases/release_49664.html.
[40] May Mobility. (2022, July 12). *May Mobility closes $111 million series C funding, begins preliminary development on Toyota's next generation mobility platform*. [Press release]. https://maymobility.com/category/press-releases/.
[41] Zoox. (2022, July 22). *The next step on our journey to public roads*. Journal. https://zoox.com/journal/self-certification/.

Figure 2-2 *Concept image of the ZF shuttle*
Photo Credit: Beep

Not all efforts are focused on FMVSS-compliant vehicles, however. Cruise and General Motors have been working toward operating the novel designed Cruise Origin shuttle and early in 2022, they filed a petition seeking approval from the NHTSA to put it into commercial service.[42] It is unclear whether the next generation of automated shuttles will overcome all the challenges the previous generation struggled with, but based on recent industry announcements work will continue on novel designed automated shuttle vehicles.

Light-Duty Vehicle ADS

Shared rides in light-duty passenger vehicles have become more common. In many cases, transit agencies are considering partnerships with transportation network companies (TNCs) such as Uber and Lyft to augment service with on-demand rides.[43] While both Uber and Lyft have both sold their ADS divisions (respectively to Aurora and Toyota), they continue to operate in this space through partnerships with ADS developers.

Some ADS developers such as Cruise and Waymo offer their own shared ride services in ADS-equipped vehicles, while others such as May Mobility and Motional offer rides through partners such as Via or Lyft. May Mobility also

[42] Grant, R. (2022, February 18). Seeking NHTSA review of the Origin. *Cruise Blog*. https://getcruise.com/news/blog/2022/seeking-nhtsa-review-of-the-origin/.
[43] APTA. (2020, November 12). *Transit and TNC Partnerships*. American Public Transportation Association. https://www.apta.com/research-technical-resources/mobility-innovation-hub/transit-and-tnc-partnerships/.

directly offers shared rides in locations where Via does not operate. While it has partnered with Via for multiple services in the United States, its rides are not exclusively through Via. As part of its efforts in Phoenix, AZ, Waymo partnered with the local transit agency, Valley Metro, to conduct a pilot that provided rides to transit agency employees and users of Valley Metro's RideChoice program.[44]

While most ADS-equipped TNC vehicles have an onboard safety operator, in some cases riders can request rides in unstaffed vehicles. The systems used by these companies are providing rides to customers (who in many cases pay fares), but the technology is still being evaluated and developed; it is not yet commercially available.

[44] Stopher, P. R., T. B. Magassy, R. M. Pendyala, D. McAslan, F. N. Arevalo, and T. Miller. (2021). *An Evaluation of the Valley Metro–Waymo Automated Vehicle RideChoice Mobility on Demand Demonstration*. Final Report, FTA Report No. 0198. Federal Transit Administration. https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-09/FTA-Report-No-0198%20REVISED.pdf.

Section 3

Selected Research and Pilot Projects

Because the market for transit bus automation systems is relatively nascent, information on R&D and pilot activities can offer insight into systems of interest that may be further developed into commercialized products in the future. Many of the projects covered in this section include those using more traditional bus formats. While low-speed shuttles may represent the largest number of projects in this area, this section will only include a sampling of those projects. For the most part, the intent of the projects covered is primarily to demonstrate a proof-of-concept and gather data. Some of the products being tested may never enter revenue service beyond initial pilot tests, but they may represent an early stage in the development of future products.

Many of the domestic projects have been funded by FTA or other USDOT programs, though some efforts have been funded through state or local government funding or are part of partnerships between private sector firms to develop and test ADS for transit buses. Beyond the ADS-equipped transit bus projects that have been announced in the United States, there is a substantial amount of work going into projects in various countries around the world, though most of the activity is centered on East Asia and Europe. The following subsections summarize several of these projects, both ADAS and ADS, in the United States and abroad.

USDOT-Funded Activities

Several transit bus automation activities have received funding from USDOT in recent years.[45] To pursue the Integrated Demonstrations that were identified in the STAR Plan, FTA included funding for projects through its Integrated Mobility Innovation (IMI) and Accelerating Innovative Mobility (AIM) programs, and it has recently issued another notice of funding opportunity (NOFO) for additional demonstrations. Also, in line with the STAR Plan, FTA has formed strategic partnerships with agencies to improve the evaluation and knowledge sharing of independent transit bus automation projects. In addition to providing funding for its own projects, FTA has managed projects funded through other USDOT efforts such as the ADS Demonstration Grants and the Better Utilizing Investments to Leverage Development (BUILD) program.[46]

[45] FTA. (2021). "FTA-Funded and Managed Transit Bus Automation Demonstrations & Pilots." Federal Transit Administration. Last updated August 18, 2021. https://www.transit.dot.gov/research-innovation/fta-funded-and-managed-transit-bus-automation-demonstrations-pilots.

[46] In 2021, the BUILD discretionary grant program was renamed the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grant program, and prior to 2018 it had been known as the Transportation Investment Generating Economic Recovery (TIGER) grant program.

IMI Program Projects

In May 2019, FTA posted the Integrated Mobility Innovation Demonstration program NOFO, which accepted applications until August 2019.[47] The program's primary stated purpose was to fund projects that demonstrate innovative, effective approaches, practices, partnerships, and technologies to enhance public transportation effectiveness, increase efficiency, expand quality, promote safety, and improve the traveler's experience. In addition to transit bus automation projects, the IMI program included funding for projects related to on-demand service and integrated fare payment technologies. In March 2020, FTA selected three Integrated Mobility Innovation (IMI) Demonstration program projects related to transit bus automation.[48] Of those, two moved forward, including the Testing and Deployment of Automated Buses on CTfastrak project led by the Connecticut Department of Transportation (CTDOT) and the Arlington Rideshare, Automation, and Payment Integration Demonstration (RAPID) project led by the City of Arlington, TX. The third project was an automated circulator shuttle project to be led by the City of Columbus, IN, but it was withdrawn from the program and did not move forward.

CTDOT CTfastrak Project

The CTDOT Testing and Deployment of Automated Buses on CTfastrak project received $2,000,000 in IMI grant funding. The project will involve the operation of automated electric buses on the CTfastrak bus rapid transit (BRT) corridor, a nine-mile stretch of dedicated road between New Britain and Hartford, CT. In June 2020, New Flyer announced it would provide CTDOT with three automated 40-foot battery electric Xcelsior CHARGE transit buses for the project. The ADS for the buses would be provided by its partner RRAI.[49] In January 2021, New Flyer and RRAI unveiled the ADS-equipped Xcelsior AV transit bus prototype (shown in Figure 3-1).[50] The buses have been tested at a RRAI facility in Clarksburg, MD, and they will be brought to the CTfastrak guideway for further testing, with a demonstration expected to begin in 2023.[51]

[47] FTA. (2019). "Integrated Mobility Innovation Demonstration Program Notice of Funding." Federal Transit Administration. Posted May 8, 2019. https://www.transit.dot.gov/funding/applying/notices-funding/integrated-mobility-innovation-demonstration-program-notice-funding.

[48] FTA. (2022). "Integrated Mobility Innovation (IMI) Fiscal Year 2019 Selected Projects." Federal Transit Administration. Accessed October 11, 2022. https://www.transit.dot.gov/research-innovation/integrated-mobility-innovation-imi-fiscal-year-2019-selected-projects.

[49] New Flyer. (2020, June 22). *New Flyer to deploy first automated heavy-duty transit bus in North America; supporting Connecticut's pursuit of integrated mobility.* [Press release]. https://www.newflyer.com/2020/06/new-flyer-to-deploy-first-automated-heavy-duty-transit-bus-in-north-america-supporting-connecticuts-pursuit-of-integrated-mobility/.

[50] New Flyer. (2021, January 29). *New Flyer unveils the Xcelsior AV™ – North America's first automated transit bus*. [Press release]. https://www.newflyer.com/2021/01/new-flyer-unveils-the-xcelsior-av-north-americas-first-automated-transit-bus/.

[51] RRAI. (2020, June 23). *Robotic Research to Help CTDOT Make U.S. Transportation History on CTfastrak by Automating First Heavy-duty Transit Buses for Revenue Service Deployment*. Business Wire. [Press release]. https://www.businesswire.com/news/home/20200623005112/en/Robotic-Research-to-Help-CTDOT-Make-U.S.-Transportation-History-on-CTfastrak-by-Automating-First-Heavy-duty-Transit-Buses-for-Revenue-Service-Deployment.

Operations on CTfastrak will include automated precision docking to minimize gaps between platforms and buses and provide for ADA-compliant level boarding, improving accessibility for passengers, as well as the use of automation for bus platooning to improve operational flexibility (i.e., adjusting bus capacity to meet levels of demand during peak and off-peak periods, and during special events).

Figure 3-1 *New Flyer Xcelsior AV transit bus equipped with an ADS from RRAI*
Photo Credit: New Flyer

Arlington RAPID Project

The City of Arlington's RAPID project received $1,698,558 in IMI grant funding. The project involved operation of automated vehicles as part of the existing on-demand rideshare service provided by Via. RAPID is an on-demand service within a geofenced area covering a square mile of downtown Arlington and the University of Texas at Arlington (UTA) campus. When using the service, riders input their desired origin and destination into the app, which identifies nearby pick-up and drop-off locations from a set of predefined stops. May Mobility supplied the ADS for the five vehicles used in the service, including four Lexus RX450h hybrid SUVs and one electric Polaris GEM e6 model.[52] The Lexus RX450h models can carry up to three passengers and they represent May Mobility's first operations using an automotive-grade platform. The Polaris GEM e6 model was modified to make it wheelchair accessible and allow it to carry two passengers—one in a wheelchair and one in the front seat next to the onboard safety operator. May Mobility began mapping streets around downtown

[52] Schrock, S. (2021, March 23). *City of Arlington Launches First-of-Its-Kind, On-Demand Self-Driving Shuttle Service with RAPID Program*. MyArlingtonTX. https://www.arlingtontx.gov/news/my_arlington_t_x/news_stories/arlington_rapid_launch.

Arlington and at the UTA campus in September 2020[53] and debuted the new Lexus RX450h platform in January 2021.[54] The service launched for public use in March 2021.[55] During the pilot, users could book rides within the RAPID service area during weekdays from 7:00 am to 7:00 pm.[56] Riders could book and pay for rides through the Via app or by calling a phone number for the service.[57] Standard Via fares applied to the general public, but UTA students were able to ride without paying a fare. Once a ride was booked, travelers were given instructions to walk to a nearby designated pick-up/drop-off location. After providing over 28,000 rides, the project team shared findings from the RAPID pilot in a final report published in April 2023.[58]

While the one-year pilot that FTA funded ended in March 2022, May Mobility and Via continued operating the RAPID service. In April 2022, May Mobility announced that the service had been extended through 2024 after the North Central Texas Council of Governments provided an additional grant to extend the pilot for two years.[59] After the first year of service, students now pay a discounted fare ($1.00 off the standard Via fare as opposed to receiving fare-free rides), while other users pay the standard Via fare.

May Mobility also announced plans to transition its fleet over to the Toyota Sienna van model beginning in late 2022.[60] Arlington RAPID currently uses one Toyota Sienna model and four Lexus RX450h models (shown in Figure 3-2), but May Mobility will eventually switch the Lexus RX450h models out for Toyota Sienna models. The vans will allow the service to offer rides to larger groups (up to four ambulatory riders), and since the Toyota Sienna can be equipped with a BraunAbility ADA-compliant wheelchair ramp and other necessary accessibility equipment, the same model will be able to provide rides to wheelchair users (up to two ambulatory riders and a wheelchair user). The new vehicle format will align with the standard human-driven Via fleet vehicles, which include multiple Toyota Sienna vans.

[53] Schrock, S. (2020, September 9). *May Mobility Begins Mapping Downtown Streets for City's Future Autonomous Vehicle Public Transportation Pilot Program*. MyArlingtonTX.
[54] May Mobility. (2021, January 19). May Mobility launches Lexus-based shuttle. *May Mobility Blog*. https://maymobility.com/may-mobility-launches-lexus-based-shuttle/.
[55] Schrock 2021, *op. cit*.
[56] The RAPID service area is bounded by Division Street and Mitchell Street (North-South) and Mary Street and Davis Drive (East-West). It includes the Arlington City Hall, the UTA campus, and numerous restaurants and other businesses.
[57] RAPID and the broader Via Arlington service use the same app, so riders can use the same app to choose between booking a ride on one of May Mobility's ADS-equipped vehicles or on the conventional vehicles operated by Via.
[58] City of Arlington, et. al. (2023). *Arlington Rideshare, Automation, and Payment Integration Demonstration (RAPID) Final Report*. Federal Transit Administration. April 2023. https://www.transit.dot.gov/sites/fta.dot.gov/files/2023-04/FTA-Report-No-0244.pdf
[59] May Mobility. (2022, April 6). Arlington deployment: Year-one lookback and renewal through 2024. *May Mobility Blog*. https://maymobility.com/arlington-deployment-year-one-lookback-and-renewal-through-2024/.
[60] May Mobility 2022, April 21, *op cit*.

Figure 3-2 *Lexus RX450h and Toyota Sienna equipped with ADS from May Mobility*
Photo Credit: May Mobility

AIM Program Projects

In March 2020, FTA announced the Accelerating Innovative Mobility (AIM) NOFO. The intent of the AIM initiative was to provide funding to help transit agencies explore new service models that offer more efficient and frequent service.[61] In August 2020, FTA selected two AIM program projects related to transit bus automation. The two selected projects were led by the Metropolitan Transit Authority of Harris County (Houston METRO) and Western Reserve Transit Authority (WRTA).

METRO Shuttle of the Future Project

Houston METRO's Shuttle of the Future project received $1,473,435 in federal funding.[62] It will test an automated electric shuttle bus that will serve Texas Southern University, the University of Houston, and Houston's Third Ward community. The shuttle will connect to Metro buses and light rail and be studied for potential use in urban and suburban environments. The pilot will use an automated ZEUS 400 cutaway bus provided by Phoenix Motorcars (shown in Figure 3-3).[63] EasyMile was originally identified as the ADS provider for the bus, but it later withdrew its participation from the project. To identify a new ADS provider, Houston METRO issued a request for proposals (RFP) to identify a new ADS provider and in August 2022, it received approval to contract with Perrone Robotics for the ADS.[64] Once the bus is equipped with the ADS and delivered to Houston METRO, the plan is for the vehicle to operate for a 12-month service period.

