FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Transit Bus Automation Market Assessment

OCTOBER 2019

FTA Report No. 0144
Federal Transit Administration

PREPARED BY
Federal Transit Administration
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)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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13. ABSTRACT

FTA has conducted research on conceptual ideas, prototypes, and commercially available products related to automated vehicle technologies for transit bus operations. The emerging automated transit bus market has received enthusiastic media coverage, but stakeholders may not clearly understand the difference between conceptual ideas, prototype systems, and available products. To help align expectations with reality and assist in transit agency planning, this market assessment report conveys the state of automated transit bus technology in terms of its availability, capabilities, and limitations. It aims to inform the Federal Transit Administration, 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. This report references company and product names, but they are included only for illustrative purposes and do not represent an endorsement.

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Abstract

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EXECUTIVE SUMMARY

The emerging automated transit bus market has received enthusiastic media coverage, but stakeholders may not clearly understand the difference between conceptual ideas, prototype systems, and available products. To help align expectations with reality and assist in transit agency planning, this market assessment report conveys the state of automated transit bus 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 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. Whereas this report references company and product names, they are included only for illustrative purposes and do not represent an endorsement.

To gather relevant information, research staff conducted a scan of literature and arranged meetings with industry representatives, including bus manufacturers, suppliers, and new entrants (such as automated shuttle providers). These efforts helped research staff learn more about current and future products (including their characteristics, availability, and costs), research and commercialization activities, and commercialization challenges.

Key findings from the report include the following:

- Media coverage related to new transit bus automation products or capabilities is often ahead of actual technology development. Currently, the transit bus automation systems that have been developed are in the pilot testing stage or earlier stages of development.
- Technology costs are unknown at this point, because the transit bus automation systems that exist are prototypes rather than commercialized products.
- Current automation technology for other vehicle types addresses use cases, such as highway driving, which may have limited applicability for transit service.
- Bringing automation technology into buses is difficult due to the relatively low volumes and high level of customization in the current domestic bus market, as well as a perceived lack of interest from transit agency customers.
- Although the technology may not be available currently, bus manufacturers are working with suppliers to understand the development timelines for new features and have high-level roadmaps for their introduction.
- A high degree of uncertainty in areas such as pedestrian and occupant behavior and safety, insurance and liability, operator acceptance, and new service models may pose additional barriers to commercialization. There are additional needs in the areas of communication and education.

- Industry representatives noted that Federal funding for demonstration and pilot programs is essential to making technological progress and answering questions on the feasibility of automation 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.

SECTION 1

Introduction

Automated vehicle technologies 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 prototypes on public roads, and introducing advanced driver assistance features on new production vehicles. Automation is being applied to all on-road modes of transportation, including personal vehicles, taxis, commercial trucks, and transit buses. Whereas the emerging automated transit bus market has received enthusiastic media coverage, stakeholders may not clearly understand the difference between conceptual ideas, prototypes, and available products. This market assessment is intended to help communicate the realities of automated transit bus technology in terms of its availability, capabilities, and limitations.

Purpose

To support the development and deployment of automated bus transit services, the U.S. Department of Transportation (USDOT) Federal Transit Administration (FTA) has 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 what technologies are commercially available or may become commercially available in the near future. It also discusses some of the challenges impeding development and commercialization of transit bus automation technologies. 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 in this report 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 a draft of the Strategic Transit Automation Research Plan document, visit https://www.transit.dot.gov/research-innovation/strategic-transit-automation-research-plan.

[2] SAE Level 0 systems include both systems without any automation that provide warnings to drivers (e.g., collision warning systems), and systems which provide momentary automated control of the vehicle (automatic emergency braking). Systems that provide momentary automated control of the vehicle are considered within 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. SAE International (2018), "J3016_201806: 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_201806/.

actuation (e.g., automated braking, steering, or throttle), it also, to some extent, addresses driver warning systems with limited or no automation. 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 (e.g., ranging from smaller shuttle vehicles to 40-ft transit buses and longer articulated buses). Whereas this report references company and product names, they 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 for transit bus automation. The findings from this scan are documented in this report and were used to inform an industry outreach effort through phone interviews and in-person meetings with industry representatives, including bus manufacturers, suppliers, and new entrants, described below:

- **Bus Manufacturers**: Vehicle manufacturers, sometimes called Original Equipment Manufacturers (OEMs), may produce light-duty vehicles (e.g., cars, pickup trucks, vans, and sports utility vehicles) and medium-duty or heavy-duty vehicles (e.g., larger work trucks, construction trucks, semi-trucks, and buses). Bus manufacturers are interested in automation systems for transit buses and are engaged in various activities, including developing technologies in-house, reaching out to suppliers who are developing systems, and developing partnerships with other organizations to further research and development (R&D) in this area.
- **Supplier Firms**: Many companies develop, manufacture, and sell components or systems needed to enable automation (e.g., steering, braking, or sensing systems). Some of these suppliers have existing commercialized systems (either in buses or in heavy-duty trucks), and others are working to develop new systems to enable automation.
- **New Entrants:** Unlike the established bus manufacturers and suppliers, some companies are not part of the traditional transit bus supply chain and have more recently become involved in developing technologies for transit bus automation. This category includes providers of automated shuttles, transportation network companies (TNCs)[3] with automated vehicle programs, and companies focused on other aspects of transit bus automation.

[3] TNCs are firms that provide the service of matching passengers with drivers via mobile apps or websites. They are sometimes referred to as ride-hailing services and include companies such as Uber and Lyft.

Research staff engaged with company representatives to learn more about current and future products (including their characteristics, availability, and costs), research and commercialization activities, and commercialization challenges.[4] Appendix A lists the organizations contacted for this report.

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.

Report Organization

Section 2, "Market Assessment," discusses relevant companies and product types along with their current market availability and future outlook. Section 3, "Selected Research and Pilot Project Summaries," provides background on domestic and international efforts to develop and test transit bus automation systems. Section 4, "Conclusions," provides concluding remarks, including key takeaways and potential implications for FTA and public transportation decision-makers.

[4] Interviewees were asked to not share confidential business information during these meetings.

SECTION 2

Market Assessment

Media coverage of new transit bus automation-related products or capabilities is often ahead of actual technology. Whereas there has been significant progress, development of automation systems for transit buses has been gradual, and such systems are not yet commercially available. Industry representatives stressed the importance of managing expectations and communicating to their transit agency customers the realities of the technology in terms of its availability, capabilities, and limitations.

To date, no suppliers offer a commercialized product for automating steering or braking in transit buses, although some of the components needed to support those systems exist. Similar systems have been developed and installed in other heavy-duty vehicles (e.g., commercial trucks, motor coaches, and school buses) to enable adaptive cruise control (ACC), automatic emergency braking (AEB), and lane-keeping functions. Some buses are using sensor-based, non-automated systems that provide warnings to drivers, although these systems have begun appearing in transit buses only relatively recently and are not particularly common; they are typically installed as retrofit systems rather than being integrated by bus manufacturers in the factory.

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 (typically between 10 and 15 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.

The following subsections discuss bus manufacturers, system suppliers, and new entrants (e.g., shuttle providers and TNCs). To the extent that products exist, they are identified and described at a high level. In cases in which a company does not have commercialized products but is engaged in relevant activities to develop or test automation systems, those activities are described.

