Low-Speed Automated Shuttles: State of the Practice

Final Report

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16. Abstract

To better understand the emerging area of low-speed automated shuttles, the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) partnered with the John A. Volpe National Transportation Systems Center (Volpe) to review the current state of the practice of low-speed automated shuttles. These vehicles share many characteristics with other forms of automated vehicles but include unique considerations in terms of design, operations, and service type, including: fully automated driving (intended for use without a driver); operational design domain (ODD) (restricted to protected and less-complicated environments); low speeds (cruising speeds around 10-15 mph); shared service (typically designed to carry multiple passengers, including unrestrained passengers and standees); and shared right-of-way with other road users, either at designated crossing locations or along the right-of-way itself. This report defines design and service characteristics; discusses the deployers, their motivations, and their partners; and provides information on demonstrations and deployments, both international and domestic. The document also provides context on common challenges and suggested mitigations. Building on all of this information, the document identifies several research questions on topics ranging from safety and accessibility to user acceptance and societal impacts.

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Executive Summary

Activity in the development of automated driving technologies has intensified over the last decade, and while the majority of attention to this field has focused on conventional vehicles and services—including passenger cars, heavy-duty commercial vehicles, and transit service—this technology may also enable nonconventional vehicle types and use cases. Within the last several years, this has been evident in the rise of a few manufacturers focusing exclusively on the development of a largely new category of vehicles and associated services—low-speed automated shuttles.

Purpose and Scope

To better understand this emerging area, the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) partnered with the John A. Volpe National Transportation Systems Center (Volpe) to review the current state of the practice of low-speed automated shuttles. These vehicles share many characteristics with other forms of automated vehicles but include unique considerations in terms of design, operations, and service type, including: fully automated driving (intended for use without a driver); operational design domain (ODD) (restricted to protected and less-complicated environments); low speeds (cruising speeds around 10-15 mph); shared service (typically designed to carry multiple passengers, including unrestrained passengers and standees); and shared right-of-way with other road users, either at designated crossing locations or along the right-of-way itself.

Key Findings

This report defines design and service characteristics; discusses the deployers, their motivations, and their partners; and provides information on demonstrations and deployments, both international and domestic. The document also provides context on common challenges and suggested mitigations. Building on all of this information, the document identifies several research questions on topics ranging from safety and accessibility to user acceptance and societal impacts. Key findings from this report include:

- There is substantial interest in low-speed automated shuttles—a variety of stakeholders have expressed interest in deploying vehicles, and many are moving forward with pilots. Several pilots are currently operating these vehicles, and, as deployers gain experience with them, they are exploring offering new or expanded services and operating in more complex environments.
- Though many of the low-speed automated shuttle models have good “fit and finish” and well-packaged sensor suites, at this point, these vehicles are undergoing frequent hardware and software updates, and should still be considered prototypes. Many systems have somewhat limited technical capabilities and may require frequent intervention from an on-board attendant.
- Appropriate use cases for low-speed automated shuttles are still somewhat unclear. Though shuttle providers and other stakeholders have conceived of use cases, current technological constraints limit which use cases can be practically piloted. As a result, existing pilots typically do not fill substantial transportation gaps.
- On-board attendants are currently used on every deployment, and the path to removing attendants is unclear, particularly in more complex operating environments or for services that take on passengers. For some use case concepts, removing the operator is a key element of the business model, as the labor cost of an on-board attendant may make the automated shuttle uncompetitive with other options using manned vehicles.
- Evaluation is challenging for new deployers, but it is necessary to advance the state of the practice. Organizations deploying low-speed automated shuttles do not always have well-defined

goals for their pilots, making it difficult to identify performance metrics of interest or to collect appropriate baseline data for comparison.

State of the Practice

The market for low-speed automated shuttles is relatively small—though a few dozen active pilots are scattered across the country and around the world, at this point, most only use one or two vehicles. While some traditional automakers have presented automated shuttle concepts (e.g., the Volkswagen Sedric and Toyota e-Palette concepts), many of the companies involved are startups with relatively little experience designing and validating systems or mass-producing vehicles. Some companies are building purpose-built vehicles from the bottom-up, while others are adapting existing shuttle vehicles manufactured by other companies and adding their own equipment to enable automated driving. The industry today is in an early phase, and vehicle production is not yet at scale.

Several low-speed automated shuttle pilots are currently operating in the United States and more than a dozen additional pilots have identified funding and are in various stages of planning. In addition to operating and planned projects, more than 20 pilots and demonstrations have been completed. Many more have been publicly proposed. Currently operating pilots include testing on closed courses, operation in parking lots, service on dedicated lanes or pedestrian pathways, and service on private or public roads. Most domestic pilots to this point have been conducted in relatively simple, closed environments, though in recent months, a few have begun operating in mixed traffic. Many pilots plan to add complexity to shuttle operation in the future, including operating at intersections, at higher speeds, and in areas with more traffic. In addition, many deployment communities are considering how to better integrate pilots into existing transportation systems and how to use low-speed automated shuttles to better address transportation needs.

Introduction and Scope

Low-Speed Automated Shuttles

Activity in the development of automated driving technologies has intensified over the last decade, and while the majority of attention being paid to this field has been focused on conventional vehicles and services—including passenger cars, heavy-duty commercial vehicles, and transit service—this technology may also enable nonconventional vehicle types and use cases. Within the last several years, this has been evident in the rise of a few manufacturers that are focusing exclusively on the development of a largely new category of vehicles and associated services. These vehicles, referred to in this paper as low-speed automated shuttles,[1] share many characteristics with other forms of automated vehicles but include unique considerations in terms of design, operations, and service type. Though the boundaries of this new category are not well defined, common features include:

- **Fully automated driving (SAE Level 4 automation[2]):** Vehicles are intended for use without a driver or operator on board.
- **Restricted Operational Design Domain (ODD):** Operation is intended for protected and less-complicated environments.
- **Low speeds:** Service is generally limited to 25 mph (or lower), with cruising speeds around 10-15 mph.
- **Shared service:** Vehicles are designed to carry the weight of 4-15 passengers,[3] including unrestrained passengers and standees.
- **Shared right-of-way:** Vehicles share the right-of-way with other road users, either at designated crossing locations or along the right-of-way itself.

To better understand this emerging area, the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) partnered with the John A. Volpe National Transportation Systems Center (Volpe) to review the current state of the practice of low-speed automated shuttles. This report defines design and service characteristics, documents the current status of demonstrations and deployments, assesses market opportunities and limitations, identifies issues and challenges, discusses possible mitigation strategies, and provides recommendations for future research. The report primarily considers domestic examples, but in light of the extensive international activity in this area, briefly summarizes global research, demonstration, and deployment activity as well.

Methodology

The findings and research questions identified in this working paper are based on a mixed methodology that includes tracking international and domestic demonstrations, pilots, and deployments; interviewing stakeholders from industry, academia, and the public sector; and convening deployment communities through a Low-Speed Automated Shuttle Deployment Information-Sharing Working Group. These are described further below.

[1] In other contexts, these vehicles may be referred to by other names, including "automated buses," "automated minibuses," "automated pods," "automated taxis," "robotaxis," and "automated first-last mile vehicles."

[2] Appendix A includes an explanation of SAE automation levels. Also see: SAE. (2016). "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles." SAE International. Standard. June 15, 2018. https://www.sae.org/standards/content/j3016_201806/.

[3] These shuttles are typically designed to accommodate 4-10 seated passengers, sometimes with additional room for standing passengers, though smaller 1-2 person pod concepts also exist, as do larger versions designed to carry 20 or more passengers, including standees.