[61] FTA. (2022). "Accelerating Innovative Mobility." Federal Transit Administration. Accessed October 2022. https://www.transit.dot.gov/AIM.
[62] FTA. (2020). "FY20 Accelerating Innovative Mobility (AIM) Project Selections." Federal Transit Administration. Accessed August 2020. https://www.transit.dot.gov/research-innovation/fy20-accelerating-innovative-mobility-aim-project-selections.
[63] Phoenix Motorcars. (2020, September 17). *Phoenix Motorcars wins grant with Houston Metro and EasyMile for development of first FMVSS compliant autonomous shuttle bus in the US*. PR Newswire. https://www.prnewswire.com/news-releases/phoenix-motorcars-wins-grant-with-houston-metro-and-easymile-for-development-of-first-fmvss-compliant-autonomous-shuttle-bus-in-the-us-301133481.html.
[64] METRO. (2022). "Resolution 2022-102." Houston METRO Board of Directors. August 25, 2022. https://metro.resourcespace.com/pages/download.php?direct=1&noattach=true&ref=7792&ext=pdf&k=

Figure 3-3 *Phoenix Motorcars ZEUS 400 bus to be equipped with an ADS from Perrone Robotics*

Photo Credit: Phoenix Motorcars

WRTA ELATE Project

WRTA's Enhancing Life with Automated Transportation for Everyone (ELATE) project received $2,331,000 in federal funding.[65] WRTA is partnering with the Santa Clara Valley Transportation Authority (VTA) to deploy an automated electric vehicle designed for accessibility in Mahoning Valley, OH, and Santa Clara Valley, CA, to augment fixed route bus and paratransit services. The two locations will test the ability of the automated vehicle to provide more efficient and cost-effective service under a variety of climates and operating conditions. The two transit agencies worked with CALSTART and a cohort of several other transit agencies—the Connected and Automated Transit Users Forum (CATUF)—to develop specifications for a small automated electric bus platform.[66] The vehicle is expected to carry between 10 and 14 seated passengers and up to two wheelchair users, as well as an onboard safety operator. The partners plan to begin vehicle testing in 2023. On March 22, 2021, VTA issued an RFP for the vehicles, which closed on May 17, 2021.[67] In August 2021, VTA announced its intent to enter into negotiations with First Transit (now owned by Transdev) as the successful proposer. First Transit is working with Perrone Robotics, which

[65] FTA 2020, *op cit.*

[66] CALSTART. (2020, October 2). *National Team Awarded Federal Grant to Build Innovative Autonomous New Transit Vehicle.* [Press release]. https://calstart.org/national-team-awarded-federal-grant-to-build-innovative-autonomous-new-transit-vehicle/.

[67] VTA. (2021). "Accessible Automated Electric Vehicles." Santa Clara Valley Transportation Authority. Procurement issued March 22, 2021. https://secure.procurenow.com/portal/vta/projects/7968.

will apply its ADS to a bus manufactured by Sun Setter. The current target start date for operations is March 2024.

ADAS and Yard Operations NOFO

In September 2022, FTA announced a $6,500,000 NOFO to solicit proposals from organizations interested in advancing research into transit bus automation through demonstrations of transit bus ADAS and automated driving in transit bus yards.[68] A total of $5,000,000 is available for ADAS demonstration and another $1,500,000 for the first phase of the yard operations demonstration. The demonstration projects are intended to better understand the potential benefits, costs, and other impacts of transit bus automation, as well as provide transit agencies with resources, guidance, and tools to make informed deployment decisions. The NOFO accepted applications until it closed on November 21, 2022. On June 8, 2023, FTA announced $11,600,000 in grants to support six transit bus automation research projects.[69] Announced selectees focusing on ADAS applications included CTDOT, University of Alabama, Virginia Polytechnic Institute and State University, and Colorado Department of Transportation. Announced selectees focusing on yard operations included CapMetro and Pinellas Suncoast Transit Authority.

STAR Plan Strategic Partners

The STAR Plan included a Strategic Partnerships work area, which was intended to improve the quality and usefulness of research by other actors and disseminate findings to a broad community, expanding participation of providers and suppliers. According to the STAR Plan, "Strategic partnerships will leverage research projects and investments led by other agencies. FTA funding and technical assistance will supplement partners' deployment and evaluation activities, so research topics of interest to FTA may be cost-effectively added and research findings can be disseminated."[70] FTA has identified three initial strategic partnerships, including work with Valley Metro, Access Services, and Port Authority of New York and New Jersey (PANYNJ).

Valley Metro in Phoenix, AZ

Valley Metro received $250,000 in FTA funding as part of the Mobility on Demand (MOD) Sandbox project that supported the evaluation of its work with Waymo to provide automated vehicle rides to Valley Metro employees and RideChoice

[68] FTA. (2022). "Advanced Driver Assistance Systems (ADAS) for Transit Buses Demonstration and Automated Transit Bus Maintenance and Yard Operations Demonstration Program." Federal Transit Administration. Accessed September 2022. https://www.transit.dot.gov/grant-programs/advanced-driver-assistance-systems-adas-transit-buses-demonstration-and-automated.

[69] FTA. (2023). "Biden-Harris Administration Announces More Than $11 Million in Grants to Support Automated Technology Research That Improves Bus Safety." Federal Transit Administration. June 8, 2023. https://www.transit.dot.gov/about/news/biden-harris-administration-announces-more-11-million-grants-support-automated.

[70] FTA. (2018). *Strategic Transit Automation Research Plan*. Federal Transit Administration. January 2018. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf.

program users. Operations for Valley Metro employees began in September 2018 and the testing expanded in fall 2019 to include a selected group of RideChoice program users (RideChoice offers subsidized on-demand rides to paratransit users).[71] Valley Metro partnered with Waymo and Arizona State University for an on-demand shared ride service pilot with RideChoice program users riding in automated Chrysler Pacifica vans in Waymo's service area of the Greater Phoenix region. The project team completed operations in summer 2020 and the final report was issued in August 2021.[72]

Access Services in Los Angeles, CA

FTA committed $120,000 to Access Services to collect data and evaluate the ADS-equipped van being tested in its pilot.[73] The intent of the project is to test an automated vehicle providing shuttle service between a light rail station and the Veterans Administration hospital and study how automated vehicles can meet the transportation needs of persons with disabilities.[74] Access Services is using an accessible ADS-equipped Dodge ProMaster van equipped with automation technology to connect medical facilities to existing transit options (shown in Figure 3-4).[75] Access Services partnered with LILEE Systems, which provided the ADS for the van.[76] The demonstration vehicle was built in October 2021 and has been displayed at regional conferences.[77] Due to the complexity of local jurisdiction preferences and interests, the project location is to be changed from a public road to a controlled environment.

[71] FTA. (2019). *Transit Automation Case Study: Valley Metro*. Federal Transit Administration. December 2019. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/146736/transit-automation-case-study-valley-metro.pdf.

[72] Stopher et al., *op cit*.

[73] Access Services. (2021). *Proposed Annual Budget Fiscal Year 2020/2021*. Accessed April 26, 2021. https://accessla.org/sites/default/files/Publications/2020_21%20Budget%20Book.pdf.

[74] Access Services. (2020). Access attends Transit Research Board (TRB) Annual Meeting. *Behind the Scenes*, (12)2. https://accessla.org/sites/default/files/Publications/BTS_Issue%202_Vol%2012.pdf.

[75] FTA. (2021). "FTA Transit Bus Automation Factsheet: Access Services." Federal Transit Administration. Last updated August 17, 2021, https://www.transit.dot.gov/research-innovation/fta-transit-bus-automation-factsheet-access-services.

[76] LILEE Systems. (2021, October 28). *LILEE Systems partners with Access Services and Sunset Vans to showcase a new accessible autonomous vehicle at APTA EXPO 2021*. [Press release]. https://www.lileesystems.com/press-releases/lilee-systems-partners-with-access-services-and-sunset-vans-to-showcase-a-new-accessible-autonomous-vehicle-at-apta-expo-2021/.

[77] SCAG. (2022). *Meeting of the Regional Transit Technical Advisory Committee*. Meeting notes, Southern California Association of Governments, August 31, 2022, https://scag.ca.gov/sites/main/files/file-attachments/rttac083122fullagn.pdf?1661804239.

Figure 3-4 *Dodge ProMaster bus equipped with an ADS from LILEE*
Photo Credit: LILEE Systems

Following final acceptance testing, which will occur at the Fairplex in Pomona, CA, Access Services plans to conduct a demonstration that will last three to six months. That demonstration will begin in early 2023 and will be held at the Rancho Los Amigos Rehabilitation Center in Downey, CA. In addition to demonstrating the ADS operation, the demonstration will include testing the HMI design and in-vehicle monitoring system. The system will use Bluetooth beacons for ticket validation and to provide turn-by-turn wayfinding information to riders.

PANYNJ in New York, NY

FTA committed $250,000 to PANYNJ to collect data and evaluate the ADAS-equipped transit buses being tested in its pilot.[78] The intent of the $4.8 million project is to test lateral lane-keeping and bus platooning to improve operations and reduce headways between buses as they traverse the Exclusive Bus Lane between the Lincoln Tunnel and New Jersey Turnpike.[79] PANYNJ partnered with Southwest Research Institute to equip three motor coaches with automation technology and conduct initial testing. Equipment installation in the motor coaches began in the first half of 2021 and off-site track testing was conducted later that year. On-site closed-lane testing was conducted in summer 2022.

[78] NJB. (2019). *Port Authority of New York & New Jersey to Test New Tech for Lincoln Tunnel.* New Jersey Business Magazine. https://njbmagazine.com/njb-news-now/port-authority-of-new-york-new-jersey-to-test-new-tech-in-lincoln-tunnel/.
[79] PANYNJ 2019, *op. cit.*

ADS Demonstration Grant Projects

In September 2019, USDOT announced $60 million in funding for the ADS Demonstration Grants, which are intended to promote the testing and integration of automated vehicles into the transportation system and address concerns about safety, security, and privacy.[80] USDOT selected eight proposals across seven states, including three projects with transit bus-related components that are led by the City of Detroit, Contra Costa Transportation Authority (CCTA), and the University of Iowa, respectively.

City of Detroit Michigan Mobility Collaborative ADS Demonstration Project

This project was selected to receive $7,500,000 in federal funding. In its early stages, the project team will implement the Cooperative Automation Research Mobility Applications (CARMA) software platform for demonstration testing. In later stages, the team will develop mobility pilots that use Level 4 ADS to improve accessibility for older adults and persons with disabilities and deploy them on the streets of Detroit. The pilots will be based on a discovery and ideation process with Detroit's older adult and disabled communities and will leverage accessibility and human factors research underway at the University of Michigan's Mcity facility.

Contra Costa Transportation Authority ADS Demonstration Project

This project was selected to receive $7,500,000 in federal funding. The project team will demonstrate ADS in shared, on-demand, wheelchair-accessible vehicles. The project is intended to support specific accessibility goals by focusing on ADS services that support medical patients to include riders with disabilities, older adults, low-income, and others with mobility challenges. The project will include piloting transportation services for a retirement community in Rossmoor, CA, and non-emergency medical transport in Martinez, CA. In addition to working with ADS, the project will install connected vehicle infrastructure along I-680 to support personal mobility. CCTA began advertising its RFP in March 2022 and it closed in April 2022. The RFP indicated plans for initial prototype testing at GoMentum Station in late 2022 and early 2023. It also indicated plans to initiate the pilot demonstration at Bishop Ranch later in 2023 and at the Rossmoor site in 2024.

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

University of Iowa ADS for Rural America Demonstration Project

This project was selected to receive $7,026,769 in federal funding. The project intends to connect rural transportation-challenged populations using an ADS-equipped Ford Starlite Transit bus (shown in Figure 3-5). The University of Iowa procured its vehicle and upfitted it with necessary equipment. Beginning in late 2020 and continuing through Q1 2021, partner organizations including Starcraft, AutonomouStuff (a subsidiary of Hexagon), and Mandli Communications assembled the vehicle for the University of Iowa project, modifying it to support automation and accessibility systems, and mapping the route.[81] The vehicle underwent multiple rounds of testing before beginning drives along a 47-mile loop from Iowa City through rural areas and small towns (Kalona, Riverside, and Hills) beginning in fall 2021.[82] The automated bus operates on mostly rural roadways of different types and conditions including marked, unmarked, and gravel roads. The project is using a phased approach, beginning with using automation on simpler roadways and maneuvers and over time including it in more complex situations (the bus travels the same route for all test phases). In April 2022, AutonomouStuff unveiled a new drive-by-wire R&D platform based on the Ford Transit chassis that was validated it as part of this project.[83] As of fall 2022, the project had completed the first four of six testing phases.

[81] Roggentien, K. (2020, December 3). *Project update: Our vehicle is now becoming automated*. ADS for Rural America, Driving Safety Research Institute, University of Iowa. https://adsforruralamerica.uiowa.edu/news/2020/12/project-update-our-vehicle-now-becoming-automated; and Roggentien, K. (2021, March 10). *Project update: Equipment installed on new research vehicle*. ADS for Rural America, Driving Safety Research Institute, University of Iowa. https://adsforruralamerica.uiowa.edu/news/2021/03/project-update-equipment-installed-new-research-vehicle.

[82] Hexagon. (2022). On the Rural Road to Autonomy. *Velocity Magazine*. https://autonomoustuff.com/velocity-magazine/velocity-2022/on-the-rural-road-to-autonomy.

[83] PRWeb. (2022, April 21). *Accelerate development of autonomous transit shuttles, last-mile delivery and university R&D programs through new by-wire platform from Hexagon | AutonomouStuff*. https://www.prweb.com/releases/accelerate_development_of_autonomous_transit_shuttles_last_mile_delivery_and_university_r_d_programs_through_new_by_wire_platform_from_hexagon_autonomoustuff/prweb18631654.htm.

Figure 3-5 *University of Iowa "ADS for Rural America" bus*

Photo Credit: University of Iowa

BUILD Program Projects

The Better Utilizing Investments to Leverage Development (BUILD) discretionary grant program has funded road, rail, transit, and port projects with the intent to achieve both national objectives and significant local or regional impacts.[84] When USDOT announced its 2018 BUILD program selections, it included three automated vehicle projects that were led by Regional Transportation Commission of Southern Nevada (RTC) in Las Vegas; Jacksonville Transportation Authority (JTA) in Jacksonville, FL; and Eastgate Regional Council of Governments in Youngstown, OH.[85] FTA is managing the RTC and JTA grants, while the Federal Highway Administration (FHWA) is managing the Eastgate Regional Council of Governments grant.

RTC Las Vegas Medical District Automated Circulator and Connected Pedestrian Safety Project

This project was selected to receive $5,319,838 in federal funding. Also called the GoMed Project, it will provide automated shuttle service in the Las Vegas Medical District. In addition to the automated shuttle service, the project includes connected vehicle and pedestrian detection technologies and other

[84] In 2021, the BUILD discretionary grant program was renamed the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grant program. Prior to 2018, it had been known as the Transportation Investment Generating Economic Recovery (TIGER) grant program.

[85] USDOT. (2018). *BUILD Grants: 2018 Awards*. U.S. Department of Transportation. https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/327856/build-fact-sheets-121118-355pm-update.pdf.

infrastructure improvements. RTC is coordinating with FTA on an approach for procuring ADS-equipped vehicles. It expects to launch service in 2025.