Bus Manufacturers

The U.S. transit bus market is relatively small, with annual sales to transit agencies of between 8,000 and 9,000 transit buses, according to the National Transit Database (NTD).[5] These sales are split roughly equally between models that are 30 ft or longer (including articulated buses) and shorter buses (e.g., smaller "cutaway" buses built on a truck chassis, such as those frequently used for paratransit service). For context, annual U.S. sales of Class 8 trucks (i.e., tractor-trailer trucks) are approximately 200,000 units,[6] and annual U.S. sales of light-duty vehicles (e.g., cars, vans, pickup trucks, and sports utility vehicles) are approximately 17 million units. For each bus sold in the United States, there are more than 20 Class 8 trucks sold and approximately 2,000 light-duty vehicles sold.

Similarly, there are relatively few bus manufacturers that supply 30-ft or longer buses to transit agencies in the United States. The largest bus manufacturers are Gillig and NFI Group (parent of New Flyer),[7] which together represent approximately 75% of all buses (not including cutaways) identified in the NTD in recent years.[8] Among other manufacturers that provide buses to U.S. transit agencies are REV Group (parent of El Dorado, Champion, Goshen, and several other brands) and Volvo (parent of Nova Bus), which each sell 200–500 buses annually, as well as many even smaller companies—Blue Bird, BYD, Freightliner, Glaval, International, Proterra, Starcraft, Startrans, and Thomas Built—which together sell 200–300 buses to U.S. transit agencies annually.

The market for buses shorter than 30 ft in length is divided more evenly among different providers. REV is the largest manufacturer in this category, representing just over a quarter of all sales to transit agencies. Coach and Equipment, Elkhart Coach, Gillig, Glaval Bus, NFI (ARBOC), Starcraft, and Startrans each sell between 100 and 400 buses to transit agencies each year.

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[5] In addition to the buses sold to transit agencies that report in the NTD, transit buses are sold to other organizations (e.g., cutaway buses used for hotel shuttle service), and those buses are not included in this estimate. These numbers also do not include over-the-road coaches (e.g., large buses such as those used for intercity travel or to provide tours). NTD (2019), "2011–2017 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.

[6] ORNL (2017), Figure 98: Class 8 Truck Sales by Manufacturer, 2012–2016, from "Vehicle Technologies Market Report," Oak Ridge National Lab, May 25, 2017, https://cta.ornl.gov/vtmarketreport/index.shtml.

[7] NFI Group was formerly known as New Flyer Industries. The company acquired the third largest U.S. bus manufacturer, North American Bus Industries (NABI), in 2013. It also acquired Motor Coach Industries (a motor coach manufacturer) in 2015, ARBOC Specialty Vehicles (a mid-sized bus company) in 2017, and Alexander Dennis (a British bus and coach manufacturer) in 2019.

[8] *Ibid.*, NTD.

Scalability of Automation Systems

Market scale becomes an issue with respect to developing or adapting automation systems for transit buses. In general, suppliers are not developing new automation systems primarily for transit buses because the potential addressable market is so much smaller than it is for other vehicle types. Instead, suppliers typically focus on developing new technologies for light-duty markets first, as the relatively large market means that a successful product may make it into tens or hundreds of thousands of vehicles each year, allowing the company to spread its R&D costs among many vehicles. 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 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 adapted 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 to be implemented in a new vehicle platform, it may be difficult to justify the R&D investment for small markets. The transit bus market faces other challenges with respect to implementing new technologies, including a lack of technologies applicable to transit bus service (e.g., most systems for heavy-duty vehicles focus on highway applications rather than slower, urban environments), 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 sets of features that transit agencies request when placing orders for buses; thus, bus manufacturers adapt bus designs to meet the needs of each transit agency customer rather than producing a single, standardized bus. In some cases, 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 the other requirements of the transit agency, potentially requiring more testing and validation, and adding more cost to including a new system in a bus.

Applicability of Existing Technologies

Not all existing technologies will be applicable to transit service. Whereas some existing 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.

Customer Interest

Many industry representatives noted that they have heard relatively little interest from transit agency customers regarding automation systems for transit vehicles, although a few noted 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 OEMs 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

Although they may not be installing automation systems in their buses yet, bus manufacturers are talking to suppliers to assess when relevant automation systems are likely to be available. Most manufacturers are also developing or have already developed internal roadmaps for future technology. Often, these roadmaps do not contain firm dates, as there is uncertainty regarding the evolution of the technology. Compounding this uncertainty further, some systems require the development and implementation of other systems before commercialization will be feasible; for example, development of an electronically-actuated braking system for transit buses is a prerequisite for a transit bus AEB system.

Collaboration

Industry coordination is in a relatively nascent stage, with little to no coordination among bus manufacturers on non-competitive research, although some bus manufacturers are working with suppliers, transit agencies, or researchers at universities or other institutions. Relationships between bus manufacturers and suppliers are critical to testing and deployment, and one industry representative noted that fostering relationships with progressive transit agencies could enable more experimentation and progress. Some of the industry representatives suggested that greater manufacturer and supplier involvement in automation system standards through participation in committees could be beneficial for progress on 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).

Some transit and transportation agencies are beginning to collaborate on procurement of automated buses; in May 2019, AECOM partnered with several such agencies to form the Automated Bus Consortium.[9] The consortium is investigating the feasibility of implementing automated bus pilots and plans to use its combined purchasing power to accelerate deployment. The consortium expects to make an initial purchase of 75–100 full-sized, full-speed automated buses.

Automated Vehicle Activities

Some companies have made public announcements regarding their automated vehicle activities. In May 2017, Proterra announced a partnership with the University of Nevada, Reno (UNR), the Regional Transportation Commission of Washoe County (RTC), and other partners to test an automated bus on a route in Nevada.[10] In October 2017, New Flyer opened its Vehicle Innovation Center in Anniston, Alabama.[11] The center is designed to conduct R&D, education, and training on automated vehicle and other technologies, including electric buses and telematics systems. In January 2018, New Flyer announced a partnership with Los Angeles County Metropolitan Transportation Authority, which is evaluating safety technologies for buses as part of an FTA Safety Research and Demonstration (SRD) grant,[12] although the project has primarily considered advanced driver assistance systems (ADAS) without an automation component. In May 2019, New Flyer announced additional automated vehicle research and development activities,[13] including a partnership with Robotic Research LLC to develop and test an SAE Level 4 automated bus.[14] Some of these domestic

[9] AECOM (2019), "AECOM Partners with transit and transportation agencies nationwide to form the automated bus consortium," AECOM, press release, May 30, 2019, https://www.aecom.com/press-releases/aecom-partners-with-transit-and-transportation-agencies-nationwide-to-form-the-automated-bus-consortium/.

[10] Proterra (2017), "Emphasizing safe, intelligent transportation, Proterra begins first autonomous bus program in the United States," press release, May 2, 2017, https://www.proterra.com/press-release/emphasizing-safe-intelligent-transportation-proterra-begins-first-autonomous-bus-program-in-the-united-states/.

[11] New Flyer (2017), "New Flyer announces official opening of the Vehicle Innovation Center set for October 12, 2017: North America's first innovation lab for bus and coach technology," Press Release, October 10, 2017, https://www.newflyer.com/2017/10/new-flyer-announces-official-opening-vehicle-innovation-center-set-october-12-2017-north-americas-first-innovation-lab-bus-coach-technology/.

[12] New Flyer (2018), "New Flyer named partner on FTA safety research and demonstration grant for L.A. County's Metro System," press release, January 8, 2018, https://www.newflyer.com/2018/01/new-flyer-named-partner-fta-safety-research-demonstration-grant-l-countys-metro-system/.

[13] New Flyer (2019), "New Flyer launches Autonomous Technology Program for buses; drives safe advancement of public transit technology forward in North America," press Release, May 6, 2019, https://www.newflyer.com/2019/05/new-flyer-launches-autonomous-technology-program-for-buses-drives-safe-advancement-of-public-transit-technology-forward-in-north-america/.