- **Project tracking:** Aggregation of information on international and domestic low-speed automated shuttle deployments through a review of publicly available literature, media sources, and websites.
- **Stakeholder engagement**: Interviews with researchers, manufacturers, local governments, transit providers, and other stakeholders, both in-person and by telephone. In addition, the project team conducted site visits and participated in demonstrations.
- **Working group:** Group of 19 early deployers spread across 15 states who were actively investigating, planning, or conducting a demonstration of shared low-speed automated vehicles in the United States in 2017-2018. These deployers include transit agencies, local governments, state transportation departments, and universities. Appendix B includes a list of working group participants.
- **Use case and barriers analysis**: A set of use cases to serve as an analysis framework to better understand potential challenges and opportunities of interest to USDOT. Identified topics were based on consultation with subject matter experts, practitioners, and deployers.

Objectives

The objective of this report is to document information on the rapidly evolving state of the practice with respect to low-speed automated shuttles. The ultimate goals of this effort are to increase the successful deployment of relevant projects, ensure efficient use of public funds, improve awareness and consideration of universal design and accessibility, and inform USDOT engagement in this area. To achieve these goals, this report seeks to document common issues and challenges, mitigations, and research priorities associated with low-speed automated shuttles.

Document Organization

The remainder of this report is divided into two sections followed by a conclusion. The first section, “Industry and Deployment Overview,” discusses vehicle and service characteristics, deployers, and demonstration and deployment activity. The second section, “Issues, Mitigations, and Future Research,” identifies risks and barriers, as well as potential mitigations and research questions to address those issues.

Industry and Deployment Overview

Vehicle and Service Characteristics

As noted in the introduction, this paper focuses on a relatively novel vehicle class, which is not yet well defined. The following sections present an overview of the vehicle characteristics and the types of service characteristics typical of low-speed automated shuttles during 2016-2018.

Though some higher-speed applications of automation (e.g., testing by Uber, Waymo, Ford, etc.) may be instructive in the study of small urban mobility vehicles, this paper focuses specifically on low-speed automated shuttles because they represent a particular market segment that has attracted substantial research and development investment from new manufacturers as well as interest from local, regional, and state governments and transportation agencies. General characteristics of these vehicles are described below, with some examples given of notable exceptions.

Vehicle Characteristics

The low-speed automated shuttle concept encompasses a range of small (typically 4-15 passengers), low-speed (typically with a top speed around 25 mph with cruising speeds around 10 mph) automated (SAE Level 4) shuttles. Vehicles share similar sensor configurations, relying upon combinations of cameras, radar, lidar, ultrasonic sensors, and GPS. Most of these shuttles are also electric vehicles. While they are designed to operate without a driver, during testing and early deployments, most low-speed automated shuttles use an on-board attendant who is able to take control of the vehicle in the event of an emergency or system failure (see Table 1).

Table 1: Typical Characteristics of Low-Speed Automated Shuttles

Metric	Units	Typical Range
Passenger Capacity	pax (total)	10-15
	pax (seated)	4-8
Weight	lbs. (vehicle + pax)	6,000-7,000
Speed	mph (top)	25-35
	mph (cruising)	10-12
Range	hours	5-10
	miles	30-60

Note: Ranges are based on specifications for shuttles such as the EasyMile EZ10, Local Motors Olli, and Navya Arma. Other shuttles may vary in size, weight, speed, and range. As these shuttle vehicles are rapidly developing, specifications for any particular model may change.

Most of the vehicles considered in this category follow a similar physical format, with low-floor, high-roof bodies allowing seating for half of passengers and an open standing area for the other half. Figure 1 shows a few examples of low-speed automated shuttles currently available and being used in pilots and demonstrations.

Figure 1: Available examples of low-speed automated shuttles
Note: from left to right: Local Motors Olli, EasyMile EZ10, Navya Arma
Sources: Local Motors, EasyMile, and Navya Websites, 2016

Outside of the typical ranges presented above in Table 1 are smaller "pod" vehicles built to serve as few as two passengers, and much larger shuttles built to accommodate up to 24 passengers. These vehicles may operate at different speeds and have different ranges than a 10- to 15-passenger vehicle.

Automated driving technology developers have also, in some cases, automated existing low-speed vehicle platforms. For example, Robotic Research modified two Cushman Shuttle 6 vehicles for the Applied Robotics for Installations and Base Operations (ARIBO) project at Fort Bragg (the shuttles have since been moved to a test site in Greenville, South Carolina). Other companies, such as Auro Robotics, May Mobility, and Optimus Ride, have added sensors and other equipment to Polaris GEM e4 and e6 shuttles to enable automated driving. These vehicle platforms tend to be smaller and lighter than the low-speed automated shuttles pictured in Figure 1, and have lower seating/cargo capacities (typically no more than six passengers or 1,400 pounds of cargo).

Infrastructure Assessment and Modification

Low-speed automated shuttles are typically designed to have a more restricted operating environment than prototype light-duty automated vehicles and consequently may not be able to operate in many locations. They also carry unrestrained passengers and standees, which contributes to the limited operational speeds and environments.

Operating environments are generally assessed by the provider to determine if the setting (i.e., the proposed route and nearby areas) and use case are appropriate for the capabilities of the vehicle platform. They may require modification to enable operation or may be considered too complex for shuttle operations. Photos, maps, and site visits can help a deployment engineer assess the site and determine the appropriate services, operating speed, and stops. Infrastructure modifications to enable operation may include installing signage, roadside equipment, eliminating blind spots, paving roadways, and improving lane markings.

Infrastructure-based Communication and Sensors

Several pilots have used a type of Wi-Fi called dedicated short range communications (DSRC) to broadcast signal phase and timing (SPaT) information from the traffic signal controller to vehicles. This SPaT information communicates to the vehicle when the light is red, green, or yellow, so the vehicle can stop at red lights and navigate through intersections on green lights. SPaT data can serve as redundant information to shuttles that are able to interpret signal data from camera systems, or can serve as the sole source of signal phase information, allowing shuttles that lack the ability to interpret traffic signals to navigate signalized intersections. Another infrastructure-based option is to mount a camera facing the light signal and use an algorithm to determine signal phasing, then send that information to the shuttle using wireless communications.

Sensors paired with wireless communications can also help address latent hazards (e.g., obscured crosswalks or blind corners). Some pilots have used stationary sensors such as radar, lidar, or camera units to monitor traffic and report when vehicles or other road users are present in an area that cannot be seen by the vehicle's on-board sensor suite (e.g., obscured by a building or other features). These sensors can be paired with a classification algorithm and wireless communications to send a message to the automated shuttle when another vehicle is approaching and direct the shuttle to slow or stop to avoid a potential collision.

Localization

Some shuttles have limited localization capabilities, depending on the deployment environment. The vehicle's sensor suite describes information from the environment and can be paired with a previously-generated high-definition map to help the vehicle determine its exact positioning along the route and in the roadway. Open, rural environments are generally more challenging for localization, as there are fewer landmarks. Changes to the environment, such as the formation of snowbanks after a storm, also may pose a challenge for localization. Infrastructure along the route (e.g., vertical poles or distinctive landscaping) may need to be added or modified to assist with the localization of the shuttle.

On-Board Attendants and Remote Intervention

Deployments surveyed by the project team have used an on-board attendant who is able to take control of the vehicle in the event of an emergency or system failure. On-board attendants may also provide assistance to passengers, answer questions, serve as tour guides, conduct surveys, or carry out other tasks. In order to realize potential cost savings, some projects hope to remove on-board attendants in future phases.

State and local regulations may require the ongoing presence of an operator, or they may have additional requirements for the testing of vehicles that operate without an on-board attendant. As an example of such regulations, in February 2018, the California Department of Motor Vehicles (DMV) released regulations for testing and deploying vehicles without a driver.[4] As part of these requirements, test vehicles must have "a communication link between the vehicle and remote operator, a process to communicate between the vehicle and law enforcement, and an explanation of how the manufacturer will monitor test vehicles." In addition, manufacturers wishing to test an automated vehicle without an on-board driver must "maintain a training program for remote operations and certify each operator has completed training." Requirements for remote operation may vary from state to state and may also depend on the use case or the specific location of the testing.