JTA Bay Street Innovation Corridor Project

This project was selected to receive $25,000,000 in federal funding. Approximately half of the grant funding will support infrastructure improvements and Complete Street efforts, while the other half will support work with automated vehicles.[86] The automated vehicle portion of the project provides for the purchase of approximately 15 automated vehicles as well as possible integrated data exchange units to collect, manage, and analyze information from the sensors and automated vehicles. In January 2022, JTA signed a deal with Balfour Beatty to design, build, maintain, and operate an automated vehicle service on an at-grade loop along Bay Street from Hogan Street to the Sports and Entertainment District in Jacksonville, FL.[87]

Prior to conducting the Bay Street Innovation Corridor project, JTA partnered with multiple ADS developers to test ADS-equipped vehicles. It has tested multiple low-speed shuttles (e.g., EasyMile EZ10, Local Motors Olli, and Navya Autonom) and more recently tested vehicles equipped with an ADS from Perrone Robotics, including a GreenPower AV Star bus (an example is shown in Figure 3-6) and a Waev GEM shuttle.[88]

[86] FTA. (2019). *Transit Automation Case Study: Jacksonville Transportation Authority*. Federal Transit Administration. December 2019. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/146746/transit-automation-case-study-jacksonville-transportation-authority.pdf.

[87] Mendenhall, M. (2022, January 28). *JTA signs $49 million contract with Balfour Beatty for Skyway replacement*. Jacksonville Daily Record. https://www.jaxdailyrecord.com/article/jta-signs-dollar49-million-contract-with-balfour-beatty-for-skyway-replacement.

[88] JTA. (2022, July 1). *JTA Receives Autonomous Shuttle from Perrone Robotics*. Jacksonville Transportation Authority. [Press release]. https://www.jtafla.com/media-center/press-releases/jta-receives-wave-gem-from-perrone-robotics/.

Figure 3-6 *GreenPower AV Star bus equipped with ADS from Perrone Robotics*

Photo Credit: Perrone Robotics

Eastgate Regional Council of Governments Youngstown SMART2 Network Project

This project was selected to receive $10,853,192 in federal funding. The project will implement various pedestrian, bicyclist, and transit improvements and will include an automated shuttle service. The improvements will help connect Youngstown State University, Mercy Health, Youngstown Business Incubator, and Eastern Gateway Community College. Western Reserve Transit Authority (WRTA) is a project partner.

Support Systems for Accessibility in ADS-Equipped Transit Buses

In addition to the role of driving, bus operators are responsible for many non-driving responsibilities including assisting with wayfinding, helping passengers board and alight, and aiding in the securement of passengers and their mobility devices. In August 2022, FTA released a report on the accessibility aspects of ADS-equipped transit bus pilot and demonstration projects.[89] USDOT activities in this area also include the Inclusive Design Challenge, which seeks to encourage accessibility related innovations for automated vehicles, and the FTA Public Transportation COVID-19 Research Demonstration Grant Program, which funded some efforts to implement automated securement technologies.

[89] Berg, I., J. Cregger, and E. Machek. (2022). *Accessibility in Transit Bus Automation: Scan of Current Practices and Ongoing Research*. FTA Report No. 0228, prepared by the Volpe National Transportation Systems Center and sponsored by the Federal Transit Administration, U.S. Department of Transportation. https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-08/FTA-Report-No-0228.pdf.

Inclusive Design Challenge

At the October 2019 Access and Mobility for All Summit, USDOT announced the Inclusive Design Challenge. The goal of the challenge is to identify solutions to improve vehicle accessibility, encourage cross-disciplinary collaborations, incentivize development of new designs and technologies, and tap into the creativity and knowledge of various stakeholders.[90] The $5 million challenge was divided into two stages. Proposals for the initial stage were due in October 2020 and semifinalists were announced in January 2021.[91] In the second stage, semifinalists participated in virtual workshops that were held in January 2022. Concepts proposed by semifinalists included a range of different applications, including wayfinding tools, trip planning tools, accessible user interfaces, automated wheelchair ramp deployment systems, and wheelchair securement systems. The 10 semifinalists concluded their work in summer 2022, and winners were announced in July 2022.[92] While the Inclusive Design Challenge is not specifically focused on ADS-equipped transit bus applications, some of the applications being developed by participants may be applicable as support systems for accessible ADS-equipped transit buses.

Public Transportation COVID-19 Research Demonstration Grant Program

In January 2021, FTA announced project selections for the Public Transportation COVID-19 Research Demonstration Grant Program, which provides grants to support strategies that develop, deploy, and demonstrate solutions that improve the operational efficiency of transit agencies and enhance rider mobility during the COVID-19 pandemic.[93] The City of Tucson and Michigan Department of Transportation (MDOT) were selected to receive $600,000 each for projects that involve installing automated wheelchair securement systems, such as those provided by Q'Straint. As part of their grants, Tucson is also working to install a contactless fare payment system and MDOT is working to implement a smartphone app that integrates dispatching, scheduling, and fare payment. While the grantees are implementing these systems in conventional human-driven transit buses, automated securement technologies represent the adoption of automated support systems that can help address the non-driving responsibilities of transit bus operators.

[90] USDOT. (2022). "DOT Inclusive Design Challenge." U.S. Department of Transportation. Last updated July 26, 2022. https://www.transportation.gov/accessibility/inclusivedesign.

[91] USDOT. (2022). "Inclusive Design Challenge Competitors." U.S. Department of Transportation. Last updated July 28, 2022. https://www.transportation.gov/inclusive-design-challenge/inclusive-design-challenge-competitors.

[92] USDOT. (2022, July 26). *On Anniversary of ADA, USDOT Announces Winners of its First-Ever Inclusive Design Challenge*. [Press release]. https://www.transportation.gov/briefing-room/anniversary-ada-usdot-announces-winners-its-first-ever-inclusive-design-challenge.

[93] FTA. (2021). "Public Transportation COVID-19 Research Demonstration Grant Program Selected Projects." Federal Transit Administration. Last updated January 19, 2021. https://www.transit.dot.gov/research-innovation/public-transportation-covid-19-research-demonstration-grant-program-selected.

Other Domestic Activities

Outside of USDOT-funded and managed transit bus automation activities, there are several other domestic activities led by state DOTs, transit agencies, and other organizations. Some are large joint efforts bringing together multiple transit agencies and other organizations to specify and procure buses for a variety of use cases and operational settings, while others are smaller efforts focused on a single route or service area. Some projects use traditional transit bus formats, while others use novel designed vehicles for shuttle service or light-duty vehicles for on-demand service.

Large Procurement Efforts

While most pilot activities to date have used a single vehicle or a few vehicles, there have been some efforts to direct technology development using larger procurement efforts. Notably, the Automated Bus Consortium (ABC) effort led by AECOM and the Connected & Automated Transportation Users Forum (CATUF) effort led by CALSTART have brought together groups of transit agencies to develop specifications for ADS-equipped buses and issue joint procurements, thus creating a larger market for ADS-equipped buses and attracting private-sector firms to offer more options. The Trenton Mobility and Opportunity: Vehicles Equity System (Trenton MOVES) project takes a similar approach, but it is focused on a single large-scale pilot rather than bringing together multiple agencies with many smaller pilots. These efforts are discussed below.

Automated Bus Consortium

The ABC was formed in May 2019 as an approach to investigate the feasibility of pilot automated bus projects and accelerate the deployment of ADS-equipped buses using the combined purchasing power of multiple agencies.[94] Initially, the consortium expected to make a purchase of 75–100 buses. In September 2019, ABC members held an Industry Forum event to present on candidate pilot projects and draft automated bus specifications.[95] Each ABC member conducted an analysis to determine appropriate pilot projects for automation and, as a group, consortium members identified the following applications: BRT (exclusive lanes), shuttle service (urban and rural), arterial rapid transit, express service (HOT/HOV lanes), fixed route service, point-to-point service, and maintenance operations (bus yard/depot).

[94] AECOM. (2019, May 30). *AECOM Partners with Transit and Transportation Agencies Nationwide to Form the Automated Bus Consortium*. [Press release]. https://aecom.com/press-releases/aecom-partners-with-transit-and-transportation-agencies-nationwide-to-form-the-automated-bus-consortium/.

[95] AECOM. (2019, October 1). *Automated Bus Consortium Transit and Transportation Agency Members Announce Candidate Pilot Projects Across the US.* [Press release]. https://aecom.com/sa/press-releases/automated-bus-consortium-transit-and-transportation-agency-members-announce-candidate-pilot-projects-across-the-us/.

Over time, the membership of ABC has shifted as new agencies join and others leave the consortium. Several agencies are listed as current ABC members,[96] including the following (listed by state):

- **Arizona:** Sun Tran and RATP Dev USA
- **Georgia:** Metropolitan Atlanta Rapid Transit Authority (MARTA)
- **Illinois:** Rock Island County Metropolitan Mass Transit District (Quad Cities MetroLINK)
- **Michigan:** Michigan Department of Transportation (MDOT), Michigan Office of Future Mobility & Electrification (OFME), Capital Area Transportation Authority (CATA), Michigan State University (MSU), and Huron Transit
- **New Jersey:** New Jersey Transit
- **Texas:** Dallas Area Rapid Transit (DART) and Houston METRO

In September 2020, AECOM developed a draft ABC bus specification for an ADS-equipped 40-foot bus and revised it during subsequent months.[97] On January 18, 2022, the ABC Policy Committee authorized the release of an RFP for the ADS-equipped buses[98] and MDOT, which served as the lead procurement agency on behalf of the ABC agencies, issued the RFP on January 28, 2022.[99] The RFP closed on May 23, 2022, though vendors have not yet been selected. ABC intends to receive a bus prototype for testing and certification in late 2023, and operations could begin as early as 2024.[100]

Connected & Automated Transportation Users Forum

In September 2019, CALSTART announced that, as part of its CATUF effort, it would use a similar approach as ABC and engage with transit agencies to develop specifications for a smaller, zero-emission, purpose-built ADS-equipped transit bus.[101] In April 2020, CALSTART issued a request for information (RFI) with

[96] ABC. (2022). "Current Members." Automated Bus Consortium. Accessed October 2022. https://www.automatedbusconsortium.com/current-members/.

[97] Dick, E. (2020, September 23). *U.S. Transit and Transportation Agencies Announce Completion of First-Ever Automated Bus Specification*. AECOM. [Press release]. https:// aecom.com/press-releases/u-s-transit-and-transportation-agencies-announce-completion-of-first-ever-automated-bus-specification/.

[98] ABC. (2022). "Updates." Automated Bus Consortium. Accessed October 2022. https://www.automatedbusconsortium.com/updates/.

[99] AECOM. (2022, January 28). *Automated Bus Consortium™ issues request for proposals to procure full-size highly automated buses*. Business Wire. [Press release]. https://www.businesswire.com/news/home/20220128005039/en/Automated-Bus-Consortium%E2%84%A2-issues-request-for-proposals-to-procure-full-size-highly-automated-buses.

[100] MDOT. (2022). "Major Public Transportation Projects & Innovation Highlights." Michigan Department of Transportation. Accessed October 2022. https://www.michigan.gov/mdot/programs/planning/five-year-transportation-program/public-transportation-highlights.

[101] CALSTART. (2019, September 9). *CALSTART to Explore New Automated Vehicle Technologies Aimed at Boosting Transit Ridership and Cutting Emissions*. https://calstart.org/catuf-matthew-lesh/.

a response deadline of June 2020.[102] Following the close of the RFI, CALSTART worked with its transit agency partners to develop a joint specification that would be used in an RFP.

CATUF currently has many members,[103] including the following (listed by state):

- **California:** Access Services of Los Angeles, Anaheim Transportation Network (ATN), Contra Costa Transportation Authority (CCTA), Los Angeles Department of Transportation (LADOT), Santa Clara Valley Transportation Authority (VTA), Tri-Valley Wheels, and UCLA Transportation (BruinBus)
- **Colorado:** Regional Transportation District - Denver (RTD)
- **Florida:** Hillsborough Area Regional Transit Authority (HART) and Jacksonville Transportation Authority (JTA)
- **Maryland:** Maryland Transportation Authority (MDTA)
- **Michigan:** Macatawa Area Express (MAX) and Michigan Department of Transportation (MDOT)
- **Nevada:** Regional Transportation Commission of Southern Nevada (RTC)
- **Ohio:** Central Ohio Transit Authority (COTA), Stark Area Regional Transit Authority (SARTA), Toledo Area Regional Transit Authority (TARTA), and Western Reserve Transit Authority (WRTA)
- **Texas:** Houston METRO
- **Utah:** Utah Transit Authority (UTA)
- **Canada (British Columbia):** Coast Mountain Bus Company (CMBC)

As part of the AIM-funded ELATE project, VTA issued an RFP in March 2021.[104] In addition to procuring a vehicle for WRTA and VTA, the RFP included an option for other agencies to procure additional ADS-equipped buses—the RFP specifically named MDOT and UTA as agencies interested in procuring additional buses. A pre-proposal conference was held in April 2021 and the RFP closed in May 2021. Follow-up interviews were held in June 2021. As a result of the RFP, VTA signed a contract with First Transit (now owned by Transdev) in April 2022. As stated previously, First Transit is working with Perrone Robotics to retrofit a Sun Setter bus with ADS technology for the ELATE project.

[102] CALSTART. (2020). *Request for Information (RFI): Next-Generation, Purpose-Built, Transit Automated Vehicle*. https://www.catuf.org/wp-content/uploads/2020/04/CATUF-Cohort-Next-Generation-Purpose-Built-Transit-AV-RFI-Final.pdf.

[103] CALSTART. (2021). *Connected & Automated Transportation Users Forum Next Generation, Purpose-Built, Transit AV Cohort*. CATUF Fact Sheet, updated June 30, 2021.

[104] VTA 2021, *op. cit.*

Trenton MOVES

In February 2022, the New Jersey Department of Transportation (NJDOT) announced a $5 million planning grant for the Trenton MOVES project.[105] The aim of Trenton MOVES is to reduce transportation inequalities for Trenton residents by developing and deploying a fleet of approximately 100 ADS-equipped vehicles in the city.

As conceived, the ADS-equipped vehicles would serve as low-capacity (four–eight passenger) shuttles providing on-demand service within the eight square miles of Trenton, NJ. Riders would request rides using a ride-hailing interface at a kiosk site (a set location where riders are picked up or dropped off) or via an app. The concept proposes 50 kiosk sites that would be located at popular points of interest and high-density residential or commercial areas.

The effort would be phased in over the course of two years, during which time the ADS-equipped vehicles would have onboard staff to serve as backup drivers and engage with and assist riders. Following the initial two years, the vehicles would operate without onboard staff.

NJDOT had previously issued a request for expressions of interest (RFEI) in December 2021.[106] The intent of the RFEI was to help gather information from firms related to the design, build-out, and operation of a transportation system using ADS-equipped vehicles. The RFEI closed on February 25, 2022. A formal call for proposal or qualifications has not yet been released.

Smaller Transit Buses and Vans for Fixed Route Service

While some efforts focus on applying ADS to standard 40-foot buses, there has been a recent proliferation of projects to apply ADS to smaller bus formats such as cutaway buses or large transit vans. Some efforts, such as ADASTEC's work in Michigan, use buses designed for foreign markets. Other efforts, such as the Perrone Robotics, work with multiple bus manufacturers. The Southwest Research Institute (SwRI) work at its campus in Texas uses domestic bus platforms that comply with relevant U.S. regulatory requirements.