[14] New Flyer (2019), "New Flyer announces Robotic Research partnership to revolutionize public transit using autonomous bus technology," press release, May 15, 2019, https://www.newflyer.com/2019/05/new-flyer-announces-robotic-research-partnership-to-revolutionize-public-transit-using-autonomous-bus-technology/.

projects as well as international efforts are discussed in greater detail in Section 3 of this report.

System Suppliers

Whereas some of the companies that manufacture vehicles develop certain systems in-house, a substantial amount of system development occurs at supplier firms, who then sell those systems to vehicle manufacturers. These suppliers will 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 costs or factory tooling costs) across many units. Many of these suppliers provide systems and components to both light-duty (e.g., passenger cars, pickup trucks, sports utility vehicles, and vans) and heavy-duty vehicles (e.g., commercial trucks and buses). With respect to automation, most of the research, development, and commercialization activity has been focused on light-duty vehicles. Multiple interviewees attributed the light-duty vehicle focus to the large market size (approximately 17 million units in recent years). At this scale, even equipping a small fraction of new vehicles with a particular system or component can mean 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 providing these different systems and components.

Driver Assistance System Firms

Many firms provide ADAS for vehicles, including Autoliv, Bosch, Continental, Delphi, DENSO, Magna, Mobileye, ZF-TRW, and others. ADAS can include driver warnings (e.g., lane departure warning, forward collision warning, and blind spot monitoring) as well as low-level automation features (e.g., ACC, AEB, lane keeping, and automated parking). Some of these systems are compatible only with light-duty vehicles, but some companies have adapted their systems for heavy-duty vehicles as well. For instance, the Mobileye Shield+ system and the Protran Object Detection System can be used on heavy-duty vehicles, and both systems have been installed on buses. Both the Mobileye system and the Protran system provide warnings, but they do not include automation features.

Mobileye's Shield+ system is a multi-sensor system that includes forward collision warning, pedestrian and cyclist collision warning, lane departure warning, headway monitoring and warning, speed limit indicator, intelligent high beam control, turn signal reminder, and low visibility indicator.[15] The system's pedestrian and cyclist collision warning system issues a warning to the bus operator when vulnerable road users (e.g., pedestrians or cyclists) are in the danger zones on the side or front of the bus, assisting the operator in avoiding

[15] Mobileye (2019), "Bus, Transit & Municipal," Mobileye website, accessed February 2019, https://www.mobileye.com/en-us/solutions/bus-transit-municipal/.

collisions. The system is mounted inside the vehicle and includes a sensor on the windshield, additional sensors for blind spot detection, and a display on the dash. The Mobileye Shield+ system only provides warnings to the driver and does not include any automated actuation.

The Protran Safe Turn Alert System is a passive system that provides an audible and visual warning to other road users (e.g., pedestrians at crosswalks) whenever the bus is making a turn.[16] The system also provides an audible sound to remind the bus operator to look both ways when turning. Protran also offers a Blind Spot Awareness System that provides an audible and visual warning to the bus operators when objects are detected in blind spot areas. The system provides warnings to the operator through the illumination of lights located on the dashboard. The Protran systems provide warnings only to the other road users and the driver; neither system includes automated actuation.

Sensor Firms

The sensors needed to support automated transit buses may not differ from those used in other vehicle types. Depending on the system and approach, a system could use a variety of sensors, potentially including camera, infrared, lidar, radar, ultrasonic, inertial measurement unit (IMU), and global positioning system (GPS) technologies. A broad range of companies produce sensor units, and some sensors are relatively-mature commodities, whereas others are more actively being developed, improved, and scaled. Although automated transit buses may use the same sensors as other automated vehicles, the number and placement of sensors will likely vary due to the size and shape of the vehicle, 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).

Brake Firms

No supplier firm currently produces an automated braking system specifically designed for transit buses. As heavy-duty vehicles, transit buses have brake systems that differ from those used in light-duty vehicles. Whereas light-duty passenger vehicles primarily use hydraulic braking systems, transit buses use pneumatic braking systems, so automated braking systems for light-duty vehicles will not be 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.

[16] Protran (2019), “Bus Safety,” Protran website, accessed February 2019, http://protrantechnology.com/bus-safety.

Several suppliers of brake systems for heavy-duty commercial trucks have been developing ADAS systems that include automated braking functionality. Although these systems have yet to be adapted for transit buses, they could potentially be a starting point for transit bus AEB or other more advanced features that include automated braking. Firms with commercialized automated braking systems for commercial trucks include Bendix (Wingman), Detroit Diesel (Detroit Assurance), and WABCO (OnGuard):

- **Bendix** purchased the VORAD collision warning system from Eaton in 2009, and since then has developed multiple systems of its own, including Wingman Active Cruise with Braking (ACB), Wingman Advanced, and Wingman Fusion.[17] These systems combine radar, camera, and brake system data inputs to enable applications such as driver warnings, ACC, AEB, and other collision mitigation features. Bendix is currently launching Wingman Fusion 2.0, which has functions including highway departure braking, lane keeping, improved blind spot detection, and a higher level of collision mitigation. In the coming years, Bendix plans to add support for pedestrian and bicyclist detection.
- **Detroit Diesel** 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.[18] Features include AEB (full or partial braking), adaptive cruise control, and driver warnings (e.g., tailgate warning and lane departure warning). Detroit Assurance 5.0 will be available during the second half of 2019, and it will combine inputs from radar and camera systems to enable a range of applications, including lane keep assist, ACC, and AEB.
- **WABCO** has developed a family of driver assistance systems under the OnGuard brand (e.g., OnGuard, OnGuardACTIVE, and OnGuardMAX).[19] Its products include features such as AEB (to avoid collisions with pedestrians and other vehicles), lane keeping, and adaptive cruise control, as well as warning systems for lane departure, turning, pedestrian collision, and blind spot detection.

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 limit application for buses, which, depending

[17] Bendix (2019), "Products," Bendix website, accessed February 2019, http://www.bendix.com/en/products/products_1.jsp.

[18] Detroit Diesel (2019), "Detroit Assurance Suite of Safety Systems," Detroit Assurance website, accessed February 2019, https://demanddetroit.com/technology/safety/.

[19] WABCO (2019), "Advanced Driver Assistance Systems," WABCO website, accessed February 2019, https://www.wabco-auto.com/en/products/category-type/advanced-driver-assistance-systems/.

on the use case being considered, may need braking functionality at lower speeds. In addition, current systems may have little or no warning or actuation for pedestrians or animals, may not reliably track objects (e.g., motorcycles, mopeds, and bicycles), and may not address oncoming vehicles or cross traffic. Detection may be impaired by weather conditions (e.g., snow or heavy rain) or other environmental characteristics.

Steering Firms

No supplier firm currently produces an automated steering system specifically designed for transit buses. As with brake systems for heavy-duty commercial trucks, steering systems in heavy-duty vehicles differ from those used 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, including Bendix, Bosch, Knorr-Bremse (formerly Tedrive), Nexteer, WABCO, and ZF TRW, have commercialized steering products to create electro-hydraulic power steering systems, which can allow the electronic actuation of heavy-duty vehicle steering systems through the addition of equipment to the steering column, large hydraulic gear, or rotary valve. These systems are being used in medium- and heavy-duty trucks to provide ADAS features such as lane keep assist and lane centering. As with automated braking systems, the currently-available heavy-duty vehicle solutions are geared towards higher-speed use cases and may not be applicable to some of the lower-speed use cases of transit buses.