Remote monitoring and intervention may also be used to provide fleet management services even while shuttles are manned. Some of the low-speed automated shuttle demonstrations in Europe have used such a system to provide fleet management services from a control room.[5] In those demonstrations, an automated shuttle encountering obstacles would halt and a control room operator would assess the situation through cameras and send a command for the vehicle to continue if the route was clear. In addition to alerts at unscheduled stops, the remote monitoring and intervention system could alert a control room operator when the shuttle reaches predefined points (e.g., bus stops), and the shuttle can wait for the operator to verify that it is cleared for departure before leaving.

In the future, in addition to providing fleet management services, these systems could also be designed to support passenger security. For instance, in some hypothetical concepts, the system would allow passengers to contact the control room if needed. Internal cameras would allow remote monitoring of passengers, and as

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[4] DMV. (2018). "Driverless Testing and Public Use Rules for Autonomous Vehicles Approved." Press release. California Department of Motor Vehicles (DMV). February 26, 2018. Retrieved April 2018, from https://www.dmv.ca.gov/portal/dmv/detail/pubs/newsrel/2018/2018_17.

[5] Pessaro, B. (2016). *Evaluation of Automated Vehicle Technology in Transit - 2016 Update*. NCTR Report 2117-9060-21. Center for Urban Transportation Research, Tampa, FL. Retrieved March 2018, from https://www.nctr.usf.edu/wp-content/uploads/2016/04/77060-21-Evaluation-of-Automated-Vehicle-Technology-for-Transit-2016-Update.pdf.

with some of today's unmanned transit systems, control room operators would be able to stop vehicles, open or close vehicle doors, and contact appropriate authorities to manage situations as they arise.

Accessibility

The first low-speed automated shuttles focused primarily on basic functionality and generally did not integrate accessibility features typical of transit vehicles used in revenue service. Shuttles have evolved to provide access to some passengers with mobility limitations—some of the first shuttle models addressing mobility limitations added manual ramps operated by on-board attendants, while more recent models have integrated automated ramps with onboard controls. Beyond the addition of ramps, most accesibility equipment is in a concept or prototype phase. For example, while multiple shuttles have integrated ramps, most have yet to implement securement systems. Some shuttle providers have been considering the broader accessibility needs of passengers with impaired mobility, cognition, vision, or hearing, though current shuttles being used for pilots lack attributes to address additional needs of disability communities.

Service Characteristics

Existing shuttle pilots typically operate relatively simple services; however, some pilots are beginning to explore more complex services, and more advanced concepts also exist. Both passenger and freight concepts have been demonstrated. A few broad categories of service include:

- **Passenger or Freight:** While most demonstrations have focused on passenger transportation service, there have been small freight delivery demonstrations.
- **Fare payment:** The project team did not identify any projects charging a fare, although some have discussed this as a future phase. The demonstration nature of the services (limited hours, very low speeds) likely would inhibit boardings if fares were charged.
- **Integration with other transportation services:** Many demonstrations are operated in areas where there are no existing transportation services (e.g., traditional bus), due at least in part to the desire to avoid labor conflicts. Transit agencies have begun to explore the use of low-speed automated shuttles and to consider their potential in a full-service fleet (e.g., Wiener Linien in Vienna). Switzerland's PostBus SmartShuttle is an exception, being operated and liveried as part of a transit fleet.
- **Service design:** Shuttle service varies by where the shuttle can go (i.e., routes and stops), when it is available (i.e., service frequency), and whether it can react to real-time needs of users (i.e., fixed schedule or on-demand). Based on these variables, three major service models emerge:
    - **Circulator service:** Low-speed automated shuttles have primarily been tested in protected environments, such as parking lots, academic campuses, and other largely controlled and closed environments. The concept of operations varies by deployment, but most deployed shuttles thus far have been used as circulators that run on a fixed schedule and follow a fixed route with fixed stops.
    - **On-demand connector service:** A few pilots have provided, or have identified as a future concept, "on-demand" service with a variable schedule, allowing riders to summon a vehicle using an application that can be accessed via a smartphone or a kiosk located at waypoints (i.e., pick-up and drop-off locations). The small number of concepts with on-demand capabilities have had limited sets of routes and waypoints.
    - **Point-to-point service:** In the future it may be possible to operate low-speed automated shuttles with variable waypoints, which would allow service between any two locations (i.e., "door-to-door") within an established service area. These shuttles would also operate "on-demand" with a variable schedule. In addition to moving people, this service type could also be used for delivery services, in particular, for urban freight deliveries.

Appendix C provides a more detailed review of some of the potential use cases that fit into these broad categories.

As pilots evolve toward revenue service operations, several service models could emerge, many of which would be motivated by the economics of operating a relatively small vehicle with no driver. These vehicles could continue operating as circulators on private campuses (e.g., office parks, stadiums, theme parks, and academic campuses). They could also help address transportation gaps that are economically challenging to meet with existing transit service, such as first/last-mile access to trunk line transit, on-demand service in areas without sufficient density to justify conventional bus transit service, and off-peak fixed route service in urban areas (i.e., during times when ridership is too low to justify conventional transit service).

Deployers

Low-speed automated shuttle projects are sponsored by a range of entities, including the private sector (e.g., shuttle providers, property developers, and other firms); the public sector (departments of transportation, transit agencies, and local governments); and other organizations (e.g., universities). Sometimes the sponsor will operate a service themselves, and other times they will bring in transport operators (e.g., First Transit, Keolis, and Transdev) or engineering firms to operate the service for them. Often the shuttle provider will provide assistance in identifying potential routes, training on-board attendants, and other activities.

Interest in low-speed automated shuttles has grown quickly over the last few years, driven perhaps by both the desire to test a new option for addressing long-standing transportation problems and by near-term interests in understanding new technology and spurring local economic development. While currently available technologies are still limited in their capabilities, some anticipated capabilities are promising enough to attract early engagement and investment. This section discusses both motivations and key roles for establishing a new demonstration or service.

Short-Term Motivations

While long-term interests in meeting transportation needs motivate interest in the technology generally, the current generation of low-speed automated shuttles can provide only limited services in limited conditions. The primary and immediate factors driving would-be deployers to explore and invest in low-speed automated shuttle testing today appear to be data gathering, economic development, and exposure to new technology. When asked about what brought them to test low-speed automated shuttles, deployers cite remaining competitive with other cities and not wanting to fall behind with technological innovation alongside the overarching motivation to fill transportation gaps. Deployers seem interested in signaling their openness to automation and innovation to private technology companies that might choose to invest in their community.

Testing low-speed automated shuttles is also seen as a mechanism to expose both the public and the deployer's internal staff to an emerging technology. Public exposure facilitates understanding and acceptance, not just for low-speed automated shuttles but for vehicle automation in general. In addition, piloting a new technology presents an opportunity to build internal capacity. In some deployments, city staff have been trained as vehicle operators, limiting the need to hire or rely on external engineers for a deployment. In some cases, deployers are also interested in building a foundation to shape the integration of new mobility technologies into the existing transportation system in accordance with their broader accessibility, sustainability, and equity objectives.

Long-Term Motivations

Deployers also frequently cite longer-term motivations for testing low-speed automated shuttles, mostly related to improving safety and mitigating long-standing transportation problems such as first- and last-mile connectivity. While low-speed automated shuttles may not currently be capable of fully delivering on these desired benefits, they are widely seen among deployment communities as an early step in the process of using automation to address transportation challenges. Table 2 describes three transportation challenges frequently cited by deployers and potential solutions offered by using low-speed automated shuttles in comparison to non-automated alternatives (e.g., a manually-operated bus or passenger van).