ADASTEC Pilot at Michigan State University

In May 2020, the Michigan Economic Development Corporation announced a PlanetM grant to ADASTEC to test a full-size automated electric bus on

[105] State of New Jersey. (2022, February 9). *Governor Murphy, Department of Transportation Commissioner Diane Gutierrez-Scaccetti, and Trenton Mayor Reed Gusciora Announce Grant for Trenton MOVES Autonomous Vehicle-Based Urban Transit System Project.* [Press release]. https://www.nj.gov/governor/news/news/562022/20220209a.shtml.

[106] State of New Jersey. (2021, December 6). *Murphy Administration Announces RFEI for Project to Create the First Autonomous Vehicle-Based Urban Transit System in America*. [Press release]. https://www.nj.gov/governor/news/news/562021/approved/20211206b.shtml.

the Michigan State University (MSU) campus in East Lansing, MI.[107] ADASTEC partnered with manufacturer Karsan to produce the Autonomous Atak Electric bus (shown in Figure 3-7), and the companies held an online debut of the bus in February 2021.[108] The bus is 8.3 meters (27 feet) long and can accommodate up to 22 seated passengers. When fully charged, it has an operating range of up to 186 miles (300 kilometers). Karsan reports that the bus can reach speeds of up to 31 mph (50 km/h) when operating in automated mode, though for its current operations at MSU, the bus operates at lower speeds. The top speed for the vehicle was limited to 15 mph for initial testing and 25 mph for later testing.[109]

Figure 3-7 *Karsan e-Atak bus equipped with ADS from ADASTEC*
Photo Credit: ADASTEC

The automated bus from ADASTEC and Karsan arrived at MSU campus in November 2021[110] and shortly after began testing on roads in East Lansing, MI. Between April 2022 and April 2023, it provided service to passengers on the MSU campus.[111] The bus offered service along a 2.5-mile route between the

[107] Achtenberg, K. (2020, May 7). *Four companies to deploy mobility solutions across Michigan with support of PlanetM grant program.* Michigan Economic Development Corporation. [Press release]. https://www.michiganbusiness.org/press-releases/2020/05/four-companies- to-deploy-mobility-solutions-across-michigan-with-support-of-planetm-grant-program/.
[108] Karsan. (2021, March 1). *Autonomous Atak Electric is Ready for the World with its Futuristic Technologies! Karsan Holds the Online Debut of Autonomous Atak Electric*. [Press release]. https://www.karsan.com/download/files/karsan-holds-the-online-debut-of-autonomous-atak-electric-_3241982586.pdf.
[109] MSU. (2021). *14 Facts About MSU's Electric Autonomous Bus*. Fact Sheet. Accessed October 2022. https://mobility.msu.edu/events/MSU%20Autonomous%20Bus%20Fact%20Sheet_3.pdf.
[110] Olsen, D. (2021, November 8). *MSU introduces electric autonomous bus*. MSU Today. https://msutoday.msu.edu/news/2021/msu-unveils-new-electric-autonomous-bus.
[111] MSU. (2022, April 28). *Quiet, clean and smart: New electric autonomous bus is ready for riders*. MSU Today. https://msutoday.msu.edu/news/2022/new-electric-autonomous-bus-accepts-riders.

MSU Auditorium and Stop #4 at the MSU Commuter Lot (#89).[112] The ADASTEC bus route uses existing Capital Area Transportation Authority (CATA) bus stops, and it kneels and precision docks at the curb. At each of the two stops, there are signs indicating that it is a bus stop location and listing a contact number. In addition to the signage at stops, signs have been installed on poles along the route to inform other road users.

The bus operates on weekdays and arrives at each stop every 30 minutes. An onboard safety operator will be present for the duration of the pilot. For the current operation, riders must be seated and some of the seats have been blocked off, reducing the total seated capacity. The bus contains two large screens that display information on the bus and the route.

Prior to the ADASTEC pilot, multiple intersections along the route were equipped with devices that broadcast signal phase and timing information. The bus is equipped with radio and cellular technology to receive this information, and it uses the signal phase and timing data to brake at intersections more smoothly (i.e., the ADS can begin slowing the bus earlier if it knows the light will be red when the bus reaches the intersection). That capability allows for improved comfort for passengers and reduced energy use.

Perrone Robotics Pilot in Philadelphia Navy Yard

In February 2022, Perrone Robotics announced that it would operate an ADS-equipped van in Philadelphia, PA, providing service in and near the Philadelphia Navy Yard.[113] Following an RFP process, Philadelphia Industrial Development Corporation (PIDC) selected Perrone Robotics for a two-phase contract with funding provided by a Delaware Valley Regional Planning Commission (DVRPC) Travel Options Program grant. In the first phase of the contract, the ADS-equipped van will augment existing transportation services between key locations within the Philadelphia Navy Yard. In the second phase, it will provide service between the Philadelphia Navy Yard to SEPTA's NRG Station located at Broad Street and Pattison Avenue.

The van used for the project will be based on a Ford eTransit platform (shown in Figure 3-8). A Ford eTransit vehicle with electric powertrain will be modified by Mobility Trans for ADA compliance and seating. Perrone Robotics will install its ADS into the vehicle platform. The press release indicated that the vehicle will be compliant with FMVSS, ADA, and Buy America requirements. An onboard safety operator will be present for the duration of the pilot. The vehicle will be designed to accommodate the safety operator, nine seated passengers and one

[112] MSU. (2022). "MSU Autonomous Bus Concludes Spring Semester Operations." MSU Mobility. Accessed October 2022. https://mobility.msu.edu/msu-auto-bus-route-summer.html.
[113] Perrone Robotics. (2022, February 24). *Pennsylvania's First Automated Shuttle Coming to the Philadelphia Navy Yard*. PR Newswire. [Press release]. https://www.prnewswire.com/news- releases/pennsylvanias-first-automated-shuttle-coming-to-the-philadelphia-navy-yard-301489811.html.

wheelchair user, and it will have a wheelchair ramp that will be accessible from a standard roadside curb.

Figure 3-8 *Lightning eMotors transit van equipped with ADS from Perrone Robotics*
Photo Credit: Perrone Robotics

Other partners for the project include the Pennsylvania Department of Transportation (PennDOT), Drexel University, and AECOM. PennDOT will oversee regulatory approvals for the project. Researchers from Drexel University will collect data to analyze system performance and rider perceptions. AECOM will provide overall program management, technical planning, testing, and deployment expertise.

Perrone Robotics has worked with multiple vehicle manufacturers to produce ADS-equipped buses for a variety of projects. In addition to its work with Philadelphia Navy Yard and the work with the JTA, Houston METRO, WRTA, and VTA projects previously discussed, it has also partnered to apply its ADS to buses for projects in Hawaii, Virginia, and Wisconsin.

Southwestern Research Institute Pilot in San Antonio

In August 2022, SwRI announced that it had developed an ADS-equipped, 14-passenger cutaway bus and launched service on its 1,500-acre campus in San Antonio, TX.[114] The vehicle is based on a Ford Transit chassis and it can

[114] SwRI. (2022, August 9). *Southwest Research Institute Develops, Deploys Automated Shuttle for Campus Tours, Research*. Southwest Research Institute. [Press release]. https://www.swri.org/press-release/southwest-research-institute-develops-deploys-automated-shuttle-campus-tours-research.

operate at up to 50 mph. An onboard safety operator is present while the bus is in operation. The system has pre-mapped information for the campus, and the operator can dynamically select routes that are within the map.

SwRI has been developing the system for more than a year, and the team debuted the ADS-equipped cutaway bus in early August 2022 during an event with San Antonio area leaders. As part of that event, attendees took a 10-minute campus tour in the vehicle. In addition to serving as a functional tour shuttle, SwRI plans to use the vehicle as a test bed to support other pilot projects. In addition to the smaller cutaway bus platform, SwRI has applied its ADS to larger motor coaches in support of a project for PANYNJ.

Novel Design Vehicles for Shuttle Service

While the past couple years have seen more announcements of projects using ADS-equipped transit vehicles with conventional designs, pilot and demonstration projects using low-speed shuttles with novel designs are still prominent. Some recent domestic shuttle projects and activities include:

- **Navya** launched a one-year shuttle pilot in August 2022 that operates along a 1.5-mile route in White Bear Lake, MN.[115] The shuttle, called Bear Tracks, operates from Monday through Friday, 9:30 am to 1:30 pm, and connects a day program that serves adults with disabilities, several apartment complexes, and a YMCA.[116] A safety operator, provided by Newtrax Transportation, will be onboard at all times. Goals for the project include operating in all weather conditions and informing future deployments in Minnesota. Project partners include the Minnesota Department of Transportation (MNDOT), AECOM, the City of White Bear Lake, White Bear Lake High School, and the University of Minnesota.
- **Navya, the Michelin Group, and beti** signed a cooperation agreement in September 2022 to pilot ADS-equipped shuttles in tourist and rural areas.[117] The agreement builds on the existing partnership of Navya and beti on rural deployments in France to accelerate project development, product trials, and pilot deployments.

[115] Navya. (2022, August 5). *Launch of a NAVYA Autonom® Shuttle pilot project at White Bear Lake, USA*. https://navya.tech/en/launch-navya-autonom-shuttle-pilot-project-at-white-bear-lake-usa/.

[116] Minnesota DOT. (2022). *Bear Tracks White Bear Lake Automated Shuttle Pilot*. Accessed November 10, 2022. https://beartrackswbl.org/wp-content/uploads/2022/07/7.28-Draft-Project-Info-Sheet-July-2022-1.pdf.

[117] Navya. (2022, June 17). *Michelin, Navya and beti enter into a technological partnership and launch their first autonomous mobility experimentation within the framework of the Movin'On Think & Do Tank*. [Press release]. https://navya.tech/en/michelin-navya-and-beti-enter-into-a-technological-partnership-and-launch-their-first-autonomous-mobility-experimentation-within-the-framework-of-the-movinon-think-do-tank/.

- **Beep** purchased an additional 8 Navya shuttles to meet growing shuttle deployments in the United States for a total of 22 Navya shuttles.[118] Beep identified the shuttles as necessary to serve new test programs as well as expand existing deployments.
- **Beep, T-Mobile, Applied Information, and Temple, Inc.,** are supporting a project in Peachtree Corners, GA, that combines ADS operations with connectivity.[119] Peachtree Corners announced the installation of 5G-connected traffic signals, which allow two-way communication between the traffic signals, mobile devices with the TravelSafely app installed, and vehicles equipped with onboard units, including four of Beep's shuttles. Such communications can support applications for red light running warnings, green light alerts, and green light preemption.
- **Beep, Balfour Beatty, Kittleson, and TESIAC** formed a project team that was selected as one of three finalists by the San Diego Association of Governments (SANDAG) in August 2022 to develop innovative transportation solutions over the next 5 to 10 years.[120] The team proposed a network of ADS-equipped shuttles to provide first mile/last mile connections to existing transit at neighborhood mobility hubs that will also feature electric vehicle chargers and other amenities. SANDAG awarded the project team $50,000 to continue concept development. Final project concepts will be presented publicly this fall for an eventual selection to participate in a partnership that will fund, plan, and construct the proposal.
- **Beep** began operation of a shuttle pilot at Zoo Miami in Miami, FL, in September 2022.[121] Project partners include Miami-Dade County and Zoo Miami; project funding was provided by the Knight Foundation. The shuttle connects zoo visitors from various points in the parking lot to the zoo entrance. A safety operator is onboard at all times. The pilot is planned to operate through the end of 2022.
- **2getthere and Oceaneering** demonstrated their Group Rapid Transit (GRT) shuttle in the Greenville-Spartanburg International Airport (GSP) Economy P1 parking area in December 2021.[122] The goal of the

[118] Navya. (2022, September 12). *Navya sells 8 self-driving shuttles in the US to autonomous mobility provider Beep.* [Press release]. https://navya.tech/en/navya-sells-8-self-driving-shuttles-in-the-us-to-autonomous-mobility-provider-beep/.

[119] Curiosity Lab at Peachtree Corners. (2022, March 2). *Applied Information and T-Mobile Deploy G-Powered Traffic Signals and Smart Infrastructure App for Residents in Peachtree Corners*. [Press release]. https://www.curiositylabptc.com/press_release/applied-information-and-t-mobile-deploy-5g-powered-traffic-signals-and-smart-infrastructure-app-for-residents-in-peachtree-corners/.

[120] SANDAG. (2022, August 3). *SANDAG Brings Innovative Public/Private Partnerships to San Diego Region*. [Press release]. https://www.sandag.org/news/innovative-partnerships-to-region-2022-08-03.

[121] Miami-Dade County. (2022). "Autonomous Vehicles (AV) Deployment." Accessed November 2022. https://www.miamidade.gov/global/transportation/autonomous-vehicles-deployment.page.

[122] Airport Experience News. (2021, December 6). *GSP Demonstrates Electric, Automated Vehicle Capabilities*. https://www.airportxnews.com/gsp-demonstrates-electric-automated-vehicle-capabilities/.

demonstration was to show how ADS-equipped vehicles could be used within an airport environment as parking lot or cargo delivery shuttles. In July 2022, the GSP Commission voted to continue exploring development of an automated transit system at the airport.[123]

Light-Duty Vehicles for On-Demand Ride-Hailing and Microtransit Services

Some companies have implemented ADS in light-duty passenger vehicles for on-demand ride-hailing and microtransit services. Some transit agencies have partnered with TNCs to augment transit service with on-demand TNC service. Although services using ADS-equipped TNC vehicles are not always coordinated with transit agencies or other local government agencies, examples of such partnerships do exist (e.g., May Mobility and the City of Arlington or Waymo and Valley Metro).

In some cases, TNCs have developed their own internal ADS development efforts or partnered with ADS developers to conduct pilot and demonstration activities. In the past, Uber and Lyft have had their own ADS development efforts, but have since sold them to other ADS developers.[124] Lyft has partnerships with Waymo in Phoenix, AZ, and Motional in Las Vegas, NV.[125] Both Uber and Via also have partnerships with Motional for on-demand service.[126] Via has partnered with May Mobility, and the two have launched on-demand microtransit services in Ann Arbor and Grand Rapids, MI; Arlington, TX; and Grand Rapids, MN.[127] ADS developers such as Cruise and Waymo are also building their own proprietary ride-hailing networks.[128]

ADS developers have continued to advance their on-demand operations in 2022, expanding on existing pilots and beginning operations in new cities. For instance.

[123] GSP International Airport. (2022, July 21). *Commission Approves Further Exploration of Automated Transit Network System*. [Press release]. https://gspairport.com/commission-approves-further-exploration-of-automated-transit-network-system/.

[124] Greimel, H. (2021. May 3). *For Toyota's Woven Planet, it's time to go big*. Automotive News. https://www.autonews.com/mobility-report/toyotas-woven-planet-its-time-go-big.

[125] Lyft. (2022). "Partners." Accessed October 2022. https://autonomous.lyft.com/partners/.

[126] Motional. (2022, October 6). *Motional and Uber Announce Industry-Leading Multimarket Commercial Agreement for Autonomous Ride-Hail and Delivery Services*. PR Newswire. [Press release]. https://www.prnewswire.com/news-releases/motional-and-uber-announce-industry-leading-multimarket-commercial-agreement-for-autonomous-ride-hail-and-delivery-services-301642553.html; and Motional. (2022, February 24). *Motional and Via Launch On-Demand Robotaxi Service in Las Vegas*. https://motional.com/news/motional-and-launch-demand-robotaxi-service-las-vegas.