New Entrants

In addition to traditional bus manufacturers and systems suppliers, many new entrants are offering shared rides in automated vehicles. These new entrants include low-speed automated shuttle companies as well as transportation network companies and other startup or technology firms.

Automated Shuttle Firms

Many companies provide automated shuttles, including 2getthere, Coast Autonomous, EasyMile, Local Motors, May Mobility, Navya, Optimus Ride, Ridecell (formerly Auro Robotics), and Robotic Research. Automated shuttles are characterized as vehicles that:

- Use SAE Level 4 automated driving systems (intended for use without a driver, though most current implementations retain an on-board attendant)
- Have an operational design domain (ODD) restricted to protected and less-complicated environments
- Travel at low speeds (typical cruising speeds around 10–15 mph)

- Are used to provide shared service (typically designed to carry multiple passengers, including unrestrained passengers and standees)
- Operate in a shared right-of-way with other road users, either at designated crossing locations or along the right-of-way itself.[20]

Companies appear to be taking two distinct approaches in developing automated shuttles. Some are designing automated shuttles from the ground up, developing both the physical vehicle platform as well as the automated driving system. Others are adapting automated driving systems to existing, commercially-available platforms (including shuttle platforms such as the Polaris GEM e6/e4 or Cushman Shuttle 6 and light-duty vehicles such as the Chrysler Pacifica van or the Nissan NV200 van) and, therefore, are focusing more specifically on the hardware and software necessary to enable automated driving.

Many companies are developing and testing automated shuttles. Although not a comprehensive list, some of the companies providing automated shuttles include the following:

- **2getthere** has been providing automated shuttles for 20 years, starting with its system in Rotterdam, Netherlands, which began operation in 1999.[21] Shuttles from 2getthere typically operate on dedicated lanes and use magnets embedded in the roadway for guidance. The Group Rapid Transit (GRT) shuttle is the latest vehicle produced by 2getthere, and it can carry up to 24 passengers. Later this year, it will replace the older vehicles in Rotterdam and the existing route will be extended to provide service in mixed traffic. The company does not currently operate shuttles in the United States but has been in conversations with potential U.S. clients and has established a relationship with a contract manufacturer (Oceaneering International) to produce vehicles domestically.
- **Coast Autonomous** has produced its own shuttle, the Coast P-1, which has been used in demonstrations in New York and Tampa.[22] In its most recent demonstration during February 2019, the Coast P-1 shuttle operated on the campus of the University of South Florida (USF), where the Center for Urban Transportation Research (CUTR) is working with Coast Autonomous to demonstrate the shuttle along a pedestrian walkway. The

[20] Cregger, J., M. Dawes, S. Fischer, C. Lowenthal, E. Machek, and D. Perlman (2018), "Low-speed automated shuttles: State of the practice final report," U.S. Department of Transportation Report DOT-VNTSC-OSTR-18-03, September 2018, https://rosap.ntl.bts.gov/view/dot/37060.

[21] 2getthere, "Group Rapid Transit," 2getthere website, accessed March 2019, https://www.2getthere.eu/group-rapid-transit/.

[22] Nghiem, A. (2019), "USF hosts its first ever autonomous vehicle demonstration," Coast Autonomous, press release, February 13, 2019, https://globenewswire.com/news-release/2019/02/13/1724305/0/en/USF-Hosts-Its-First-Ever-Autonomous-Vehicle-Demonstration.html.

Coast P-1 shuttle can travel up to 25 mph and can accommodate up to 8 seated passengers and 4 standees.

- **EasyMile** is a French company that designed the EZ10 shuttle and provides automation technology (the vehicle itself is produced by Ligier). The EasyMile EZ10 can travel up to 25 mph and can accommodate up to 6 seated passengers and 9 standees.[23] It was one of the two vehicle models used in the CityMobil2 project, which conducted demonstrations across several European cities between 2014 and 2016. Since those initial tests, the EasyMile EZ10 has been tested in 27 countries, operating on both public and private roads in mixed traffic and in varied weather. It also has been tested at several sites in the United States. Some of the organizations that have used EasyMile shuttles in pilot projects include the City of Arlington (TX), Babcock Ranch (FL), Contra Costa Transportation Authority (CA), Denver Regional Transportation District (CO), Jacksonville Transportation Authority (FL), Minnesota Department of Transportation (MN), Texas Southern University (TX), and Utah Department of Transportation (UT). EasyMile has a North American headquarters in Denver, Colorado. In Q4 2019, EasyMile announced that it plans to release a third generation of the EZ10 shuttle with several new features, including seat belts and ADA-compliant wheelchair anchor points.[24]
- **Local Motors** is a U.S. company that uses 3D-printing methods to produce the Olli shuttle.[25] The Olli can travel up to 12 mph and accommodate up to 8 passengers. The shuttle debuted in June 2016 and provided rides around the Local Motors facility in National Harbor, Maryland. In the summer of 2018, the University of Buffalo began testing an Olli shuttle on its campus, and in September, Local Motors launched the "Olli Fleet Challenge" with winners in Phoenix, Arizona and Sacramento, California receiving a fleet of Olli shuttles for proposed pilot projects. In December 2018, Local Motors announced a similar challenge for the Washington, DC area.
- **May Mobility** is based in Ann Arbor, Michigan, and equips Polaris GEM shuttles with automation equipment.[26] The Polaris GEM shuttles can carry 6 seated passengers and operate at a maximum speed of 25 mph. In addition to adding the equipment necessary for automation, May Mobility redesigns certain aspects of its vehicles, including modifications to the doors, seating

[23] EasyMile (2019), "Products," EasyMile website, accessed March 2019, http://www.easymile.com/#Products.

[24] EasyMile (2019), "EasyMile launches new EZ10 driverless shuttle featuring innovative safety architecture and enhanced passenger experience," press release, June 10, 2019, https://easymile.com/easymile-launches-new-ez10-driverless-shuttle-featuring-innovative-safety-architecture-and-enhanced-passenger-experience/.

[25] Local Motors (2019), "Meet Olli," Local Motors website, accessed March 2019, https://localmotors.com/meet-olli/.

[26] May Mobility (2019), May Mobility website, https://maymobility.com/.

configuration, and steering mechanism, as well as installation of large dashboard displays. May Mobility's first pilot occurred in Fall 2017, and the company is currently operating shuttles in Detroit, Michigan; Columbus, Ohio; and Providence, Rhode Island, with multiple vehicles at each site.[27] In July 2019, May Mobility plans to begin operating in Grand Rapids, Michigan.[28]

- **Navya** is a French company that produces the Navya Autonom Shuttle (formerly the Navya Arma).[29] The Autonom Shuttle can travel up to 25 mph and accommodate up to 11 seated passengers and 4 standees. Navya shuttles have been used in pilots in various countries around the world, and domestically, they have been used in pilots where they operated in mixed traffic on roads in Las Vegas, Nevada and Ann Arbor, Michigan. The company currently has operational manufacturing facilities in Lyon, France and Saline, Michigan.
- **Optimus Ride** equips Polaris GEM shuttles with automation equipment.[30] The Polaris GEM shuttles can carry 6 seated passengers and operate at a maximum speed of 25 mph. The initial pilot site for Optimus Ride was a residential development in Weymouth, Massachusetts, where the shuttles operated in mixed traffic, providing service to a local transit stop. In February 2019, Optimus Ride announced that it would be beginning a second pilot in Reston, Virginia later in the year.
- **Ridecell** acquired **Auro Robotics** in October 2017.[31] Prior to its acquisition, Auro equipped Polaris GEM shuttles with automation equipment. The Polaris GEM shuttle used could carry 4 seated passengers and operate at a maximum speed of 25 mph. Auto Robotics' major pilot site was on a pedestrian walkway on the campus of Santa Clara University. Under Ridecell, Auro Robotics still focuses on automation for low-speed first/last-mile use cases and offers integration with the Ridecell mobility platform for fleet management.
- **Robotic Research** modified two Cushman Shuttle 6 vehicles for the Applied Robotics for Installations and Base Operations (ARIBO) project at

[27] Walsh, D. (2019), "May Mobility secures $22 million investment amid expansion," *Crain's Detroit Business*, February 12, 2019, https://www.crainsdetroit.com/mobility/may-mobility-secures-22-million-investment-amid-expansion.