Table 2: Transportation Challenges and Potential Solutions with Automated Shuttles

Transportation Challenge	Potential Solution Using Low-Speed Automated Shuttles	Comparison to Traditional Alternatives
Many transportation networks contain first/last-mile gaps	Feeder service to existing high-capacity transit	May be more cost-effective and more customizable than human-operated feeder service
Low-volume transit routes are often expensive to run	Smaller (lower-capacity) vehicles without drivers	May be more cost-effective than human-operated 40-foot bus
Paratransit is often expensive to operate and may require passengers to book rides in advance	Automated paratransit	May be more responsive to demand and less expensive on a per-ride basis than human-operated paratransit (practicality is still untested)

Low-speed automated shuttles appear to offer an opportunity for lower-cost public transportation in specific use cases outside of mass transit as a result of two assumptions: 1) reduced labor costs associated with not employing a driver or other on-board attendant and 2) reduced capital and operational costs associated with smaller, lower-capacity vehicles. These assumptions depend on the evolution of the technology to a level of capability that would 1) enable operation without an on-board attendant to achieve labor cost savings and 2) enable economies of scale, improve reliability, and justify the investment relative to other options to achieve vehicle cost savings.

Deployment Partners

The marketplace is constantly evolving as partnerships form and dissolve. One organization may play multiple roles, that organization's role may change in future projects, and new entrants are still emerging. Some key actors include:

- **Vehicle providers**, such as 2getthere, EasyMile, Local Motors, Lohr, and Navya, who design low-speed automated shuttles and may manufacture them in-house or contract out manufacturing to other companies. Some companies, such as Auro Robotics, May Mobility, Optimus Ride, and Robotic Research, upfit commercially available vehicles with additional equipment to enable automated driving capabilities.
- **Automated system providers**, such as Coast Autonomous or BestMile, who provide a variety of products from vehicle systems (e.g., lidar, radar, and camera systems) to fleet management software, along with related services.
- **Operators**, such as First Transit, Keolis, and Transdev, who staff and maintain vehicles. These types of organizations also provide traditional public transit, paratransit, and other transportation services.
- **Deployment communities**, such as transit agencies, local governments, state agencies, universities, or other organizations, who are interested in low-speed automated shuttle deployments to provide a new service, augment other transportation options, or replace an existing service.

Deployers have options in terms of procuring vehicles and service. The vehicle itself can typically be purchased or leased from the shuttle provider. Often both purchase and lease options will include regular costs for software updates. In some cases, shuttle providers or operators may offer subscription services that include the staffing, maintenance, and other operating activities in the contract price.

Shuttle providers and operators often work closely together to support pilot deployments, with shuttle providers training operators on the functions and operation of the system. Rather than hiring an operator to manage shuttle operations, some deployers have opted to take on the role of operator. This strategy is one way for deployers to build up internal knowledge and experience from these early pilot deployments that may be useful for future work, which may use different vehicles or different operating environments.

Overview of Demonstration and Deployment Activity

This section discusses the origin of the low-speed automated shuttle, which featured prominently in the European CityMobil and CityMobil2 projects. It also discusses the state of demonstrations and pilots, both domestically and globally, and describes several prominent ongoing pilot projects.

Background: CityMobil Program

It is difficult to overstate the role that the CityMobil and CityMobil2 projects played by serving as a catalyst to the current surge of activity in low-speed automated shuttles. CityMobil, a European Commission (EC)-funded research project that operated from 2006 to 2011, demonstrated different automated road concepts, including automated car share, "CyberCars," bus rapid transit (BRT), and personal rapid transit (PRT). These various concepts were demonstrated at several sites across Europe, including in Italy, Spain, the United Kingdom, Norway, Finland, and France. The project highlighted two major barriers to transport automation: implementation framework and legal framework.

The follow-on to the CityMobil project, CityMobil2, ran from 2012 to 2016 and focused on the testing of low-speed automated shuttles, referred to as ARTS (Automated Road Transport Systems) in Europe (CityMobil2 2016). The project convened a consortium of 45 partners (including 12 cities and 5 manufacturers), and had a budget of €15.5 million (including a €9.5 million contribution from the EC). Selection criteria for deployment sites included operation on a fixed route, ideally on moderately dense, predefined urban routes. Many European cities applied to host demonstrations and seven selected cities hosted two- to five-month demonstrations between 2014 and 2016 (see Table 3).

Table 3: CityMobil2 Demonstration Sites

Location		***Vehicles***		***Time***		***Demonstration Type***
City	***Country***	***#***	***Manufacturers***	***Start***	***End***	
Oristano	Italy	2	ROBOSOFT	7/2014	8/2014	Small-scale demo
La Rochelle	France	6	ROBOSOFT	10/2014	4/2015	Large-scale demo
Lausanne	Switzerland	6	EasyMile	10/2014	4/2015	Large-scale demo
Vantaa	Finland	4	EasyMile	7/2015	8/2015	Small-scale demo
Trikala	Greece	6	ROBOSOFT	8/2015	2/2016	Large-scale demo
Sophia Antipolis	France	4	EasyMile	3/2016	5/2016	Small-scale demo
San Sebastian	Spain	4	ROBOSOFT/EasyMile	4/2016	7/2016	Small-scale demo

Source: CityMobil2 2016

In addition to these demonstrations, shorter "showcase" events that lasted a few days were held in León, Spain (9/2014); Bordeaux, France (ITS World Congress – 10/2015); Warsaw, Poland (Transport Research Arena Conference – 4/2016); and Stockholm, Sweden (Kista Mobility Week – 4/2016). In all CityMobil2 deployments, vehicles drove in automated mode but had on-board human operators to meet regulatory requirements and mitigate system limitations that occurred in some operating environments.

The CityMobil2 project used a “mobility first” approach where manufacturers work with cities directly and collaboratively develop mobility solutions. Infrastructure certification was a key component of the project; individual sections of the route were investigated for specific vulnerabilities and mitigations were identified and made. In addition to proving out the technical feasibility of low-speed shuttles, the project allowed for research into sociological issues (e.g., human factors and user acceptance).

Some challenges identified over the course of the project include the fragmentation of the legal framework/legislation (across and within EU countries), illegal motorist behavior that interfered with demonstrations, and difficulty in navigating even simple routes. The project demonstrated the feasibility and safety of low-speed shuttles, promoted awareness among the general public and other road users, and provided insight on methods for future integration in medium density areas. Over the course of testing, the vehicles traveled more than 26,000 km (~16,000 miles) and provided rides to more than 60,000 passengers.

Summary and Analysis of Current Demonstrations and Deployments

As of the beginning of August 2018, the project team had identified and documented more than 260 demonstrations and pilots (some planned, some ongoing, and some completed), in North America, Europe, Asia, Oceania, and Africa. Three quarters of the identified shuttle projects are in Europe and North America, though it is important to note that the tracker likely has a bias toward the inclusion of projects in the United States and projects that have received English-language media attention. Europe was an early leader in piloting low-speed automated shuttles, with its CityMobil and CityMobil2 projects. In 2015 and 2016, many other high-profile projects were announced in Europe, such as the Postbus SmartShuttle in Switzerland, WEpods in the Netherlands, and SOHJOA in Finland. During that same period, several shuttle projects were also announced in Asia and North America. In 2016 and 2017, many U.S. pilots received their vehicles and began testing, including the EasyMile EZ10 shuttles for GoMentum Station and Bishop Ranch, and the Navya Arma shuttle for Mcity. Awareness of these vehicles and interest in deploying them is growing, with approximately two-thirds of all domestic pilots and demonstrations in the tracker being announced since the beginning of 2017.

Short Demonstrations

Much of the low-speed automated shuttle activity is in the form of short demonstrations that last anywhere from a few hours to several days. Both domestically and abroad, deployments are split roughly equally between demonstrations and pilots. Demonstrations are often tied to events, such as conferences. Typically, these demonstrations are hosted in a parking lot, in a campus environment, or on a public road that has been closed off to other traffic. Some demonstrations are part of a series of traveling demonstrations, such as the “Autonomous Vehicle Road Trip,” which visited several U.S. cities in January and February 2017. Shuttle providers and operators may use demonstrations as a method to build awareness and increase interest in longer-term pilots, and in some cases, such as Arlington, Texas and Atlanta, Georgia, communities have pursued pilots following a demonstration.