[127] May Mobility. (2022, September 28). *May Mobility and Via launch first rural transit program to use wheelchair accessible ADA-compliant autonomous vehicles*. [Press release]. https://maymobility.com/may-mobility-and-via-launch-first-rural-transit-program-to-use-ada-compliant-autonomous-vehicles/.

[128] Muller, J. (2022, October 19). *Want a ride in an autonomous car? Try Lyft or Uber*. Axios. https://www.axios.com/2022/10/19/uber-lyft-autonomous-robotaxis.

- **Cruise:** While Cruise had been operating in San Francisco, CA, for multiple years, it expanded operations by offering unstaffed rides to the public in February 2022,[129] and it started charging fares for rides in June 2022.[130] In November 2022, Cruise announced it would expand its service area to include the majority of San Francisco.[131] Cruise also announced plans to begin paid service in unstaffed cars in Phoenix, AZ, and Austin, TX, by the end of 2022.[132]
- **May Mobility:** In April 2022, May Mobility announced its next generation accessible vehicle platform (including an ADA-compliant ramp) based on the Toyota Sienna van and that it would begin phasing it in at various sites across the country, including its pilots in Ann Arbor, MI, and Arlington, TX.[133] In September 2022, May Mobility and Via launched a new service covering a 17-square-mile area and serving 70 pick-up and drop-off points in Grand Rapids, MN.[134] The service uses five Toyota Sienna vans, three of which are wheelchair accessible. It provides rides between 70 different stop locations in a 16-square-mile service area. May Mobility has also announced plans to begin its first unstaffed operations in 2023.[135]
- **Motional:** In February 2022, Motional and Via launched on-demand service in downtown Las Vegas, NV.[136] In August 2022, Motional introduced its new Hyundai IONIQ 5-based prototypes to its existing Las Vegas, NV, pilot with Lyft and announced plans for unstaffed operation beginning in 2023.[137] While it did not specify initial sites for additional ride-hailing service, Motional announced a 10-year partnership with Uber in October 2022.[138]
- **Waymo:** While Waymo had been operating in the Phoenix, AZ, area for multiple years, it announced expanded operations for the area in 2022, including plans for unstaffed operation in downtown Phoenix and staffed operation at Phoenix Sky Harbor International Airport.[139] Waymo

[129] Vogt, K. (2022, February 1). Welcome, Riders. *Cruise Blog*. https://getcruise.com/news/blog/2022/welcome-riders/.
[130] Reuters. (2022, June 23). *GM's Cruise starts charging fares for driverless rides in San Francisco*. https://www.reuters.com/business/autos-transportation/gms-cruise-starts-charging-fares-driverless-rides-san-francisco-2022-06-23/.
[131] Truong, K. (2022, November 1). *Self-Driving Cruise Cars Are Expanding to Most of SF, Says CEO*. The San Francisco Standard. https://sfstandard.com/business/self-driving-cruise-cars-are-expanding-to-most-of-sf-says-ceo/.
[132] Jin, H. (2022, September 12). *GM's Cruise robotaxi unit to offer driverless rides in Phoenix, Austin this year.* Reuters. https://www.reuters.com/business/autos-transportation/gms-self-driving-car-unit-cruise-offer-driverless-rides-phoenix-austin-this-year-2022-09-12/.
[133] May Mobility 2022, April 21, *op. cit.*
[134] May Mobility 2022, September 28, *op. cit.*
[135] May Mobility 2022, July 12, *op. cit.*
[136] Motional, 2022, February 24, *op. cit.*
[137] Motional. (2022, August 16). *Motional and Lyft Deliver the First Rides in Motional's New All-Electric IONIQ 5 Autonomous Vehicle.* https://motional.com/news/motional-and-lyft-deliver-first-rides-motionals-new-all-electric-ioniq-5-autonomous-vehicle.
[138] Motional, 2022, October 6, *op. cit.*
[139] Waymo. (2022, May 18). Cities, freeways, airports: How we've built a scalable autonomous driver. *Waymo Blog*. https://blog.waymo.com/2022/05/howwevebuiltascalableautonomousdriver.html.

also began unstaffed rides for employees in San Francisco, CA,[140] and announced plans to pilot an on-demand service in Los Angeles.[141]

International Activities

Outside of the United States, there is a substantial amount of transit bus automation activity. This section provides information on selected recent projects in Europe, Asia, and the Middle East.

SHOW Project

The SHared automation Operating models for Worldwide adoption (SHOW) project is run by a consortium of research and industry firms in Europe that aim to conduct demonstrations of autonomous transportation for passengers and goods in 20 cities. Each demonstration will last at least 12 months and they hope to deploy more than 70 vehicles during the lifespan of the project. SHOW has identified 16 use cases that fall under one of three "families" of use cases:

- automated mobility in cities
- automated mixed mobility in cities
- added value services for cooperative and connected automated mobility in cities

SHOW has three tiers of demonstration sites: mega sites, satellite sites, and follower sites.[142] Mega sites will address all the identified use cases. Each site may have pilot programs in more than one city. The five mega sites are Germany, Sweden, Spain, France, and Austria. Activities at the mega sites include:

- **Germany:** The mega site includes three cities in Germany. Each city will have a pilot providing passenger transportation on ADS-equipped vehicles of varying automation levels. The demonstration in Aachen will operate Level 3 and 4 vehicles. The fleet will comprise three passenger vehicles and two minibus-sized e.GO Mover shuttles. The shuttles were developed by Sensible 4 and MOOVE GmbH and were slated to begin operations in February 2022.[143] The demonstration in Karlsruhe was first shown at the 2022 IT-TRANS Conference in May 2022.[144] A fleet of Level 4 and 5 vehicles (one passenger car and two shuttles) offered autonomous passenger and

[140] AP News. (2022, March 30). *Waymo to expand autonomous vehicle rides to San Francisco*. https://apnews.com/article/technology-business-san-francisco-41fa273e54f77926ca011d29c96c86c2.
[141] Waymo. (2022, October 19). Next Stop for Waymo One: Los Angeles. *Waymo Blog*. https://blog.waymo.com/2022/10/next-stop-for-waymo-one-los-angeles.html.
[142] SHOW. (2020). *Shared automation Operating models for Worldwide adoption*. Grant Agreement Number: 875530. https://show-project.eu/wp-content/uploads/2021/04/SHOW-WP02-D-UIP-003-01_-_SHOW_D2.2_Business_Models_and_mapping_to_pilot_sites_SUBMITTED.pdf.
[143] Sensible 4. (2022, December 2). *New Autonomous Shuttle Bus Collaboration Between Sensible 4 and Moove GmbH*. [Press release]. https://sensible4.fi/2021/12/02/new-autonomous-shuttle-bus-collaboration-between-sensible-4-oy-and-moove-gmbh/.
[144] SHOW. (2022). "Karlsruhe real-life demo to kick off at IT-TRANS." Accessed May 20, 2022. https://show-project.eu/2022/05/05/karlsruhe-real-life-demo-to-kick-off-at-it-trans/.

cargo transportation.[145] The Mannheim demonstration, called RABUS (Reallabor für den Automatisierten BUSbetrieb im ÖPNV in der Stadt und auf dem Land), will integrate on-demand shuttles manufactured by ZF into the existing public transportation network in the area. The vehicles can carry 8 seated and 14 standing passengers in addition to one safety driver who will always be present. That pilot program is slated to begin in 2023 and will run until 2024.[146]

- **Sweden:** The mega site will have demonstrations in two cities, Kista and Linkoping. Both sites will have fleets of Level 4 ADS-equipped vehicles. The fleet in Kista will have three shuttles and the fleet in Linkoping fleet will have two Navya shuttles and another passenger vehicle.[147] On October 13, 2022, the Kista project, called 5G RIDE, had a closed demo day where the vehicles and technology were unveiled.[148]
- **Spain:** Madrid will be the mega site in Spain with a fleet of five vehicles having automated driving systems for passenger transportation. The fleet will have three types of vehicles: a minibus, a full-size bus, and passenger vehicles.[149] The platform for the passenger vehicles will be a Renault Twizy, and a IRIZAR electric bus will be used for the full-size bus platform.
- **France:** The mega site will have demonstrations in two cities: Rouen and Rennes.[150] The demonstration in Rouen will have a fleet of six ADS-equipped i-Cristal minibuses manufactured by Lohr, plus four on-demand passenger vehicles. The i-Cristal seats 16 passengers, is fully electric, and is accessible to riders with mobility impairments.[151] The ADS will be provided by Transdev. The demonstration at the Rennes site will have six automated minibuses by Navya and EasyMile operating.
- **Austria:** The mega site will have demonstrations in three cities. The demonstration in Graz will have a fleet of ADS-equipped shuttles that connect a train station to a shopping center. The demonstration in Salzburg will connect a suburb to the city center, demonstrating a first mile/last mile automated transportation solution. The demonstration in Carinthia

[145] SHOW. (2022). "Germany: Level 4/5 operation in complex scenarios & combined urban and peri-urban environments." Accessed November 2022. https://show-project.eu/mega-sites-germany/.
[146] Marquordt, C. (2022, October 24). Autonomous in Mannheim – RABUS. *Urban Transport Magazine.* https://www.urban-transport-magazine.com/en/autonomous-in-mannheim-rabus/.
[147] SHOW. (2022). "Sweden: 5G control tower concept for remote monitoring, tele-operation & AV fleet management." Accessed November 2022. https://show-project.eu/mega-sites-sweden/.
[148] Kista Science City. (2022, October 18). "Seeing through obstacles and around corners, the 5G Ride project rolls on." https://kista.com/blog/2023/02/09/shaping-the-future-of-mobility-3/.
[149] SHOW. (2022). "Madrid, Spain: Real traffic bus/shuttle service and bus depot operation and links to established MaaS platform." Accessed November 2022. https://show-project.eu/mega-sites-madrid/.
[150] SHOW. (2022). "France: Seamless automated vehicle chains for PT, DRT and MaaS (Rouen)/LaaS (Rennes)." Accessed November 2022. https://show-project.eu/mega-sites-france/.
[151] Transdev. (2017, November 14). *Transdev and Lohr present i-Cristal: the future electric full autonomous shuttle designed for tomorrow's shared mobility.* [Press release]. https://www.transdev.com/en/press-release/transdev-and-lohr-present-i-cristal-the-future-electric-full-autonomous-shuttle-designed-for-tomorrows-shared-mobility/.

will connect a train station to the city center. Seven vehicles will be used between the three sites. The fleet will be made of Navya shuttles, passenger vehicles, and passenger vans. The three demonstration sites will also exhibit the use of V2X (vehicle-to-everything) technology using ITS G5.[152]

In addition to the mega sites, there will be several satellite and follower sites that will address a subset of use cases. Activities at the satellite sites include:

- **Czech Republic**: As part of the Urban Mobility Days 2022 conference, an automated minibus demonstration was kicked off in the city of Brno.[153] The demand-responsive automated shuttles were developed by a group of Czech companies including Technotrade, Roboauto, and ARTIN.[154] The demonstration fleet included two shuttle vehicles and one light-duty passenger vehicle. The Czech Transportation Research Centre is leading the project, which is part of the SHOW program. The vehicle began operating on a subset of existing public transit routes in Brno during the conference. The Czech Transportation Research Centre had previously tested the autonomous driving system in the spring on a closed course before moving on to a "pre-demo" phase during which they practiced how to run operations.[155] The demonstration was free to the public and was only open during the event, September 20–22.
- **Finland:** In January 2022, Sensible 4 began a "bad weather" pilot in Tampere.[156] The pilot lasted 2.5 months. Vehicles in this pilot traveled at a maximum speed of 18.6 mph (30 km/h) along a 2.2-mile (3.5-kilometer) route with mixed traffic conditions. The pilot's purpose was not only to test the automated driving system in inclement weather, including extreme low temperatures, but also to collect relevant feedback from riders, including on accessibility.[157]
- **Denmark:** Copenhagen will be a satellite site for the SHOW project and will demonstrate Level 4 bus rapid transit. The project, called Copenhagen Commute, will use a fleet of three shuttles and two buses.[158]

[152] SHOW. (2022). "Austria: Connecting peri-urban regions to intermodal mobility hubs in mixed traffic." Accessed November 2022. https://show-project.eu/mega-sites-austria/.
[153] SHOW. (2022). "SHOW Brno demo launch will take place during Urban Mobility Days 2022." Accessed November 2022. https://show-project.eu/2022/08/26/show-brno-demo-launch-will-take-place-during-urban-mobility-days-2022/.
[154] Esagono Energia. (2022). "GRIFO SHUTTLE Digitally-controlled vehicle (by Technotrade)." Accessed March 2022. https://esagonoenergia.com/en/esagono-energia-grifo-shuttle-digitally-controlled-vehicle-by-technotrade/.
[155] Pinton, E. (2022, March 23). *Self-Driving Minibus Begins Trial on the Streets of Brno.* Brno Daily. https://brnodaily.com/2022/03/23/brno/self-driving-minibus-begins-trial-on-the-streets-of-brno/.
[156] Sensible 4. (2022, May 3). *Self-Driving Pilot in Finland a Success Despite Extreme Weather Conditions*. [Press release]. https://sensible4.fi/company/newsroom/self-driving-pilot-in-finland-a-success-despite-extreme-weather-conditions/.
[157] McGowran, L. (2022, May 3). *Self-driving vehicle pilot successful in Finland during extreme weather.* Silicone Republic. https://www.siliconrepublic.com/machines/finland-self-driving-vehicles-weather-sensible-4.
[158] SHOW. (2022). "Denmark, Copenhagen: Level 4+ (with no on-board driver) in real PT and DRT operations in the City." Accessed November 2022. https://show-project.eu/mega-sites-copenhagen/.

- **Netherlands:** The satellite site of Brainport has released footage of closed-course testing. The project is demonstrating V2X technology, platooning, and vulnerable road user safety at intersections using connected intelligent transportation systems services.[159]
- **Italy:** Turin is another satellite site. In July 2022, two Navya shuttles began operating on a 1.2-mile (2.0-kilometer) route that will allow hospital patients to book an on-demand ride to their appointments. The shuttles are accessible and can carry up to 14 passengers at a time.[160]
- **Greece:** The satellite site of Trikala will demonstrate automated passenger and goods transportation using a fleet of Weichai vehicles. The demonstration will have nine months of pre-launch testing followed by two years of operations.[161]

CAVForth Pilot

Project CAVForth is an ADS-equipped bus pilot that will operate along a 14-mile route across the Forth Road Bridge between Fife and Edinburgh in Scotland, the United Kingdom.[162] The project is led by UK technology company Fusion Processing Ltd., with key project partners including Stagecoach Plc, Alexander Dennis Ltd. (which is part of NFI Group), Transport Scotland, Napier University, and Bristol Robotics Lab. The project has been partially funded by £4.5 million from the government's Centre for Connected and Autonomous Vehicles and Innovate UK.