[28] Nagl, K. (2019), "May Mobility set to roll out driverless shuttles in Grand Rapids in July," *Crain's Detroit Business*, June 24, 2019, https://www.crainsdetroit.com/mobility/may-mobility-set-roll-out-driverless-shuttles-grand-rapids-july.

[29] Navya (2019), "Autonom shuttle, the revolutionary first and last mile travel solution," Navya website, accessed March 2019, https://navya.tech/en/autonom-shuttle/.

[30] Optimus Ride (2019), Optimus Ride website, accessed March 2019, https://www.optimusride.com.

[31] Ridecell (2017), "Ridecell introduces the first complete autonomous new mobility solution with acquisition of Auro and the launch of the Ridecell Autonomous Operations platform," press release, October 9, 2017, https://www.prnewswire.com/news-releases/ridecell-introduces-the-first-complete-autonomous-new-mobility-solution-with-acquisition-of-auro-and-the-launch-of-the-ridecell-autonomous-operations-platform-300532889.html.

Fort Bragg, which operated during 2014–2017.[32] In Fall 2017, those shuttles were relocated to a test site in Greenville, South Carolina, where they were used to support the initial phase of a project funded through an Advanced Transportation and Congestion Management Technology Deployment (ATCMTD) grant. Robotic Research also partnered with Local Motors to provide a new automation system for the Olli shuttle.[33]

TNCs and Technology Firms

Shared rides in passenger vehicles have become more common, and, in many cases, transit agencies are considering partnerships with TNCs to augment transit service. TNCs Uber and Lyft have both been testing automated vehicles and have used them to provide rides to customers of their on-demand services.[34] Uber has tested vehicles in Phoenix, Arizona; Pittsburgh, Pennsylvania; and San Francisco, California. Lyft has also tested automated vehicles in San Francisco and has partnered with Aptiv/nuTonomy to provide automated vehicle rides to TNC users in Boston, Massachusetts and Las Vegas, Nevada. In addition, some technology companies (e.g., Drive.ai and Waymo) have begun operating shared ride services using automated vehicles, including Waymo in Phoenix and Drive.ai in Arlington and Frisco, Texas. As part of its efforts in Phoenix, Waymo has partnered with the local transit agency, Valley Metro, to provide rides to transit agency employees, with eventual plans to provide rides to users of Valley Metro's RideChoice program.[35] Although the systems used by these companies are providing rides to customers, the technology is still being evaluated and further developed; it is not yet commercially available.

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[32] Robotic Research (2019), "ARIBO – Applied Robotics for Installation and Base Operations," Robotic Research website, accessed March 2019, https://www.roboticresearch.com/programs/aribo/.

[33] Robotic Research, (2019), "Public Transportation," Robotic Research website, accessed March 2019, https://www.roboticresearch.com/technologies/public-transportation/.

[34] Verger, R. (2019), "Where to find self-driving cars on the road right now," *Popular Science*, February 9, 2019, https://www.popsci.com/self-driving-cars-cities-usa.

[35] Waymo (2018), "Partnering with Valley Metro to explore public transportation solutions," Waymo Team Medium Post, July 31, 2018, https://medium.com/waymo/partnering-with-valley-metro-to-explore-public-transportation-solutions-ff01ae36484d.

SECTION

3

Selected Research and Pilot Project Summaries

Because the market for automated transit buses is relatively nascent, information on R&D and pilot activities can provide insight into systems of interest, which may be further developed into commercialized products in the future. The largest number of projects in this area focus on automated shuttles;[36] but, as many of the companies active in that space have already been discussed in the previous section, this section focuses primarily on projects involving larger buses. For the most part, the intent of the projects covered in this section is primarily to demonstrate proof-of-concept and gather data. The products being tested may never enter revenue service beyond initial demonstrations, but they may represent an early stage in the development of future products.

Some automated transit bus projects have been announced in the United States, but they tend to involve lower levels of automation or are still at relatively early stages of development. Domestic tests have also included ADAS for transit buses that does not include any automated actuation; whereas such technologies are outside the scope of this report, they may represent precursor systems. Examples of such ADAS testing include the Minnesota Valley Transit Authority (MVTA) Driver Assist System (DAS) for Bus-on-Shoulder (BOS) operations demonstration[37] and the Greater Cleveland Regional Transit Authority (GCRTA) Enhanced Transit Safety Retrofit Package (E-TRP) project.[38] Some more ambitious automated transit bus projects are taking place around the world, with the majority of the activity centered on East Asia and Europe. The following summarizes several of these projects in the United States and abroad.

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[36] *Ibid.*, Cregger et al.

[37] Fant, T. (2019), "Driver Assist System (DAS) technology to support Bus-on-Shoulder (BOS) operations," Minnesota Valley Transit Authority, FTA Report No. 0135, June 2019, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/132941/driver-assist-system-technology-support-bus-shoulder-operations-ftareport0135.pdf.

[38] Valentine, D., Polinori, A., Windholtz, M., Gibbs, B., Neumeister, D., Baumgardner, G., and Paselsky, B. (2019), "Connected Vehicle (CV) Infrastructure – Urban Bus Operational Safety Platform," Battelle Memorial Institute, FTA Report No. 0133, May 2019, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/132626/connected-vehicle-infrastructure-urban-bus-operatational-safety-platform-ftareportno0133.pdf.

Domestic Projects

Oregon – Vehicle Assist and Automation (VAA) Demonstration

In 2008, FTA and the Intelligent Transportation Systems Joint Program Office (ITS JPO) awarded $1.9 million to the California Department of Transportation (Caltrans) for the "Pilot Program to Demonstrate the Benefits of Vehicle Assist and Automation Applications for Full-Size Public Transit Buses." In addition to the $1.9 million, Caltrans provided a $1.5 million match. The project included Lane Transit District (LTD) in Oregon, among other partners. The objective was to test lateral guidance/control and precision docking on a 1.5-mile segment of LTD's Emerald Express (EmX) Bus Rapid Transit (BRT) route with an equipped 60-ft articulated bus. The VAA system used two sensing technologies—magnetic markers as the primary system and differential global positioning system (DGPS) with inertial navigation sensors as the secondary back-up system. The demonstration of the VAA in revenue service at LTD began on June 10, 2013, and continued on-and-off until the project was completed in February 2015.[39]

Washington – Active Safety-Collision Warning Pilot

Beginning in January 2016, the Washington State Transit Insurance Pool (WSTIP) and the University of Washington conducted an 18-month project to test bus collision avoidance warning systems (CAWS).[40] Commercially-available CAWS were modified and adapted for use on standard transit buses and installed on 38 buses operating at 8 transit agencies, including 7 buses at Pierce Transit. The buses used included models from Gillig, New Flyer, and Orion. Each bus also was equipped with a cellular telematics unit and supplemental cameras with video recording. Buses were operated in revenue service for several months, including a three-month testing and data collection period.