Pilot Deployments

Pilots are longer than demonstrations and often last anywhere from a few months to an entire year or longer. Typically, deployers involved in pilots are interested in learning about longer-term aspects of operating a shuttle, including service capabilities, costs, and user acceptance. In many cases, the pilot is used to determine if there is a business case for operating a shuttle in revenue service. While it is too early to say what the future of the pilots will be, some, such as the PostBus pilot in Sion, Switzerland, have extended their initial deployment period, while others, such as the shuttle deployments at Gardens by the Bay in Singapore and the nuclear power plant in Civaux, France, will continue operations for the foreseeable future.

Domestic

Several low-speed automated shuttle pilots are currently operating in the United States and more than a dozen additional pilots have identified funding and are in various stages of planning. In addition to operating and planned projects, there are more than 20 pilots and demonstrations that have been completed and many more that have been publicly proposed. Currently operating pilots include testing on closed courses, operation in parking lots, service on dedicated lanes or pedestrian pathways, and service on public roads in mixed traffic. This section briefly describes some of the prominent pilots that are currently operating.

Table 4: Selected Domestic Low-Speed Automated Shuttle Deployments

Location	Project Partners	Vehicle Model	Shuttles	Type
Dublin, CA	Livermore Amador Valley Transit Authority, First Transit	EasyMile EZ10	1	Ongoing Pilot
San Ramon, CA	Contra Costa Transportation Authority, and Central Contra Costa Transit Authority (CCCTA), GoMentum Station, and Bishop Ranch	EasyMile EZ10	2	Ongoing Pilot
Gainesville, FL	Florida Department of Transportation, University of Florida, and City of Gainesville	EasyMile EZ10	1	Ongoing Pilot
Jacksonville, FL	Jacksonville Transportation Authority, Transdev, First Group, and Stantec	Multiple (including EasyMile EZ10, a Navya vehicle, and another shuttle TBD)	1-2 per model	Ongoing Pilot
Weymouth, MA	Optimus Ride, Lstar Ventures	Polaris GEM	5	Ongoing Piot
Ann Arbor, MI	Mcity (University of Michigan)	Navya ARMA	2	Ongoing Pilot
Detroit, MI	May Mobility, Bedrock	Polaris GEM	5	Ongoing Pilot
Las Vegas, NV	City of Las Vegas, AAA, Regional Transportation Commission of Southern Nevada, and Keolis	Navya ARMA	1	Ongoing Pilot
Greenville, SC	Greenville County, Robotic Research, and Robocist	Cushman Shuttle 6, Local Motors Olli, and possibly others TBD	2+	Ongoing Pilot
Arlington, TX	City of Arlington	EasyMile EZ10	2	Ongoing Pilot

In October 2015, **Contra Costa Transportation Authority (CCTA)** announced that it would be testing low-speed automated shuttles at GoMentum Station (a converted military base in Concord, California that is being used as a closed test facility for automated vehicles). Following initial testing at GoMentum Station, the two EasyMile EZ10 shuttles were brought to Bishop Ranch (a 585-acre business park in San Ramon, California) for additional testing in parking lots. In March 2018, CCTA began testing the shuttles in mixed traffic along a stretch of road between two parking lots.

In December 2016, the **Jacksonville Transportation Authority (JTA)** announced plans to modernize the Jacksonville Skyway (an automated people mover) and modify the existing elevated track to replace the existing vehicles with automated shuttles. It also plans to build ramps from the elevated structure to ground level, enabling shuttles to reach additional destinations using dedicated lanes or operating in mixed traffic. JTA has developed a test track near the local stadium and will test three different shuttles (including vehicles from EasyMile and Navya) managed by three different operators (Transdev, First Group, and Stantec). The three shuttles will be tested for six months each.

In December 2016, the **University of Michigan** began testing a Navya Arma shuttle at its Mcity test facility. Mcity uses the shuttle for research, training, and tours. In early 2017, Navya sent a second shuttle to Mcity after it had completed demonstrations in Las Vegas. The two shuttles were going to be used in mixed traffic, providing service between Mcity and the university's North Campus on a two-mile round-trip route in fall 2017, but the project was delayed due to unplanned road maintenance along the route. In June 2018, the shuttles began operating on a portion of that route, and are providing rides to faculty, staff, and students.

In November 2017, the **City of Las Vegas, Nevada,** launched an automated shuttle pilot using a Navya Arma shuttle to provide service around a two-block loop in the city's downtown. The pilot was soon expanded to cover a three-block loop. The one-year pilot is operating on a public street with mixed-flow traffic and high pedestrian activity. The route uses vehicle-to-infrastructure communications to provide the shuttles with light-phase information at signalized intersections (six of the route's eight intersections have traffic lights).

In May, 2017, **Greenville County, South Carolina** received an automated vehicle through Robotic Research in an approved re-deployment of a Cushman 6 Shuttle that was previously tested and validated at Fort Bragg in North Carolina during 2014-2017 as part of the ARIBO project. In October 2017, the community received $4 million in a 2017 Advanced Transportation and Congestion Management Technology Deployment (ATCMTD) grant for an automated shuttle deployment—with matching funds, the project budget is more than $8 million. The deployment will use two ARIBO shuttles and is purchasing additional shuttles from other manufacturers. In the initial deployment, the shuttles are being used to provide service around Clemson University International Center for Automotive Research. Later phases of the project will provide first/last-mile service in an in-fill, upscale, mixed-use community (Verdae) and in an older, mixed-use, low-income area (Parker). Greenville will also address low-speed automated shuttles as an alternative solution to non-emergency medical transport needs. Project reports will document benefits from the shuttles and identify operational business models.

In August 2017, the **City of Arlington, Texas,** has a one-year lease on two EasyMile EZ10 shuttles for use on off-street trails in the Entertainment District, home to a baseball park, a football stadium, an amusement park, a water park, and a bowling museum. The service is intended to expose the public to automated vehicles and shorten the walk between activities and parking facilities. In August 2018, the initial low-speed automated shuttle pilot was completed and Arlington announced a partnership with another company, Drive.ai, for another one-year pilot program to begin in October 2018. The Drive.ai pilot will use three Nissan NV200 vans that have been equipped for automated driving. The vans will travel up to 35 mph and will provided service between remote parking lots and various venues in the Entertainment District.

International

As previously mentioned, the development of low-speed automated shuttles primarily began with work in Europe. As a result, more low-speed automated pilots and demonstrations have been conducted throughout Europe than in other regions. The majority of projects have occurred in France and Germany, though there have also been several efforts in other countries, including Finland, the Netherlands, Norway, Switzerland, and the United Kingdom. Several countries in Asia have also hosted low-speed automated shuttle deployment activity, with much of the activity concentrated in Japan, Singapore, and Taiwan. This section briefly describes a few prominent pilots currently operating, including the Greenwich Automated Transport Environment (GATEway) Project in the United Kingdom, the Sion SmartShuttle in Switzerland, Auto Rider at Gardens by the Bay in Singapore, and ParkShuttle in the Netherlands.

In December 2014, the United Kingdom announced that it would be funding three automated vehicle projects, including the **GATEway Project** which sought to test low-speed automated shuttles on the Greenwich Peninsula. The four-passenger shuttles used in the project were developed by British companies Westfield Sportscars and Heathrow Enterprises. [6] They are operating on a 3.4-km (2.1-mile) fixed route and travel up to 10 mph. The route is in an area with diverse multimodal connections (e.g., ferry, bus, heavy rail, and cable car), several attractions (e.g., ecology park and the O2 Arena), and major hotels. The shuttle trial is only one

[6] GATEway. (2018). "About." Greenwich Automated Transport Environment (GATEway) Project Website. Retrieved March 2018, from https://gateway-project.org.uk/about/.

part of the GATEway Project; other elements include testing automated urban delivery vehicles, remote monitoring and intervention, accessibility systems, and simulators.