Early demonstrations began in late 2019[163] and on-road testing began in April 2022.[164] CAVForth expects to carry fare-paying passengers as a registered bus service by spring 2023. The five 42-seat ADS-equipped diesel buses equipped with an ADS from Fusion Processing will provide service every 20 minutes between 6:00 am and 9:00 pm and run at up to 50 mph.

[159] SHOW. (2022). "Netherlands, Brainport: Integrated L4-L5 Bus and cars operating on dedicated bus lanes of a city environment." Accessed November 2022. https://show-project.eu/mega-sites-netherlands-brainport/.

[160] Sustainable Bus Editorial Staff. (2022, July 14). *Navya's autonomous shuttles launched in Turin*. Sustainable Bus. https://www.sustainable-bus.com/its/autonomous-shuttles-turin-gtt-navya/.

[161] Gkritsi, E. (2022, January 22). *Chinese driverless buses to hit European streets for first time.* Technode. https://technode.com/2020/01/22/chinese-driverless-buses-to-hit-european-streets-for-first-time/.

[162] Alexander Dennis. (2018, November 22). *Scotland to trial first autonomous full-sized bus fleet in passenger service after £4.35M Innovate UK funding*. [Press release]. https://www.alexander-dennis.com/scotland-to-trial-first-autonomous-full-sized-bus-fleet-in-passenger-service-after-4-35m-innovate-uk-funding/.

[163] Eden, T. (2019, November 13). *Scotland's first self-driving bus tested in Glasgow ahead of launch next year.* Daily Record. https://www.dailyrecord.co.uk/news/scottish-news/scotlands-first-self-driving-bus-20876444.

[164] Ramey, J. (2022, September 14). *Here's What City Will See Autonomous Buses This Year.* Autoweek. https://www.autoweek.com/news/technology/a41209698/autonomous-bus-fusion-processing-scotland/.

In addition to the initial CAVForth trial, the Centre for Connected and Autonomous Vehicles announced in February 2023 an additional £10.4 million in funding to support the next phase of the project, CAVForth 2.[165] The additional funding will allow the project team to extend the current route by an additional five miles and add an ADS-equipped electric Enviro100EV bus, which will be tested using a remote safety driver.

ADASTEC Activities

In addition to the project underway in Michigan, ADASTEC has some notable activity in Europe. Its largest current pilot is in Norway, but it has also conducted test and demonstration activities in France, Germany, Romania, and Turkey.

In May 2022, ADASTEC and bus manufacturer Karsan jointly launched a two-year ADS-equipped bus pilot in Stavanger, Norway, to explore the utility of automated buses in an urban environment. According to a press release from transit operator Kolumbus, this is the first test of a large, ADS-equipped bus in open city traffic in Europe.[166] The Karsan Autonomous e-ATAK bus operates in regular passenger service on a 2.5-mile (4.0-kilometer) route at a maximum speed of 20 mph along public streets.[167] During the testing phase, the bus operates with a safety driver to monitor and assume operations as needed. All passengers are required to be seated, limiting the full bus capacity from 52 passengers to 21 seated passengers.[168]

ADASTEC and Karsan have also partnered on several smaller projects in Europe. ADASTEC has conducted two limited demonstrations of unstaffed operation, including one in Norway in January 2022[169] and one in Turkey at the Presidential Palace in Ankara in February 2021.[170] The limited demonstrations were performed on controlled courses closed to cars and pedestrians. In addition to those unstaffed operations, the ADS-equipped e-ATAK buses have been used

[165] Alexander Dennis. (2023, February 1). *CAVForth2 extends autonomous bus trial with next-generation Alexander Dennis Enviro100AEV.* [Press release]. https://www.alexander-dennis.com/cavforth2-extends-autonomous-bus-trial-with-next-generation-alexander-dennis-enviro100aev/.

[166] Nikel, D. (2022, January 21). *Driverless Bus Test Announced in Downtown Stavanger, Norway.* Forbes. https://www.forbes.com/sites/davidnikel/2022/01/21/driverless-bus-test-announced-in-downtown-stavanger-norway/.

[167] TS Nordic Plus. (2022, September 8). *The first autonomous large bus in the world in open traffic.* https://itsnordicplus.com/news/the-first-autonomous-large-bus-in-the-world-in-open-traffic/.

[168] Schreiber, R. (C. Hampel, translation). (2022, July 9). "*Not a pilot, but a series vehicle" – Autonomous e-bus enters regular service in Norway.* Electrive. https://www.electrive.com/2022/07/09/not-a-pilot-but-a-series-vehicle-autonomous-e-bus-enters-regular-service-in-norway/.

[169] ADASTEC. (2022). "Stavanger Demo in Norway NRK channel News." Video from January 2022 demo. Accessed October 2022. https://www.adastec.com/videos; and Oppedal, M. (2022, January 21). *Driverless buses are to go into city traffic: - We are the first in Europe.* NRK. https://www.nrk.no/rogaland/na-skal-denne-autonome-bussen-sleppast-laus-i-bytrafikken-i-stavanger-1.15819751.

[170] ADASTEC. (2021). "Presidential Palace Demo." Video from February 2021 demo. Accessed October 2022. https://www.adastec.com/videos.

in single-bus pilots in France and Romania.[171] In early 2022, an ADS-equipped e-ATAK bus was tested at the Keolis Group test facility in Châteauroux, France.[172] In May 2020, Karsan announced an order from BSCI to use an ADS-equipped e-ATAK bus for a pilot at an industrial park in Ploieşti, Romania.[173]

EasyMile Activities

EasyMile built upon previous unstaffed shuttles launched in 2020 on the GreenTEC campus in Schleswig-Holstein, Germany,[174] and at Herøya Industripark AS in Porsgrunn, Norway,[175] when it signed a €4 million contract in October 2022 to provide a fleet of EZ10 shuttles for unstaffed operation for 10 years at the Terhills resort in Belgium.[176] Two shuttles have been operating with a supervisor onboard; by mid-2023, the goal is to operate five to six unstaffed shuttles with one remote supervisor. Passenger wait times are expected to be no longer than 10 minutes. The vehicles will operate at a top speed of about 12 mph (20 km/h) for seven days per week, eight hours per day, on the 1.5-mile (2.5-kilometer) route alongside cyclists, pedestrians, and a minibus.[177]

EasyMile has also partnered with Via to launch an on-demand service with two EZ10 vehicles in the Kelheim district north of Munich, Germany, dubbed KelRide. Passengers can use the Via mobile app to book an on-demand ride on one of the two EZ10 shuttles Monday through Friday from 9:00 am to 4:00 pm. Passengers can choose from 147 stops in Kelheim and to a nearby train station along an 8.7-mile (14-kilometer) road network.[178]The EZ10 vehicles will travel at a top speed of about 12 mph (20 km/h), will have a safety operator onboard, and rides will be free. The project anticipates expanding to a mixed fleet of ADS-equipped and conventional vehicles in 2023.[179]

[171] Buchholz, K. (2022, October 20). *Autonomous transit bus nears its first year of operation*. SAE International. https://www.sae.org/news/2022/10/msu-automated-bus.

[172] ADASTEC. (2022). "Test Drive in Châteauroux, France." Video from March 2022 testing. Accessed October 2022. https://www.adastec.com/videos.

[173] Karsan. (2020, May 6). *Karsan Receives Its First Autonomous Atak Electric Order!* [Press release]. https://www.karsan.com/ua/press-ua/current-news-ua/karsan-receives-its-first-autonomous-atak-electric-order-ua.

[174] EasyMile and GreenTEC. (2020, October 28). *GreenTEC and EasyMile Bring Level 4 Autonomous Driving to Germany.* [Press release]. https://easymile.com/news/greentec-and-easymile-bring-level-4-autonomous-driving-germany.

[175] EasyMile. (2020, October 30). *EasyMile in First Fully Autonomous Level 4 Driving Operation in Northern Europe*. [Press release]. https://easymile.com/news/easymile-first-fully-autonomous-level-4-driving-operation-northern-europe.

[176] Marcaillou, L. (2022, October 28). *EasyMile obtains a first contract for its autonomous shuttle*. Les Echos. https://www.lesechos.fr/pme-regions/occitanie/easymile-obtient-un-premier-contrat-pour-sa-navette-autonome-1874012.

[177] Nath, K. (2022, October 13). *EasyMile wins deal for driverless shuttles at Terhills, Belgium*. Travel Daily Media. https://www.traveldailymedia.com/easymile-wins-deal-for-driverless-shuttles-at-terhills-belgium/.

[178] Via. (2022, September 13). *KelRide launches autonomous, on-demand public transport service*. [Press release]. https://ridewithvia.com/news/kelride-launches-autonomous-on-demand-public-transport-service.

[179] KelRide. (2022). "KelRide in Operation." Accessed October 31, 2022. https://kelride.com/en/operation-use/.

Navya Activities

Navya continued work on European deployments, most notably with the EU-funded Advancing Sustainable User-centric Mobility with Automated Vehicles (ULTIMO) project.[180] Building on its predecessor, the Autonomous Vehicle to Evolve to a New Urban Experience (AVENUE) project, ULTIMO aims to deploy larger-scale projects to explore the integration of mixed fleets, goods transportation, and public transportation with on-demand components. The ULTIMO project plans to pilot in three yet-to-be-determined European cities with fleets of at least 15 vehicles in each city. The four-year project kicked off in October 2022 with an end date of September 2026.[181] Total project costs are estimated at €37.8 million including an EU contribution of €24.2 million. Other major project partners include Ruter (the Norwegian transit authority for Oslo and Akershus counties) and the Centre for Research and Technology-Hellas in Greece.

Navya also continued its work related to unstaffed operations. In June 2020, Keolis and Navya began operating an unstaffed automated shuttle at the National Shooting Sport Centre in Châteauroux, France.[182] The shuttle travels at up to 9 mph (15 km/h) along a 0.9-mile (1.6-kilometer) route between the parking lot and the reception area. Operators can monitor and manage the shuttle from an on-site remote supervision center. This deployment is expected to be in operation for the 2024 Olympic Games in Paris.[183] Additionally, Navya demonstrated the remote operation of four automated shuttles at two different sites through 11 simulated scenarios in Paris at the Autonomy Paris 2022 show in March 2022.[184] Navya also completed several remote operation testing and validation exercises at the UTAC testing facility in Linas-Montlhéry, France, in May 2022.[185]

[180] Navya. (2022, June 1). *Navya to provide self-driving shuttles for large scale deployment within the EU-funded ULTIMO project*. [Press release]. https://navya.tech/en/navya-to-provide-self-driving-shuttles-for-large-scale-deployment-within-the-eu-funded-ultimo-project/.

[181] CORDIS. (2022). "ULTIMO - Advancing Sustainable User-centric Mobility with Automated Vehicles." European Commission, CORDIS EU research results. Last updated September 15, 2022. https://cordis.europa.eu/project/id/101077587.

[182] Navya. (2020, October 19). *Keolis and Navya take a new step in autonomous mobility with the entry into service of their first shuttle without an onboard safety operator, in Châteauroux, France*. Business Wire. [Press release]. https://www.businesswire.com/news/home/20201018005052/en/Keolis-and-Navya-take-a-new-step-in-autonomous-mobility-with-the-entry-into-service-of-their-first-shuttle-without-an-onboard-safety-operator-in-Ch%C3%A2teauroux-France.

[183] Marcaillou 2022, *op. cit.*

[184] Navya. (2022, March 21). *NAVYA's technology is ready for the commercialization of Level 4 remotely supervised driverless fleets*. [Press release]. https://navya.tech/en/navyas-technology-is-ready-for-the-commercialization-of-level-4-remotely-supervised-driverless-fleets/.

[185] Navya. (2022, May 16). *Navya strengthens its technology roadmap and advances on significant milestones thanks to the test and validation environment provided by UTAC*. [Press release]. https://navya.tech/en/navya-strengthens-its-technology-roadmap-and-advances-on-significant-milestones-thanks-to-the-test-and-validation-environment-provided-by-utac/.

Some of Navya's other international activities included:

- Launching a two-shuttle pilot in Sophia Antipolis, a technology park in France from April through August 2022. The vehicles provided peak-hour first mile/last mile connections from existing bus service to destinations within the technology park.[186]
- Selling a third shuttle to an existing pilot project (which already had two Navya shuttles) in Bavaria, Germany, in September 2022. The additional vehicle will allow the extension of the current 1.9-mile (3.0-kilometer) route to Kronach Castle, a major tourist attraction.[187]
- Conducting a short-term demonstration in Aveiro, Portugal, during Aviero Tech Week in October 2022.[188]
- Launching a pilot in Scotland, where a Navya vehicle will operate on a 1.9-mile (3.0-kilometer) route between Inverness Campus and the Inverness Retail and Business Park. Operations will occur from 10:00 am through 4:20 pm on Monday through Saturday. Service began in early October 2022 and will run fare-free for the first six weeks. The pilot is scheduled to operate until March 2023.[189]
- Signing a memorandum of understanding with Macnica (Navya's distributor in Japan) for the sale of the next generation of Navya's products in June 2022.[190]
- Signing a distribution agreement with Electromin (a Saudi Arabian mobility company) for distributing Navya's products in the Middle East in July 2022.[191]
- Signing a memorandum of understanding with Red Sea Global to study and scope ADS-equipped shuttle needs at the Red Sea tourism development.[192]

[186] Binacchi, F. (2022, April 7). *Alpes-Maritimes: The first autonomous shuttles in Sophia-Antipolis transport the public*. 20 Minutes. https://www.20minutes.fr/nice/3267463-20220407-alpes-maritimes-premieres-navettes-autonomes-sophia-antipolis-transportent-public.

[187] Navya. (2022, September 6). *The district of Kronach orders a new EVO self-driving shuttle from Navya*. [Press release]. https://navya.tech/en/the-district-of-kronach-orders-a-new-evo-self-driving-shuttle-from-navya/.

[188] Navya. (2022, October 10). *First deployment in Portugal of a Navya Autonom® Shuttle*. [Press release]. https://navya.tech/en/first-deployement-in-portugal-of-a-navya-autonom-shuttle/.

[189] White, G. (2022, October 6). *Scotland's first trial of a driverless passenger bus service launched at Inverness Campus*. The Inverness Courier. https://www.inverness-courier.co.uk/news/scotland-s-first-trial-of-a-driverless-passenger-bus-service-289843/.

[190] Navya. (2022, June 30). *Macnica orders two new NAVYA autonomous shuttles and signs a MoU to buy NAVYA next generation platforms.* [Press release]. https://navya.tech/en/macnica-orders-two-new-navya-autonomous-shuttles-and-signs-a-mou-to-buy-navya-next-generation-platforms/.

[191] Navya. (2022, July 27). N*avya and Electromin sign a non exclusive distribution agreement to accelerate sales of Navya autonomous solutions in the Middle East.* [Press release]. https://navya.tech/en/navya-electromin-sign-a-non-exclusive-distribution-agreement-to-accelerate-sales-of-navya/.

[192] Navya. (2022, November 3). *Navya signs an MoU with Red Sea Global to take part in the innovative transportation scheme of one of the most ambitious tourism projects in the world.* [Press release]. https://navya.tech/en/navya-signs-an-mou-with-red-sea-global-to-take-part-in-the-innovative-transportation-scheme-of-one-of-the-most-ambitious-tourism-projects-in-the-world/.