In January 2017, FTA awarded Pierce Transit a $1.66 million FTA SRD grant to fund a $2.9 million project to implement and research collision warning and automated braking technology in buses.[41] As part of the project, an AEB system will be installed on up to 30 Pierce Transit buses. Initial testing at Virginia Tech Transportation Institute (VTTI) used simulated pedestrian and vehicle targets and included more than 150 scenarios with different driving maneuvers, weather

[39] Gregg, R., and Pessaro, B. (2016), "Vehicle Assist and Automation (VAA) demonstration evaluation report," prepared for U.S. Department of Transportation, Federal Transit Administration, Washington, DC, January 2016, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Report_No._0093.pdf.

[40] Lutin, J., Wang, Y., Ke, R., and Clancy, S. (2017), "Active safety-collision warning pilot in Washington State: IDEA Program final report," Washington State Transit Insurance Pool, May 9, 2017, http://onlinepubs.trb.org/onlinepubs/IDEA/FinalReports/Transit/Transit82.pdf.

[41] FTA (2017), "Fiscal Year 2016 SRD Program Grant Selections," FTA website, January 2017, https://www.transit.dot.gov/research-innovation/fiscal-year-2016-srd-program-grant-selections.

conditions, and lighting. VTTI is also assisting with the evaluation of the impact of the AEB system on passengers—two buses will have cameras installed for passenger monitoring. The University of Washington will be conducting validation (false positives/negatives) on the AEB system using front mounted cameras on five of the buses. After completion of non-revenue service testing in Summer 2019, a revenue service field demonstration will be conducted (initially in stealth mode to gather data) and operate through April 2021.

Nevada – Automated Bus Research

In 2017, Proterra announced an automated bus pilot, working with Reno's transportation agency and engineers, roboticists, and artificial intelligence experts at the Living Lab Coalition at UNR to collect data on how to integrate automated public transit buses into cities.[42] Using a variety of sensors, Proterra and its partners collected data along the roadway and used it to develop a set of perception algorithms. The pilot is studying the positioning and orientation of subject vehicles, pedestrian and cyclist behavior, and the performance and coordination of multiple vehicles and traffic control systems. Other partners on the project include RTC, the Governor's Office for Economic Development, City of Reno, City of Sparks, Carson City, Nevada Department of Transportation, Nevada Department of Motor Vehicles, West Virginia University, and Fraunhofer Institute for Transportation and Infrastructure Systems in Germany.[43] Ultimately, the goals of this project are to improve sensors to eliminate blind spots, provide support in degraded situations (e.g., night-time driving or bad weather), and reduce brake-time response.

International Projects

China – Yutong Automated Bus Demonstration

In September 2015, Chinese bus manufacturer Yutong conducted a demonstration of its automation system on a 20-mile stretch of public roads through an urban environment from Zhengzhou to Kaifeng.[44] The trip involved automated lane changes, overtaking other vehicles, and responding to traffic lights (26 in total) without human intervention. The bus was equipped with a lidar unit and cameras on each side. Yutong uses Mobileye technology in all of its electric buses and has partnered with Mobileye to develop additional transit automation features for its buses.[45]

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[42] Poon, Linda (2017), "Reno's road to the future of autonomous buses," *CityLab*, May 2, 2017, https://www.citylab.com/transportation/2017/05/proterra-eyes-the-future-of-autonomous-buses/524937/.

[43] Tors, Jane (2017), "Ambitious, university-led effort explores mobility technologies," *Nevada Today*, January 19, 2017, https://www.unr.edu/nevada-today/news/2017/intelligent-mobility-launches.

[44] Yutong (2015), "Yutong completes world's first trial operation of unmanned bus," September 2, 2015, http://en.yutong.com/pressmedia/yutongnews/2015/2015IBKCFbteUf.html.

[45] Wu, D. (2017), "Mobileye expanding presence in China," *Nikkei Asian Review*, September 6, 2017, https://asia.nikkei.com/Business/Mobileye-expanding-presence-in-China.

Netherlands – Mercedes-Benz "Future Bus" Testing

In July 2016, the Mercedes-Benz Future Bus with CityPilot was demonstrated in the Netherlands, running along the 12-mile BRT route between Schiphol airport and the town of Haarlem.[46] The route included traffic lights, tunnels, and required the bus to navigate around people. The technology of the CityPilot in the Mercedes-Benz Future Bus was based on that of the automated Mercedes-Benz Actros truck with Highway Pilot presented in 2014. The bus used an SAE Level 2 system (operator in the driver seat and ready to reassume control) with automated lane-keeping, acceleration, and braking. The system was also designed to react to traffic lights, use precision docking at stops, and automatically open the doors for boarding and alighting passengers. The bus had a top speed of 43 mph and was programmed to operate in bus-only lanes.[47]

The integrated technology systems included cameras, radar sensors, and GPS, which were used for localization, object detection, and monitoring factors such as road surface quality, bus movement, and driver actions. Data fusion was used to combine the various sensor inputs and provide a finalized image of the location and vicinity of the bus. The Future Bus was capable of recognizing changes in traffic lights phase and identifying pedestrians, stopping to allow their passage and automatically opening doors for them at bus stops.[48]

China – Alphaba Bus Demonstration

In December 2017, four automated Alphaba minibuses began operating on the roads in Shenzhen, China. The buses were developed by Shenzhen Haylion Technologies and manufactured in China.[49] They cost 500,000 yuan ($76,000) each. Shenzhen Bus Group Co is the operator of Alphaba buses, which can carry up to 19 passengers and operate on public roads, serving 3 stops in Shenzhen's Futian District along a 1.2 km (0.75 mi) route. The vehicles can reach speeds of 40 kph (25 mph), completing the route in approximately 5 minutes. The buses are equipped with lidar, cameras, infrared sensors, radar, and GPS. In the first four months of private testing prior to the pilot, the buses logged 8,000 km (5,000 mi).[50] If approved, the buses may be used in revenue service operations, and Shenzhen Bus Group has stated that it plans to begin similar demonstrations in 10 other Chinese cities following the completion of the initial pilot.

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[46] Daimler (2019), "The Mercedes-Benz Future Bus: The Future of Mobility," Daimler website, accessed January 2019, https://www.daimler.com/innovation/autonomous-driving/future-bus.html.

[47] Thompson, C. (2017), "Mercedes created the bus of the future—and it looks awesome," *Business Insider*, June 11, 2017, https://www.businessinsider.com/mercedes-future-bus-city-pilot-photos-features-2017-6.

[48] *Ibid*., Daimler.

[49] Hua, C. (2017), "Four self-driving buses tested in Shenzhen," *China Daily*, December 4, 2017, http://www.chinadaily.com.cn/china/2017-12/04/content_35190702.htm.

[50] Ho, V. (2017), "China launches Alphaba public self-driving bus project," December 4, 2017, https://mashable.com/2017/12/04/self-driving-bus-china/#grakogzPnOqD.