In December 2015, Swiss Post, a company that provides regional and rural bus service in Switzerland, launched the **Sion SmartShuttle Project** and began testing two Navya Arma shuttles on a closed section of road in Sion, Switzerland. In June 2016, it began piloting shuttles on public roads.[7] Technology partners include Navya and BestMile. The initial route in the city center was expanded to include service to the train station. The shuttles provided free service on a 1.5-km (0.9-mile) route from Wednesday through Sunday. In addition to the free service, on certain days the shuttles are used for tours priced at $10 for children and $15 for adults.[8] The initial phase of the pilot was scheduled to end after October 2017, but the pilot was extended through the end of 2018.

The **Auto Rider Project** at Gardens by the Bay in Singapore features an EasyMile shuttle that provides tours of the park. Initial tests occurred in December 2015 on a 1.5-km (0.9-mile) loop through the park.[9] Members from the general public were invited to ride in the vehicles for 15-minute trips. A trained staff member was present in each vehicle to provide instructions to riders, monitor the vehicle, and gather feedback. The project was co-funded by the Ministry of National Development and National Research Foundation, with technical advice from the Agency for Science, Technology and Research. Following the initial tests, the park began offering a permanent Auto Rider service to park attendees. The shuttles operate daily from 10:00 am to 12:00 pm and from 2:00 pm to 4:00 pm. Shuttles run at 20-minute intervals from Bayfront Plaza to the Flower Dome attraction, and rides cost $5 per passenger.[10]

In the Netherlands, the **ParkShuttle** has been operational since 1999.[11] The service connects the Rivium business park to a bus and subway station. Beginning in 2006, the system began using six second generation 2getthere shuttles to provide service to five stations along a 2.0-km (1.2-mile) route. In 2016, the city of Capelle aan den IJssel announced its intent extend the system further. The plan is for six new 2getthere shuttles to be operational on the current route by summer 2019, and in 2020, the route will be expanded to include a longer route that crosses public roads with mixed traffic.[12] The service currently uses shuttles which operate at grade using magnets embedded in the roadway for guidance. The current shuttles operate without on-board attendants, and the plan is for the shuttles to operate unattended on the extended route as well.

[7] PostBus. (2018). *SmartShuttle Project*. PostBus Website. Accessed March 2018, from https://www.postauto.ch/en/project-smartshuttle-0.

[8] Sion Tourisme. (2018). "Sion, a Trip to the Heart of SmartShuttle." SmartShuttle, Sion Tourisme Website. Accessed March 2018, from http://siontourisme.ch/index.php/fr/sports-et-loisirs/smartshuttle.

[9] Gardens by the Bay. (2015). "First Fully-Operational Self-Driving Vehicle in Asia Set To Ply Gardens by the Bay in mid-2016." Media Room, Gardens by the Bay Website. October 12, 2015. Accessed March 2018, from https://www.gardensbythebay.com.sg/en/the-gardens/media-room.html.

[10] Gardens by the Bay. (2018). *Outdoor Garden Cruiser Tours: Auto Rider*. Gardens by the Bay Website. Accessed March 2018, from http://www.gardensbythebay.com.sg/en/plan-your-visit/tours-and-trails/outdoor-garden-cruiser-tours.html.

[11] van Sluis, D. (2016). *Driverless ParkShuttle.* 2getthere Website. September 11, 2016. Accessed March 2018 from https://www.2getthere.eu/driverless-parkshuttle/.

[12] Lohmann, R. (2017) First Autonomous System. 2getthere Website. December 22, 2017. Accessed March 2018 from https://www.2getthere.eu/first-autonomous-system/.

Issues, Mitigations, and Future Research

The rapid emergence of low-speed automated shuttles has raised both technical and institutional questions in the private and public sectors. Note that many of the issues identified here are not necessarily unique to low-speed automated shuttles, but rather are common to automated driving systems. Current shuttle models have significant technical limitations: they require highly controlled environments, they are not accessible to all users, and their low speeds and frequent stops may limit passenger demand. There are also policy and institutional challenges related to federal, state, and local requirements for testing on public roads, accessibility, funding eligibility, and other issues. Consequently, deployers are generally proceeding with caution. This section summarizes issues identified from early deployments, followed by suggestions for possible mitigations, and concludes with areas for future research.

Issues

Given the rapid changes in this area, it is impossible to definitively identify all of the issues encountered by those seeking to deploy low-speed automated shuttles. Challenges documented in this paper may be addressed in the very near future, or may have already been addressed by the time of publication. The authors encourage any interested readers to consider the issues identified here in the development of a pilot or deployment, but recognize that mitigations or solutions may be available.

Deployers of low-speed automated shuttles must take into account the new technical considerations associated with driverless vehicle operations. These include both hardware and software issues related to the vehicles and the deployment environment, as well as broader concerns about maintaining interoperability with existing infrastructure and systems. Deployers must also ensure that they have adequate resources and permissions for identifying, procuring, and operating these systems.

Key areas that could pose early obstacles to deployment include:

- Vehicle capabilities
- Operating environment
- Product availability
- Planning and implementation
- Financial considerations
- Labor considerations
- Data and evaluation
- Public acceptance
- Federal, state and local regulations

Vehicle Capabilities

The market for low-speed automated shuttles is relatively small, and many of the companies involved are startups with relatively little experience designing and validating systems or mass-producing vehicles compared to traditional automakers. The industry today is in an early phase, and vehicle production is not yet at scale. Challenges related to vehicle capabilities include the following:

- **Evolving vehicles:** Many of the problems associated with low-speed automated shuttles are related to the evolving nature of these vehicles. Low-speed automated shuttles produced by relatively-small startup companies generally have undergone less testing and validation compared to commercially-produced vehicles sold by large automakers—they have logged fewer miles under more limited conditions, and both hardware and software are constantly being updated to improve performance and deal with new challenges. As a result, these vehicles may have more performance and reliability issues than would be expected from mature, mass-produced vehicles.
- **Lack of standardization:** Because the technology for these vehicles is rapidly advancing, standards have not yet been developed for safety, vision systems, or mapping. As a result, each company may have a different approach for these systems and processes. Service providers may need time to learn new systems if they are working on a deployment with an unfamiliar vehicle. In addition, mapping procedures may need to be redone to add new shuttles, and different mitigation procedures (e.g., signage, infrastructure modification, and education and outreach) may be needed if new vehicles are added to an existing deployment.
- **Battery limitations**: Battery performance is a core issue for electric vehicles. Use of heating, ventilation, and cooling systems or operating on sloped route segments can deplete battery power more quickly than operating in moderate temperatures or on flat routes. Operating in more extreme environments (e.g., Texas summer or Minnesota winter) can potentially reduce service hours by half, an important consideration when planning for service duration. As with any electric vehicle, there are concerns about how the range and charge time fit in with planned service characteristics (e.g., whether the charge will support a full day of operations and whether there will be enough time to fully recharge the battery between service periods). In a commuter-oriented production service, all vehicles may not need to be in service other than during peak hours, so off-peak hours may potentially be used to recharge some vehicles. The same factors that affect operations may also affect the battery's performance over its lifecycle. Some manufacturers are working on inductive charging, which would reduce some of the battery limitation concerns, but this technology is in its infancy and will require infrastructure installation for deployment.
- **Perception systems:** Identification and classification of signs and traffic lights is an ongoing area of research, and improvements are expected. Existing shuttles have limited ability to determine signal phase at signalized intersections, though some pilots are using or considering the use of communications technologies to broadcast signal phase from infrastructure-based systems (e.g., SPaT information via DSRC radios). Similarly, some pilots have experimented with infrastructure-based sensors (e.g., lidar or radar units) and communications technologies to mitigate blind spots along the deployment route.
- **Road user interactions:** Shuttle interactions with other road users and animals pose challenges, both anticipated and unanticipated. Current shuttle models have limited or no ability to classify objects, and therefore do not discriminate well between various obstacles. For example, a shuttle may not be able to distinguish between a pedestrian, a flock of birds, or a bag blowing in the wind, and therefore may not be able to react differently to objects it detects in its path.
- **Driving strategies:** Shuttles may not have the same defensive driving strategies that may be available to other services. For instance, a shuttle may have a horn, but not be programmed to honk at an object that is actively backing toward the vehicle. In addition, shuttles drive differently than human-operated vehicles, which may cause confusion for other road users, including drivers, bicyclists, and pedestrians.
- **Interoperability:** Low-speed automated shuttle technology is developing simultaneously with other technologies, including light- and heavy-duty vehicle automation, and vehicle-to-vehicle and