The 10,811-square-mile (28,000-square-kilometer) sustainable tourism project located in northwest Saudi Arabia is scheduled to open to tourists in 2023 with 50 hotels, up to 1,000 residential units, and an international airport planned by 2050.

In early 2023, Navya announced that it was suspending trading on the public markets as it went into receivership proceedings.[193] The deadline for takeover bids was set for March 2023, and the company's operations will continue in the meantime.

Sensible 4 Activities

Sensible 4 began another pilot program in Bodø, Norway, in June 2022. The pilot, called Smarter Transport Bodø, is scheduled to last through the end of 2022.[194] Two Toyota Proace vehicles are used for the pilot, which connects a local harbor to the hospital. The route has eight stops. Vehicles are operating in automated mode but still have onboard safety drivers to comply with Norwegian law.

In addition to the two active pilot programs in Europe, Sensible 4 is testing vehicles in two other cities in Finland. These test sites are not open to the public.[195] Sensible 4 and MUJI collaborated on a new shuttle bus, called GACHA. GACHA was used for a 2.5-week demo in Chiba, Japan, in February 2022. The route was 0.7 miles (1.2 kilometers) long and was open to the public.[196]

LILEE Systems Bus in Taiwan

LILEE Systems is operating a retrofitted 30-foot diesel ADS-equipped bus (shown in Figure 3-9) that is providing service to passengers on a 1.8-mile (2.9-kilometer) route along public roads in Taichung City, Taiwan.[197] Service began on December 21, 2018, and continued until January 20, 2019. During the pilot, the bus carried more than 7,500 riders on a fixed route on regular streets that were open to traffic. The demonstration was part of the city government's Shuinan Smart City automated vehicle project. Partners included Wistron,

[193] Navya. (2023, February 2). *Navya announces the opening of a receivership procedure.* [Press release]. https://www.navya.tech/en/navya-announces-the-opening-of-a-receivership-procedure/.
[194] Sensible 4. (2022, June 27). *World's First Long-term Autonomous Driving Service North of the Arctic Circle Begins – Crucial Public Transport Link for Local Residents*. [Press release]. https://sensible4.fi/company/newsroom/worlds-first-long-term-autonomous-driving-service-north-of-the-arctic-circle-begins-crucial-public-transport-link-for-local-residents/.
[195] Sensible 4. (2022). "Testing Areas." Accessed November 2022. https://sensible4.fi/deployments/.
[196] Sensible 4. (2022, June 2). *Sensible 4 Opens Tokyo Office—Runs an Autonomous Driving Pilot with MUJI-Designed Driverless Shuttle.* [Press release]. https://sensible4.fi/company/newsroom/sensible-4-opens-tokyo-office-runs-an-autonomous-driving-pilot-with-muji-designed-driverless-shuttle/.
[197] Realpozo, P. (2019, January 15). *LILEE Systems Presents Major Advances in Autonomous Rapid Transit (ART) at Silicon Valley's Innovation Without Borders Event.* Business Wire. [Press release]. https://www.businesswire.com/news/home/20190115005982/en/.

THI Consultants, TopMSO, Startrii, and Green Transit Company (a local bus operator).[198]

Figure 3-9 *Transit bus equipped with an ADS from LILEE*

Photo Credit: LILEE Systems

In March 2020, LILEE Systems announced a partnership with Tainan City in Taiwan to launch revenue service operations that would collect fares from passengers.[199] In July 2020, LILEE Systems received a license plate from the Motor Vehicles Office to operate its bus on public streets for two years on two routes, connecting a high-speed rail station, exhibition center, university, shopping mall, and science park. In August 2020, it announced the launch of test operations on open streets without passengers.[200] In January 2021, the Tainan City government issued a press release noting that the buses had completed tests without passengers and that trial runs with passengers onboard would begin in February 2021.[201] Testing was completed in March 2021 and included transporting more than 800 passengers.[202] An April 2021 press release from the Tainan City government stated overall feedback on the pilot was positive and the pilot was extended for another year. The press release also identified several areas for improvement to be addressed during the next phase of the pilot.

[198] LILEE Systems. (2018, February 18). *LILEE Systems Partners with Leading Transportation Companies To Develop Driverless Buses in Taiwan*. [Press release]. https://www.lileesystems.com/announcements/lilee-systems-partners-with-leading-transportation-companies-to-develop-driverless-buses-in-taiwan/.

[199] LILEE Systems. (2020, March 23). *LILEE Systems selected to drive the first revenue-generating autonomous bus for Tainan's smart transit system*. [Press release]. https://www.lileesystems.com/press-releases/selected-for-first-revenue-generating-autonomous-bus/.

[200] LILEE Systems. (2020, August 10). *LILEE Systems launches autonomous rapid transit services in Taiwan.* PR Newswire. https://www.prnewswire.com/news-releases/lilee-systems-launches-autonomous-rapid-transit-services-in-taiwan-301108824.html.

[201] Liao, G. (2021, January 31). *Taiwan's Tainan to conduct self-driving bus tests with passengers*. Taiwan News. https://www.taiwannews.com.tw/en/news/4116435.

[202] Tainan City government. (2021, April 22). *Tainan Team of Self-driving Buses Signs Letter of Intent. Mayor Huang Hopes Autonomous Bus Operations Can Be Transferred to Private Sector As Soon As Possible*. [Press release]. https://www.tainan.gov.tw/en/News_Content.aspx?n=13205&s=7759238.

In 2022, LILEE completed three projects in Taiwan. The passenger-carrying demonstration in Tainan ended in April 2022. Another project focused on infrastructure-based systems that could monitor pedestrian and traffic light status and broadcast that information to ADS-equipped buses was completed in September 2022. The third project, which integrated the passenger-carrying service with the operational control center and dispatching center, completed technical validation goals and concluded in October 2022. The technology used in these proof-of-services will be on display to the public at Tainan's city hall until December 2023.

LILEE has another potential project at Taiwan's Taoyuan International Airport for the brand-new Terminal 3, which is currently under construction. The new service will use a bidirectional ADS-equipped bus on a 1.4-mile (2.2-kilometer) route, and it is scheduled to begin operations in 2026 when Terminal 3 opens to the public. When the legacy people mover system that serves Terminals 1 and 2 reaches its retirement age, the new system could be extended to serve the entire airport (including Terminals 1, 2, and 3).

National Competitions

Some countries have created competitions to encourage development and accelerate deployment of ADS-equipped transit vehicles. Israel and the United Arab Emirates have both taken this approach.

In April 2022, the Israel Ministry of Transportation, the National Authority for Public Transportation, the Innovation Authority, and the Ayalon Highway Company announced an approximately $6 million national initiative to conduct public transportation pilots with automated vehicles.[203] The initiative is split into two parts. The first phase will connect autonomous driving developers with public transportation operators to conduct testing. Companies that can demonstrate successful, safe autonomous driving will move to the second phase and will be awarded a license to carry passengers in their automated vehicles as part of a new transportation service. The project is expected to deliver autonomous vehicles that are open to the public within two years. In early November 2022, the Ministry of Transport, the Israel Innovation Authority, and Ayalon Highways announced four teams selected to conduct ADS-equipped bus pilots.[204] The teams include:

[203] Israel Ministry of Transportation and Road Safety. (2022). "Promote autonomous public transportation." Last updated April 13, 2022. https://www.gov.il/he/departments/news/autonomous-public-transportation.

[204] Israel Ministry of Foreign Affairs. (2022). "Autonomous bus trials to begin shortly." Last updated November 6, 2022. https://www.gov.il/en/departments/general/autonomous-bus-trials-to-begin-shortly-6-nov-2022.

- Metropolin, B.G. Motors, Karsan, ADASTEC, Applied Autonomy, and Ottopia
- Egged and an undisclosed French technology developer
- Dan, Via, EasyMile, Enigmatos, and Ottopia
- Nateev Express and Imagry

Dubai RTA launched its third Dubai World Challenge for Self-Driving Transport 2023 with a focus on ADS-equipped buses.[205] The challenge has two entry categories: industry leaders and local academia. International autonomous driving system companies may enter through the industry leaders category as long as they are operating a vehicle at least 5.6 meters long that can carry at least 12 passengers. The local academia category includes UAE-based universities and research institutions and will be focused on improving the passenger experience rather than delivering complete autonomous driving solutions.

New Transit Bus and Shuttle Platforms

While many new transit bus and shuttle platforms for use in the United States were discussed in other sections, several companies are also developing new ADS-equipped bus and shuttle platforms to be used in various pilots around the world. Some of these new platforms have novel designs, whereas others adapt existing conventional vehicle platforms that are already in production. Some examples of the companies developing ADS-equipped platforms for other markets include:

- **Auve Tech:** The company launched its next generation 4.2-meter (14-foot) ADS-equipped electric MiCa shuttle capable of carrying up to eight passengers.[206] The vehicle can operate in snowy or rainy conditions. Auve Tech has partnered with BOLDLY to pilot the shuttle in Japan.
- **MOGO Bus and Xiamen Golden Dragon Bus:** The two companies began producing the MOGO BUS M1 (a shuttle) and the MOGO BUS M2 (a bus) in Xiamen, China.[207]
- **Navya and Bluebus:** The two companies developed two ADS-equipped 6-meter (20-foot) IT3 model buses capable of carrying up to 34 passengers.[208] They plan to conduct closed-facility testing in France

[205] Dubai Roads and Transport Authority. (2022). "Challenge 2023 – Overview." Dubai World Congress for Self-Driving Transport. Accessed November 2022. https://sdcongress.com/challenge-overview-2023/.
[206] Auve Tech. (2022, October 24). *BOLDLY partners with Estonia-based Auve Tech to roll out new autonomous shuttle "MiCa" in Japan*. [Press release]. https://auve.tech/uncategorized/auve-tech-launched-a-new-generation-self-driving-vehicle-mica/.
[207] Pandaily. (2022, September 23). *Tencent-Backed Mogo Auto Unveils Autonomous Mass Production Bus*. https://pandaily.com/tencent-backed-mogo-auto-unveils-autonomous-mass-production-bus/.
[208] Navya. (2022, October 14). *Navya and Bluebus achieve a key milestone in the automation of the 6 meter IT3 bus*. [Press release]. https://navya.tech/en/navya-and-bluebus-achieve-a-key-milestone-in-the-automation-of-the-6-meter-it3-bus/.

beginning in late 2022 as part of the Emergence d'une Filière Industrielle Bus Autonome (EFIBA) project, with further pilot testing to follow in 2023.

- **Navya and Lohr:** The two companies announced a partnership to design an ADS-equipped electric Cristalya shuttle capable of carrying up to 18 passengers.[209] The vehicle will be based on the Lohr Cristal model.
- **Perrone Robotics and Rampini:** The two companies announced a partnership to produce ADS-equipped 6-meter (20-foot) electric low-floor SIXTRON buses.[210] Perrone Robotics plans to begin pilots with the new platform in 2023.
- **QCraft and Dongfeng Motor Corporation:** The two companies partnered for the development and production of the Sharing Bus and shared plans to launch it in Wuhan, China.[211]
- **WeRide and Yutong:** The two companies partnered to build an electric Robobus shuttle platform.[212] They began testing on Guangzhou International Bio Island in China in 2021 and launched a public service on two routes in January 2022.

[209] Navya. (2022, September 22). *Navya and Lohr form a strategic alliance to speed up their technological, industrial and commercial development in the field of autonomous mobility.* [Press release]. https://navya.tech/en/navya-and-lohr-form-a-strategic-alliance-to-speed-up-their-technological-industrial-and-commercial-development-in-the-field-of-autonomous-mobility/.

[210] Perrone Robotics. (2022, October 12). *Perrone Robotics and Rampini announce Partnership to Provide Automated 6-meter Electric Buses*. PR Newswire. https://www.prnewswire.com/news-releases/perrone-robotics-and-rampini-announce-partnership-to-provide-automated-6-meter-electric-buses-301647316.html.

[211] Pandaily, (2021, December 30). *QCraft and Dongfeng Yuexiang Partner Up With Sharing Bus.* https://pandaily.com/qcraft-and-dongfeng-yuexiang-partner-up-with-sharing-bus/.

[212] WeRide.ai. (2022, January 7). *WeRide launches fully driverless Robobus service to the public.* https://werideai.medium.com/weride-launches-fully-driverless-robobus-service-to-the-public-6d6bab0c0a0e.

Section 4 Key Themes

The original *Transit Bus Automation Market Assessment* report from October 2019, along with its 2020 and 2021 addenda, characterized the state of the market and identified several key themes. While many of those previous findings still hold, this new edition of the report updates and expands upon them. Key themes identified during the research and preparation of this report include the following.

Development and commercialization of driving automation systems for transit bus applications is still at an early stage.

- **System Maturity:** Media coverage related to new transit automation products or capabilities is often ahead of actual technology development. A few transit bus ADAS features exist (e.g., driver warning and alert features), though they do not include automated actuation. Automated driver support features and ADS for transit buses have not yet been commercialized and, to the extent that they exist, can be considered prototypes at this point in time. Given the current state of research and development, such systems are still at least a few years away from early commercial availability. It will likely be a few more years beyond that before systems are available in the quantities and with the capabilities needed to move beyond pilot testing and support broader deployment in revenue service.
- **Cost and Price Estimates:** Publicly available information on technology costs and prices is quite limited. Given that nearly all systems with automated actuation exist only as prototypes (if they exist at all), cost estimates vary widely, prices may not be firmly established, and they may be subject to change.
- **Timing Estimates:** Company timelines to commercialization and mass production are largely unavailable. Some firms have publicly announced targets for certain capabilities, but such goals are often vague and may need to be revised. Many previously announced timelines related to ADS development for other modes have been pushed back or discarded.

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:** The relatively low-volume market for buses, high level of customization demanded by transit agencies, and constrained resources for investing in transit pose a challenge for developing ADAS and ADS systems for transit buses. The small overall market and small orders from individual transit agencies reduce the number of buses that R&D, testing, and validation costs can be spread over. This results in high costs on a per

unit basis, disincentivizing investment in new products and technologies and limiting commercialization. To overcome this challenge, some organizations have proposed larger-scale projects or joint procurement activities.

- **Transferability:** Current driving automation technology for other vehicle formats (e.g., ADAS for light-duty passenger vehicles or heavy-duty commercial trucks) addresses use cases that may have limited applicability for transit service and require substantial work to adapt to transit bus architectures and control systems. Many of the lower-level automation systems currently available for heavy-duty vehicles are intended to operate at high speeds on divided highways, while most transit buses operate at low speeds on urban roads. In addition, current sensing technology has too many false positives to be implemented in transit operations, especially due to concerns about standees and unrestrained passengers.