Japan – Automated Driving for Universal Services

The Strategic Innovation Program – Automated Driving for Universal Services (SIP-adus) is a five-year joint research program on connected and automated driving led by the Japanese government that began in 2014.[51] The project consists of five themes: dynamic map, human-machine interface (HMI), cybersecurity, pedestrian collision reduction, and next-generation transport. Automated shuttles are being tested in rural areas in Japan as a mobility solution for older adults. Testing began in 2018 in Okinawa. Bosch is collaborating on the dynamic map field tests. Technology evaluations are being conducted for lane-maintenance speed control, precision docking, narrow road "alternating passage" capability, and location-detection tests using GPS to verify navigation and distance-measurement systems.[52]

Japan – Haneda Airport Automated Bus Demonstration

In January 2019, All Nippon Airways partnered with NEC, SB Drive, and Aichi Steel to launch a 10-day demonstration of an SAE Level 3 automated bus at the Haneda Airport.[53] The system is supervised by an on-board operator and a remote dispatcher. The bus holds a maximum of 10 people and has a top speed of approximately 20 mph on its 1/3-mile route connecting two terminals. The system uses GPS and magnetic markers on the road for localization. Officials plan to use the buses during the 2020 Olympics. In addition to ANA's demonstration at Haneda Airport, similar testing will also take place at airports in Narita, Sendai, and Nagoya.

Sweden – Volvo Automated Bus Projects

In June 2018, Volvo debuted an automated bus in conjunction with the Volvo Ocean Race competition in Gothenburg, Sweden.[54] The prototype was based on Volvo's commercially-available 40-ft electric city bus and was featured in

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[51] Sugimoto, Y., and Kuzumaki, S. (2018), "SIP-adus: An update on Japanese initiatives for automated driving," *Lecture Notes in Mobility Road Vehicle Automation* 5, 17–26. doi:10.1007/978-3-319-94896-6_2.

[52] Tao, M. (2018), "Kyocera to participate in self-driving bus test in Japan involving several other companies," *Robotics & Animation*, December 31, 2018, https://roboticsandautomationnews.com/2018/12/13/kyocera-to-participate-in-self-driving-bus-test-project-in-japan-involving-several-other-companies/20285/; Kawamoto, M. (2016), "SIP-adus next generation transport activity update: Study of precise docking," lecture presented at SIP-adus Workshop, Tokyo International Exchange Center, November 16, 2016, http://en.sip-adus.go.jp/evt/workshop2016/file/evt_ws2016_s7_MasayukiKawamoto.pdf.

[53] Sugiyama, S. (2019, Jan 22), "Driverless terminal bus goes on test run at Tokyo's Haneda Airport," *The Japan Times*, https://www.japantimes.co.jp/news/2019/01/22/business/driverless-terminal-bus-goes-test-run-tokyos-haneda-airport/#.XFGqr_ZFyUka; *Straits Times* (2019), "Tokyo Airport tests driverless bus to shuttle visitors," January 22, 2019, https://www.straitstimes.com/asia/east-asia/tokyo-airport-tests-driverless-bus-to-shuttle-visitors.

[54] Volvo (2018), "Volvo demonstrates autonomous bus," press release, June 18, 2018, https://www.volvogroup.com/en-en/news/2018/jun/volvo-demonstrates-autonomous-bus.html.

demonstration events. Volvo announced that the bus would be featured in the "Autonomous City Buses" and "Next-Generation Travel and Transport" projects in Sweden over the following two years. Potential applications to be explored with the automated bus include BRT, depot operations, and platooning.

Taiwan – LILEE Systems Automated Bus Demonstration

LILEE Systems is operating a retrofitted 30-ft diesel automated bus that is providing service to passengers on 2.9 km (1.8 mi) route along public roads in Taichung City, Taiwan.[55] Service began on December 21, 2018, and continued until January 20, 2019. Over the course of 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, iAuto, Mobiletron, THI Consultants, Industrial Technology Research Institute (ITRI), and Green Transit Company (a local bus operator).[56]

China – Baidu Apolong Buses

Baidu has been producing a fleet of automated minibuses as part of the Baidu Apollo program. The Apolong buses are being manufactured by King Long and can carry up to 14 passengers each. The latest version of the program, Apollo 3.0, supports multiple automated vehicle applications, including valet parking, automated mini buses, and automated microcars. In July 2018, Baidu announced that 100 Apolong buses had been produced. Baidu plans to use its vehicles to provide bus service in the Chinese cities of Beijing, Shenzhen, Pingtan, and Wuhan. Outside of China, Baidu is partnering with SB Drive to bring Apolong buses to Japan in 2019.[57]

Singapore – Automated Bus Demonstration

Singapore's Land Transport Authority (LTA) and Nanyang Technological University (NTU) signed an agreement in October 2016 to equip two hybrid electric buses with sensors and other capabilities to enable automated driving.[58]

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[55] Realpozo, P. (2019), "LILEE Systems presents major advances in Autonomous Rapid Transit (ART) at Silicon Valley's Innovation without Borders event," *Business Wire*, January 15, 2019, https://www.businesswire.com/news/home/20190115005982/en/.

[56] LILEE Systems (2018), "LILEE Systems partners with leading transportation companies to develop driverless buses in Taiwan," press release, February 27, 2018, https://www.lileesystems.com/announcements/lilee-systems-partners-with-leading-transportation-companies-to-develop-driverless-buses-in-taiwan/.

[57] Korosec, K. (2018), "Baidu just made its 100th autonomous bus ahead of commercial launch in China," July 3, 2018, https://techcrunch.com/2018/07/03/baidu-just-made-its-100th-autonomous-bus-ahead-of-commercial-launch-in-china/.

[58] Land Transport Authority (2016), "Joint news release by the Land Transport Authority (LTA) & NTU – On the road to a more sustainable and reliable transport system," October 19, 2016, https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=2bc42aac-6b74-4e58-bca3-e2e819c66d20.

District) were identified as potential test routes for the demonstration. In January 2018, Volvo announced that it had signed an agreement with NTU to provide automated electric buses to begin testing in Singapore starting in early 2019.[59] In March 2019, Volvo unveiled the 40-ft, 85-passenger Volvo 7900 Electric bus that it has been testing at the Centre of Excellence for Testing and Research of Autonomous Vehicles (CETRAN), noting that it will soon begin testing at the NTU campus.[60] The bus is equipped with a sensor suite that includes four lidar units, 360-degree camera coverage, and an advanced GPS that is augmented with input from an IMU.

Scotland – Automated Bus Demonstration

In 2018, the United Kingdom government announced a £4.35 million award through Innovate UK to demonstrate five SAE Level 4 automated buses.[61] Bus manufacturer Alexander Dennis Limited (ADL) will be providing the ADL Enviro200 buses, which can carry up to 42 passengers. The buses will provide service every 20 minutes along a 14-mile route between Fife and Edinburgh across the Forth Road Bridge. In addition to vehicle manufacturer ADL, other partners include the Transport Scotland, Stagecoach, Fusion Processing, ESP Group, Edinburgh Napier University, and the University of the West of England. In compliance with national regulations, a driver will be onboard ready to take control of the bus while it is in operation on public roads. When the bus is not in service, the automation system may be used for parking and moving the vehicle into the fueling station and bus wash. The project began depot testing in March 2019,[62] and on-road testing will begin in 2020, with the pilot scheduled to end in late 2021.

Sweden – Scania and Nobina Automated Bus Demonstration

Starting in 2020, bus manufacturer Scania and bus operator Nobina will be piloting two automated Scania Citywide LF buses on a three-mile route with four stops along dedicated bus lanes near Stockholm, Sweden, between the

[59] Volvo (2018), "Volvo and NTU to trial autonomous electric buses in Singapore," press release, January 11, 2018, http://www.volvobuses.com/en-en/news/2018/jan/volvo-ntu-to-trial-autonomous-electric-buses-in-singapore.html.

[60] Aravindan, A. (2019), "Volvo to test full-size driverless bus in Singapore," Reuters, March 5, 2019, https://www.reuters.com/article/us-singapore-electric-bus/volvo-to-test-full-size-driverless-bus-in-singapore-idUSKCN1QM0IN.