vehicle-to-infrastructure capabilities. As these shuttles begin to operate on public roads, it will be critical to ensure that they can communicate and maintain interoperability with existing and new infrastructure and systems (e.g., integration with emergency medical services).

- **Accessibility:** Shuttle accessibility features have evolved to provide access to passengers using wheeled mobility devices—from manual ramps to automated ramps—and other features are being added. However, remaining accessibility limitations currently constrain the possible uses of low-speed automated shuttles, especially for travelers with disabilities (e.g., passengers with impaired mobility, cognition, vision, or hearing) and temporarily limited mobility (e.g., passengers with heavy bags, strollers, or other large or heavy items).
- **On-board attendants:** At the current stage of technology, shuttles generally use an on-board operator who can intervene in emergencies (in some cases, an on-board operator is required by regulation), if the vehicle encounters an unusual situation, or if the vehicle must deviate from its mapped route (e.g., to go around an object blocking its path). Inclusion of an on-board attendant or safety operator will likely increase the cost of service beyond that of more traditional non-automated transportation services (e.g., shuttle van service), as cost savings are not realized while on-board attendants are still required. Experience and data on shuttle operation at each site is needed before an on-board attendant can be phased out.

Operating Environment

Low-speed automated shuttles may not be suitable for all environments and services. Initial deployments have been limited to relatively simple, premapped environments with relatively simple service models.

- **Deployment environment:** Due to the emerging nature of automated shuttle technologies, there are still many limitations in terms of which deployment environment operational characteristics the vehicle can manage. Current demonstrations have generally been restricted to flat surfaces and either private roadways or non-road pathways. Because the shuttles are constrained to low speeds and highly controlled environments, use cases may be limited (e.g., shuttles may not be well suited to serve complex, high-traffic areas). In addition, vehicles may need infrastructure features (e.g., vertical posts, large boulders, or other features) added to the environment to provide supplemental reference points for localization. These additional features may be particularly important for flat, open areas without similar existing features.
- **Route modification and mapping:** Early-stage demonstration and deployments of low-speed automated shuttles have largely been limited to predetermined routes with fixed stops. The mapping requirements associated with identifying and implementing an appropriate route or modifying an existing route can result in schedule delays or unanticipated costs. In most cases, shuttle providers are extensively involved in setting up new routes, creating a greater risk of delay if personnel are not available when the need to map a new route arises (e.g., to respond to changing demand for an event or unscheduled construction on an existing route).
- **Complex operational requirements:** The nature of transit service, with vehicles making frequent service stops, often in congested areas with high volumes of vulnerable road users (i.e., pedestrians, bicyclists, and other non-motorists) and varying road conditions—including extreme weather conditions—could present particular challenges for sensing systems and control algorithms. Harsh weather challenges the performance of the current generation of sensors, many of which are less effective or not usable in rain, in snow, or at night. Transit vehicles are expected to run in all of these conditions.

Product Availability

Low-speed automated shuttles have developed more rapidly than other forms of automated transit; however, they still represent a market in its early stages with inherent limitations.

- **Emerging market challenges**: The number of existing automated shuttle manufacturers is still relatively few, resulting in a limited amount of technical and operational support for deployers. Early demonstrations frequently act as a learning experience for both deployers and manufacturers, which can result in unanticipated cost, schedule, or logistical challenges.

- **Limited market size:** In the United States, the small size of the transit market and the reliance on politically-driven public funding create disincentives to investment in research and development. To date, the vast majority of automation R&D has focused on the light-duty and heavy truck markets. Adapting automation features from those markets to shuttles or other transit vehicles will require additional research and testing due to differences in vehicle dynamics (e.g., stopping distance) and operational environments. As a result, vehicle technologies used in automated shuttles may lag behind some of the technologies used in light-duty vehicles.

- **Certification:** Low-speed automated shuttles being used in transit applications need to meet applicable federal and state safety standards. Safety standards and testing protocols for automated functions have not yet been developed in the light-duty vehicle market, much less for shuttles, so this remains an open question. Until safety test procedures are developed, deployers may be unable or unwilling to pursue automation, while traditional vehicle manufacturers, who provide basic vehicle chassis (e.g., Fiat Chrysler Automobiles, Ford, and General Motors), and upfitters of paratransit shuttles, who convert the vehicle and add mobility features (e.g., ARBOC, Braun Mobility, and MobilityWorks), may not include automated driving in their research and product development processes.

Planning and Implementation

- **Misaligned expectations regarding performance:** Project sponsors are excited by the possibility of cost-effectively addressing transportation challenges, but shuttles being tested and deployed today have significant limits. Some may not understand the limitations of the technology or may have unrealistic expectations. As a result, the shuttles may not be able to operate in a particular environment or provide an envisioned service.
- **Service planning and demand:** As some deployers are relatively new to transit operations, they may have limited prior experience with service planning, and as a result, deployment routes and service characteristics (e.g., hours of operation) are not always well aligned to the needs of potential passengers. Uncertain passenger demand poses a challenge to pilot deployments, though it is likely that passenger demand will evolve along with the capabilities of the vehicles.
- **Unanticipated costs and delays:** In most cases, pilot deployments have run into unanticipated costs and delays. For example, it may take significantly more staff time than anticipated for a deploying community to prepare and run a pilot—one interviewee cited an increase of 300 percent. Similarly, sponsors may not be prepared for downtime related to planning and calibration, maintenance, or other activities.

Financial Considerations

- **Procurement:** Stipulations in deployers' grant funding agreements or procurement regulations could make it difficult to purchase automated vehicles. More generally, while not necessarily a hard barrier, the tendency for procurement processes to favor tried-and-true vehicle designs and industrywide standards means that there may be a considerable lag between the availability of new automation functions and their incorporation into request for proposal (RFP) specifications. Procurement processes with lengthy time requirements may also make it difficult for agencies to act nimbly in rapidly changing technology markets.
- **Buy America:** Requirements for minimum domestic content and assembly under the Buy America Act could also prevent such investments, to the extent that automated vehicles do not meet those requirements.
- **Availability of funding:** Deployers may lack the financial resources to purchase low-speed automated shuttles (or the required maintenance and support infrastructure) if they command a price premium. Deployers may also not view low-speed automated shuttles as a cost-effective use of funds due to various risk factors or a perceived limited return on investment. To date, no automated shuttle demonstrations in the United States are charging fares to passengers, so additional research and testing will be needed to determine whether a sustainable business case exists. While there is some grant funding available for low-speed automated shuttles (e.g., via the

ATCMTD Program, the Congestion Mitigation and Air Quality Program, and the Federal Lands Transportation Program), funding eligibility will need to be determined on a case-by-case basis.