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:** While bus architectures are slowly evolving and becoming more conducive to drive-by-wire integration, many challenges remain particularly with respect to the availability of systems and components that are reliable, redundant, and validated. In addition, since product cycle times are long, bus manufacturers have the challenge of designing a bus architecture that can integrate with technologies that may not be specified or available for years. Such architecture designs aim to be flexible enough to accommodate the addition of those future technologies without adding substantial cost to the vehicle.
- **Vehicle Formats:** While many of the earlier ADS pilots and demonstrations used low-speed shuttles with novel designs, those vehicles typically had challenges meeting regulatory requirements (e.g., FMVSS, ADA, and Buy America). Recent efforts have been announced to develop next-generation shuttles that meet regulatory requirements, but companies have also begun to develop prototypes using traditional bus formats such as 40-foot city transit buses and smaller buses (e.g., cutaways), which have higher passenger capacities and already meet regulatory requirements.
- **Factory Installed Systems:** While retrofit systems may be useful for small, agile proof-of-concept testing with early prototype vehicles, transit agencies prefer to work with bus manufacturers for safe, scalable, and integrated solutions. As the market develops systems that may be used in pilots with riders drawn from the public, there is a preference to work with bus manufacturers and install equipment as buses are assembled rather than after they leave the factory. These arrangements help address

warrantee and liability concerns, improve quality and consistency in installation, and reduce the likelihood of added equipment conflicting with other bus systems.

- **Partnerships:** Bus manufacturers, ADAS and ADS developers, and other suppliers have partnered to bring new technologies into buses and in many cases have announced their partnerships. These partnerships are often non-exclusive, meaning that the same ADS developer may apply its system to vehicles from many different companies, or that a bus manufacturer may consider integrating systems from different ADS developers into its vehicles. For example, RRAI is working with both Gillig and New Flyer, the two largest full-size transit bus developers. Similarly, Perrone Robotics is working with GreenPower, Lightning eMotors, Mobility Trans, Phoenix Motorcars, and Rampini, which all produce smaller buses.

Component technologies that enable automation are maturing and there are more commercially available options for many systems on the market.

- **Powertrain Technology Preferences:** Electric powertrains are a common choice for automated buses, but they are not necessarily seen as required for integration with ADS. Electric buses are currently seen as a new and improved technology that aligns with transit agency interest and available funding. Most transit bus automation projects using new vehicles have chosen buses with electric powertrains, but the choice is not necessarily driven by a technical need. While electric buses may have some benefits related to having more information available or electronic control integration, they may also face additional challenges related to energy consumption or design constraints related to space and battery pack placement.
- **Sensors:** The availability, capability, and affordability of sensor technologies (e.g., camera, infrared, lidar, radar, and ultrasonic systems) continue to improve due to competition from the many companies that produce sensor units. Some sensor technologies are relatively mature commodities that are widely available on the market, while others are being developed and improved. Sensor suites for transit bus systems will likely include a variety of sensors that complement each other's capabilities.
- **Connectivity:** There is interest in wireless technologies to enable transit priority at intersections or to allow communication between buses and first responder vehicles. However, those applications may be valuable independent from automation and they are not necessary to enable ADS operation. Connected intersections that broadcast information on signal phase and timing are important for some ADS, though many systems can interpret traffic light status through machine vision. The broadcasts serve as a redundant sensor (to validate camera-based sensing) or to enable smoother braking, improving passenger comfort and energy management.

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 Domain (ODD):** Protected and controllable environments such as bus yards, dedicated lanes, closed campuses, or military bases are easier for ADS-equipped transit bus operation. While transit service on fixed routes or other geographically limited-service areas may be more conducive to automation than other transportation applications, ADS for transit buses and shuttles face many challenges. For instance, ADS-equipped transit buses may not be able to operate at higher speeds safely and reliably or in adverse weather (e.g., heavy rain or snow). In most cases, attentive onboard safety operators will be needed to manage disengagements, including those caused by the vehicle exiting its operational design domain (e.g., because of a change in weather, lighting, or traffic conditions).
- **Bus Yard Automaton:** In the past year or two, there has been more discussion about the use of ADS-equipped buses in bus yards (e.g., to park and recall buses or move them to maintenance facilities or through fueling/recharging and bus wash stations). While bus yards may be easier for current technologies to manage, bus yard applications are less visible and they may address more limited transit agency needs. In addition, the sensor equipment added to a bus may face challenges in a bus yard environment (e.g., lenses may be susceptible to scratches from traditional bus wash bristles). Depending on the characteristics and needs of a specific transit agency, transit bus automation for yard operations may have a business case on its own or it may not provide enough value to justify investment.
- **Automated Bus Rapid Transit (BRT):** Driving automation systems applications on BRT lanes have also seen more discussion in public fora. While such BRT systems would operate in revenue service while transporting passengers, they also present a simplified ODD as they provide service on fixed guideways and dedicated transit lanes. As a result, they may be an early demonstration opportunity for transit agencies with existing BRT infrastructure. Some of the pilots and demonstrations that have recently occurred or will begin soon are focused on BRT-related applications.
- **Driver Support Features:** While non-automated ADAS for buses have existed for a few years, systems with automated actuation of foundational systems (e.g., steering, acceleration, deceleration, or braking) are beginning to be applied to transit bus applications. Bus manufacturers and ADAS developers are working together to create and integrate new ADAS features that do include automated control.

- **Goods Movement**: Although it is outside of the scope of transit service, using ADS-equipped vehicles for goods movement is seen as a more practical, near-term application with a positive return on investment and a business case. Interest in automation for goods movement applications is further driven by a tight labor market where ADS could free qualified drivers to work on other high-value activities. In some cases, companies are prioritizing goods movement applications or looking to get into goods movement in addition to transit service.

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:** While some future concepts envision the shift to unstaffed operation, the desire for an official staff presence aboard may mean transitioning operator roles away from driving the bus to more customer-centric, service-oriented tasks such as assisting passengers and providing information on the service. For at least the next few years, however, ADS will remain prototype systems, so onboard staff will likely maintain roles like those of conventional bus drivers. Additional training or certification processes are currently determined by transit agencies or private sector partners, but as the technology matures, there may be opportunities for standards or guidance to improve those processes. Moving forward, however, transit staff will require new workforce skills and capabilities, both for onboard safety operators and support staff (e.g., maintenance workers and remote monitoring and assistance staff). Transit agencies are increasingly aware of workforce training needs due to the adoption of other technologies (e.g., new vehicle powertrains and new information systems). Although it may be too soon for most transit agencies to invest in such training, some agencies (domestically and abroad) are beginning to address those future workforce needs. Some agencies have expressed the view that work with ADS may be a potential strategy to attract younger workers to transit jobs.
- **In-Vehicle Unstaffed Operation:** Companies continue to develop and test systems for unstaffed operation, though testing varies by vehicle format. However, current pilot and demonstration practices do not include unstaffed operation of ADS-equipped transit buses in revenue service on public roads under mixed-traffic conditions. Some companies have started operating unstaffed buses with passengers present, but only in highly controlled, closed environments and overseas. Unstaffed operation is slightly more common for low-speed shuttles than it is for transit buses, but in the United States it remains limited to closed-course testing without passengers from the public. Some companies providing on-demand service in light-duty vehicles have begun operating unstaffed vehicles, first with company employees, then transitioning to pre-approved members of

the public, and eventually opening service to the general public. However, such service is limited to a few select cities and not broadly available. Many transit agencies have expressed the need for an official staff presence on their buses to serve as an ambassador and assist users who require it.

Implementing driving automation systems in transit buses is a big investment and funding may be a challenge, especially as fare collection is rare for pilots and transit agencies face resource constraints while trying to meet their core missions.

- **Fare Collection:** Though fare collection is relatively uncommon in transit bus automation pilots, some services are incorporating it. In the United States, the Arlington RAPID service has collected standard or discounted fares. Similarly, during the on-demand service pilot that Valley Metro conducted with Waymo, riders paid standard RideChoice fares. The CTDOT CTfastrak project will also collect fares from riders, although it has not yet begun the demonstration in revenue service operations.
- **Competing Priorities:** The COVID-19 pandemic and the accompanying drop in fare revenues have led many transit agencies to reevaluate priorities and, in some cases, defer ADAS and ADS projects. Given that driving automation systems are relatively immature technologies and there are limited resources to meet core missions, some transit agencies that had considered transit bus automation pilots and demonstrations may choose to defer or cancel those efforts to free up resources for other priorities that support core mission services.
- **Public Funding:** Industry representatives noted that demonstration and pilot programs are essential to making technological progress and answering questions on the feasibility of ADAS and ADS systems for transit buses. Multiple interviewees noted that the high cost of pilots and demonstrations is prohibitive without government grants to help enable research, demonstration, and implementation.

Section 5 Conclusions

The ADAS and ADS markets for transit buses are still in their infancy. Although many concept vehicles and systems exist, and some have been developed into prototypes, few, if any, systems with automated actuation have been commercialized. Media coverage may add to the confusion if it does not communicate realistic timelines for implementation or clearly differentiate conceptual ideas and prototypes from commercially available products.

This market assessment is intended to help appropriately manage expectations and communicate a realistic depiction of the current state of the industry with respect to the availability, capabilities, and limitations of transit bus automation technologies. It aims to inform FTA staff, transit agency stakeholders, and others interested in understanding the market.

Key findings from the report indicate that:

- The **development and commercialization** of driving automation systems for transit bus applications is still at an early stage and less advanced than it is sometimes portrayed in media reporting or marketing materials. To the extent that they exist, cost estimates and commercialization timelines are tentative.
- The **small size of the transit bus market** compared to other vehicle formats and the difficulty in adapting driving automation systems from one platform to another (i.e., from light-duty passenger vehicles and heavy-duty commercial trucks to transit buses) has slowed the introduction of driving automation systems to transit buses.
- **Bus architectures** are evolving to integrate more readily with driving automation systems and prototype vehicle models are increasingly chosen for their compatibility with transit service needs (e.g., regulatory requirements). Private sector firms are partnering to expand the availability of ADAS and ADS in different bus formats and to enable factory installation of those systems.
- **Component technologies** (e.g., electrified powertrain systems and various sensors) that enable automation are maturing and there are more commercially available options for many systems on the market. Systems that augment vehicle sensor suites, such as connectivity technologies, are also being developed and tested.
- Many pilot and demonstration activities are focusing on **near-term applications in simplified ODDs**. Bus yard automaton and automated BRT applications have received increased interest in recent years and may present a simplified ODD that addresses transit agency needs and capabilities. ADAS features with automated actuation have also received more attention and are appearing in transit bus applications. The draw

of freight applications may lead some firms to focus on goods movement instead of passenger service applications.

- **Transit agency staff** will continue to play an important part in enabling transit service. New roles will emerge as driving automation systems for transit buses continue to mature, resulting in new workforce needs. Unstaffed operation has been limited in transit bus pilots (and non-existent in U.S. pilots) and demonstrations, but it could enable new types of transit service and create new types of transit jobs.
- While transit agencies may be able to link implementing driving automation systems in transit buses with current challenges or broader goals, such as improving safety, mobility, and efficiency, it will be a **big investment and funding may be a challenge**. This is especially true as fare collection is rare for pilots and transit agencies face resource constraints while trying to meet their core missions. Public funding of pilot and demonstration projects may enable industry and transit agency partners to conduct testing and evaluation of driving automation systems for transit buses.

Many of the findings from the original 2019 Market Assessment report hold true today, such as limited commercialization of products, uncertainty in costs and timelines, and challenges in developing and implementing systems, though some things have changed. For instance, the vehicle formats have changed, there are more companies with publicly announced work and partnerships, and the use cases targeted by pilot and demonstration activities have shifted. Overall, activity in driving automation systems for transit bus service has increased and more organizations are participating in related work.

Obtaining an accurate assessment on the state of the market is difficult, but transit agencies need reliable information to support planning of longer-term initiatives related to the procurement, testing, and deployment of ADAS and ADS in transit buses. As the industry matures and more products enter the market, more information should become available, though in most cases progress is expected to be incremental. FTA will continue to monitor developments in this area and seek to share information to keep relevant stakeholders updated.

Appendix A Companies Contacted

The research team contacted several companies during this research, both over the past year and in previous years' editions of the *Transit Bus Automation Market Assessment* report. The team scheduled meetings with the following transit bus manufacturers, systems suppliers, transit operator firms, low-speed shuttle providers, driving automation system developers, and others listed below. Organizations that participated in discussions for this edition of the report are marked with an asterisk (*).

Transit Bus Manufacturers

- Gillig Corporation*
- GreenPower Motors*
- New Flyer*
- Phoenix Motorcars*
- Proterra
- Volvo (Nova Bus)*

Systems Suppliers

- Bendix
- Continental
- Mobileye
- ZF/TRW

Transit Operator Firms

- Beep*
- Via*

Low-Speed Shuttle Providers

- 2getthere
- EasyMile*
- Local Motors
- Navya

ADAS and ADS Developers

- ADASTEC Corp.*
- LILEE Systems*
- Motional
- May Mobility*
- Perrone Robotics*
- RRAI*

Other Organizations

- AECOM (ABC)
- CALSTART (CATUF)
- Trenton MOVES*

Acronyms and Abbreviations

ABC	Automated Bus Consortium
ACC	Adaptive cruise control
ADA	Americans with Disabilities Act
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving Systems
AEB	Automatic emergency braking
AIM	Accelerating Innovative Mobility
APTA	American Public Transportation Association
BRT	Bus rapid transit
BSM	Blind spot monitoring
BUILD	Better Utilizing Investments to Leverage Development, now renamed Rebuilding American Infrastructure with Sustainability and Equity (RAISE) and previously known as Transportation Investment Generating Economic Recovery (TIGER)
CATA	Capital Area Transportation Authority
CATUF	Connected and Automated Transportation Users Forum
CCTA	Contra Costa Transportation Authority
CTDOT	Connecticut Department of Transportation
ELATE	Enhancing Life with Automated Transportation for Everyone
FCW	Forward collision warning
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GSP	Greenville-Spartanburg International Airport
Houston METRO	Metropolitan Transit Authority of Harris County
IMI	Integrated Mobility Innovation
JTA	Jacksonville Transportation Authority
LDW	Lane departure warning
LKA	Lane keep assistance
MCI	Motor Coach Industries
MDOT	Michigan Department of Transportation
MSU	Michigan State University
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NOFO	Notice of funding opportunity
NTD	National Transit Database
ODD	Operational design domain
PANYNJ	Port Authority of New York and New Jersey
R&D	Research and development
RAPID	Arlington Rideshare, Automation, and Payment Integration Demonstration
RFEI	Request for expressions of interest

RFI	Request for information
RFP	Request for proposals
RRAI	Robotic Research OpCp, LLC
RTC	Regional Transportation Commission of Southern Nevada
SAE	SAE International, formerly the Society of Automotive Engineers
SANDAG	San Diego Association of Governments
SHOW	SHared automation Operating models for Worldwide adoption
STAR Plan	Strategic Transit Automation Research Plan
SwRI	Southwest Research Institute
TNC	Transportation network company
Trenton MOVES	Trenton Mobility and Opportunity: Vehicles Equity System
ULTIMO	Advancing Sustainable User-centric Mobility with Automated Vehicles
USDOT	United States Department of Transportation
UTA	University of Texas at Arlington
UTA	Utah Transit Authority
VTA	Santa Clara Valley Transportation Authority
WRTA	Western Reserve Transit Authority

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