[61] Alexander Dennis (2018), "Scotland to trial first autonomous full-sized bus fleet in passenger serviced after £4.35M innovate UK funding," Alexander Dennis website, November 22, 2018, https://www.alexander-dennis.com/media/news/2018/november/scotland-to-trial-first-autonomous-full-sized-bus-fleet-in-passenger-service-after-435m-innovate-uk-funding/.

[62] Alexander Dennis (2019), "UK'S First full-sized autonomous bus begins depot trials," Alexander Dennis website, March 18, 2019, https://www.alexander-dennis.com/media/news/2019/march/uk-s-first-full-sized-autonomous-bus-begins-depot-trials/.

residential area of Barkarby and the Akalla metro station.[63] Initial stages of the demonstration will be conducted with no riders aboard the buses. When in service, the buses will have a safety driver onboard, and the automation system will be engaged for a fifth of the route, with the driver manually operating the bus for the remainder of the route.

Australia – Sydney Automated Bus Demonstrations

Transport for New South Wales (TfNSW) is considering a demonstration of full-sized automated commuter buses on routes around Sydney, Australia.[64] It has begun a market sounding process to gauge interest from consortia made up of organizations such as public transport operators, bus manufacturers, and technology companies. Demonstration arrangements with the selected consortium are expected to begin before the end of 2019 and may run for up to three years.[65] Previous projects in New South Wales had demonstrated smaller automated shuttles from EasyMile (Coffs Harbour and Armidale) and Navya (Sydney Olympic Park).

[63] *Automotive World* (2019), "Nobina and Scania pioneer full length autonomous buses in Sweden," February 20, 2019, https://www.automotiveworld.com/news-releases/nobina-and-scania-pioneer-full-length-autonomous-buses-in-sweden/.

[64] TfNSW (2019), "Exciting opportunity to participate in a TfNSW market sounding for automated bus service trial in Sydney – TfNSW 2019/001," Transport for New South Wales, February 1, 2019, https://tenders.nsw.gov.au/?event=public.rft.show&RFTUUID=811D2B33-93F1-ED62-F204D7F2D70BF2D6.

[65] Hendry, J. (2019), "Driverless buses trialed on Sydney's busiest routes by 2022," *iTnews*, February 4, 2019, https://www.itnews.com.au/news/driverless-buses-trialled-on-sydneys-busiest-routes-by-2022-518815.

SECTION

4

Conclusions

The automated transit bus market is still in its infancy; although many concept vehicles and systems exist, and some have been developed into prototypes, few 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 communicating a realistic depiction of the current state of the industry with respect to the availability, capabilities, and limitations of automated transit bus technologies. It aims to inform FTA staff, transit agency stakeholders, and others interested in understanding the market. Key findings from the report include the following:

- **Media coverage related to new transit bus automation products or capabilities is often ahead of actual technology development.** Relatively few automation features are available for transit buses, although smaller automated shuttles are becoming increasingly available. At this point, the transit bus automation systems that have been developed are in the pilot testing stage or earlier stages of development. Systems are not broadly available for revenue service, and it will likely be years before systems are available in the quantities and with the capabilities needed to support broader deployment.
- **Technology costs are unknown at this point.** Given that automation systems SAE Level 1 or higher exist only as prototypes (if they exist at all), pricing is typically not available. Even for low-speed automated shuttles, prices are not firmly established and are subject to change.
- **Current automation technology for other vehicle types addresses use cases that may have limited applicability for transit service.** Many of the lower-level automation 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. In addition, current sensing technology has too many false positives to be implemented in transit operations.
- **Bringing automation technology into buses is difficult due to the relatively low volumes and high level of customization in the current domestic bus market, as well as a perceived lack of interest from transit agency customers.** The relatively small market and high level of customization from transit agency to transit agency reduces the number of vehicles that R&D, testing, and validation costs can be spread

over, resulting in high costs on a per unit basis, disincentivizing investment in new products and technologies and limiting commercialization.

- **Bus manufacturers are working with suppliers to understand the development timelines for new features and have high-level roadmaps for their introduction.** These roadmaps are internal and may not contain firm dates due to uncertainty surrounding key aspects of technology development. Conversations between bus manufacturers and suppliers are ongoing, and in some cases they are working together to enable new technologies.
- **There is a high degree of uncertainty regarding other issues, including pedestrian and occupant behavior and safety, insurance and liability, operator acceptance, and new service models. There are additional needs in the areas of communication and education.** More research may be needed to resolve some of these issues, and outreach activities may be needed to ensure that all relevant stakeholders understand the capabilities and limitations of any new system implemented.
- **Industry representatives noted that demonstration and pilot programs are essential to making technological progress and answering questions on the feasibility of automation systems for transit buses.** Multiple interviewees noted that the high cost of pilots and demonstrations is prohibitive, and Federal grants and programs help enable research, demonstration, and implementation.

Obtaining an accurate assessment on the state of the market is difficult, but reliable information is necessary for planning longer-term initiatives related to the procurement, testing, and deployment of automated transit buses. Various organizations are beginning to develop committees and working groups to help facilitate information sharing among members. As the industry matures and more products enter the market, more information should become available.

APPENDIX

A

Companies Contacted

The Research Team contacted several companies over the course of this research. The team scheduled meetings with the following bus manufacturers, suppliers, and new entrants listed below. Separate questionnaires were developed for companies representing different categories so the conversations could be better tailored to their roles and experience.

Bus Manufacturers

- Gillig Corporation
- New Flyer
- Proterra
- Volvo (Nova Bus)

Suppliers

- Bendix
- Continental
- Mobileye
- ZF / TRW

New Entrants

- 2getthere
- Aptiv / nuTonomy
- EasyMile
- Local Motors
- May Mobility
- Navya

Acronyms and Abbreviations

ACC	adaptive cruise control
ADA	Americans with Disabilities Act
ADAS	advanced driver assistance systems
ADL	Alexander Dennis Limited
AEB	automatic emergency braking
ANA	All Nippon Airways
APTA	American Public Transportation Association
ARIBO	Applied Robotics for Installations and Base
ATCMTD	Advanced Transportation and Congestion
BOS	Bus-on-Shoulder
BRT	Bus Rapid Transit
Caltrans	California Department of Transportation
CAWS	collision avoidance warning systems
CETRAN	Centre of Excellence for Testing and Research of
CUTR	Center for Urban Transportation Research
DAS	Driver Assist System
DGPS	differential global positioning system
E-TRP	Enhanced Transit Safety Retrofit Package
EmX	Emerald Express
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GCRTA	Greater Cleveland Regional Transit Authority
HMI	human-machine interface
IMU	inertial measurement unit
ITRI	Industrial Technology Research Institute
ITS JPO	Intelligent Transportation Systems Joint Program
LTA	Singapore's Land Transport Authority
LTD	Lane Transit District
MVTA	Minnesota Valley Transit Authority
NTD	National Transit Database
NTU	Nanyang Technological University
ODD	operational design domain
OEM	Original Equipment Manufacturers
R&D	research and development
RTC of Washoe County	Regional Transportation Commission of Washoe

ACC	adaptive cruise control
SIP-adus	Strategic Innovation Program – Automated Driving
SRD Program	Safety Research and Demonstration Program
STAR Plan	Strategic Transit Automation Research Plan
TfNSW	Transport for New South Wales
UNR	University of Nevada, Reno
USDOT	U.S. Department of Transportation
USF	University of South Florida
VAA	Vehicle Assist and Automation
WSTIP	Washington State Transit Insurance Pool

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