Labor Considerations

- **Opposition from labor:** Expanded deployment of fully-automated low-speed shuttles without on-board attendants may be expected to reduce employment for transit operators and thus may face opposition from transit employees and labor unions, as well as other stakeholders, including the general public. Even expanded deployment of low-speed automated shuttles with on-board safety attendants and additional technical maintenance and service jobs may be opposed because of a perception that such projects would represent a step in the direction of job losses or a "de-skilling" of the vehicle operator role. There are also specific legal protections for transit labor in Section 13(c) of the Federal Transit Act, and potentially in state law and/or collective bargaining agreements, which would create legal complexities for agencies seeking to achieve labor cost savings through automation.
- **Training and workforce needs:** The lack of a transit workforce with the appropriate skills to manage technologically complex automated systems could also be a barrier. Transit agencies and operators may not be nimble enough to recruit and retain these highly skilled workers, or may not have the resources to commit to ongoing professional development for such a workforce. Faced with such challenges, agencies may elect not to pursue automation.

Data and Evaluation

Low-speed automated shuttles deployers may not define data needs and agreements with deployment partners. If these aspects are not considered upfront, evaluation may be complicated or less useful for informing decisions following the initial pilot.

- **Data sharing:** Many shuttle providers and suppliers are reluctant to share data broadly, making it difficult for deployment communities to get unrestricted access to vehicle data, as it is viewed as proprietary. Some shuttle providers may be willing to share operational data (e.g., regarding vehicle charging, emergency stops, and other operational details) with their clients, but others may be unwilling to share certain types of data. Operators can also collect some types of data using aftermarket products. Due to potential tensions in data sharing, it is advisable for deployers to identify their important metrics of interest in advance and negotiate data sharing agreements upfront.
- **Evaluation metrics:** Often, evaluations are based on readily available metrics rather than data collected with evaluation specifically in mind. Deployment communities would benefit from considering evaluation in advance of starting a pilot deployment in order to collect useful data that map to the specific project objectives.

Public Acceptance

Though future automated vehicle deployments may vary significantly from tests and demonstrations of today, early low-speed automated shuttle deployments may represent the first public exposure to automated driving technologies and models and may therefore influence public acceptance more broadly. Public acceptance is one of the key things that current pilots are testing, but it is also difficult to test due to selection bias (those who choose to ride in shuttles may not reflect the general population and may exclude specific groups). It is also difficult to get more detailed responses from users (simple, single-question surveys administered as riders board or alight shuttles get high response rates, but longer online surveys have low response rates).

As communities test new automation technologies such as low-speed automated shuttles, public opposition could be strong if the public does not understand the rationale or anticipates negative changes to service provision. There could also be a more general unease about the prospect of driverless vehicles and rapid technological change. Certain aspects of automation could also generate privacy concerns (e.g., if electronic fare payment could be used to track passengers' origins and destinations) or impinge on other civil liberties. Opposition could also be expected if low-speed automated shuttles create or are perceived to create unacceptable inequities or disparities in service. All of these factors could dissuade potential deployers from considering greater levels of automation, or even prohibit it altogether if public opposition is translated into legislative or funding actions.

While many pilot deployments are attempting to assess user acceptance through demonstration rides and surveys, all pilots currently have on-board attendants, limiting the relevance of conclusions on user acceptance. Riders who are willing to use a low-speed automated shuttle with an on-board attendant may be unwilling to take similar rides with strangers if the vehicle is otherwise unattended due to concerns about safety and security. To date, little to no work has been done on user acceptance of shared ride services in unattended automated vehicles.

Federal, State, and Local Regulations

Federal, state, and local governments have different roles in regulating vehicles and operations. Early deployers in the United States have experienced regulatory and permitting challenges, as shuttles do not always fall into clearly established categories. See below for some examples.

- **Federal Motor Vehicle Safety Standards (FMVSS) compliance:** FMVSS compliance is a critical issue for low-speed automated shuttle services that will operate on public roads. Given the nontraditional designs of these vehicles (e.g., no steering wheel, no brake pedal, and non-standard seating arrangements), they do not comply and require an exemption or waiver from the National Highway Traffic Safety Administration (NHTSA).
- **Federal Motor Carrier Safety Regulations (FMCSR) compliance:** The Federal Motor Carrier Safety Administration (FMCSA) is the lead federal government agency responsible for regulating and providing safety oversight of commercial motor vehicles. The mission of FMCSA is to reduce crashes, injuries, and fatalities involving large trucks and buses. Depending on the specific implementation, low-speed automated shuttles may be subject to FMCSR, which includes regulation in areas such as safety, labor, and reporting.
- **Federal Transit Administration (FTA) Grant Requirements:** Agencies using FTA funding must also comply with certain requirements, such as Buy America, which specifies certain minimum percentages for domestic manufacturing. These requirements may present a barrier for low-speed automated shuttle diffusion in the United States, as thus far the majority of vehicles have been manufactured in Europe.
- **Americans with Disabilities Act compliance:** The current generation of low-speed automated shuttles is not fully accessible to all travelers with disabilities, although most now provide manual or automatic ramps to assist in boarding passengers with mobility devices. ADA applies regardless of whether there is federal funding involved.
- **Operator licensing requirements:** Some states have passed legislation or enacted regulations on automated vehicle testing that have licensing requirements for human operators. In other states, licensing requirements for the on-board operator are unclear.
- **Necessity of an on-board attendant:** No federal agency appears to explicitly require the presence of an on-board attendant; rather, requirements for human-centric controls are specified in the FMVSS and the FMCSRs, which present training and licensing requirements for human commercial vehicle drivers. Similarly, the ADA may implicitly require a human on the vehicle to provide assistance to riders with mobility limitations. The latter, however, does not explicitly state that a human driver is needed. Determinations for whether low-speed automated shuttles require on-board attendants are more likely to fall to state-level requirements, which conventionally cover vehicle operation (other than interstate commercial vehicle operation).
- **Insurance and liability:** Insurance is generally regulated at the state level. While there are insurers willing to underwrite automated vehicles, deployers may face ongoing challenges as insurance policies, internal safety regulations, and state laws are updated to account for highly automated vehicles. For agencies that do not self-insure, insurance policies may be unavailable through previously-established contracts, at least in the short term. Underwriters may not be

familiar with the impacts of automation, or there may be unresolved concerns about potential cybersecurity vulnerabilities, legal liability in the event of system failure, or similar issues.

- **Public road restrictions:** States and localities have taken varying approaches to regulating the testing and use of automated vehicles on public roadways. Deployers of low-speed automated shuttles may need to coordinate with their respective city or state government to ensure that their deployment or demonstration meets legal requirements. Depending on the location, these requirements could include applying for a permit, obtaining manufacturer license plates, or requiring a human driver to remain behind the wheel. As automated vehicle policy is a rapidly developing field, deployers must stay abreast of sometimes ambiguous and frequently changing legal and institutional requirements as their projects are planned and implemented.

Mitigations

Where barriers can be anticipated, it is possible to create mitigation strategies. These strategies need to be targeted to different organizations, including private firms, transit agencies, academia, deployment communities, and the general public, including transit riders. These strategies include understanding technical capabilities, operating environment requirements, and evaluation metrics early on in the project design phase. Considering those elements upfront may help deployers match capabilities to requirements, plan for contingencies, and ensure that data collection can support decision-making.

- **Technical assistance:** Deployers contemplating low-speed automated shuttle pilots may benefit from outreach, planning assistance, and professional capacity building. For example, technical assistance could include educational materials for both agency staff and the traveling public or a paper documenting best practices for procuring advanced technologies.
- **Technical capabilities:** Before committing to a particular vehicle, deployers can work to understand its limitations and talk to other communities or operators who have previously used the particular shuttle model being considered to understand its capabilities and limits.
- **Operating environment requirements:** Communities can identify early applications that provide useful services in low-risk environments to allow for early demonstrations and learning. As technical capabilities expand, more ambitious applications may be considered in an incremental manner.
- **Simplified operating environments:** Measures such as adding signage, training, or use of an on-board operator—can allow a shuttle to operate in an environment that might otherwise be too complex for safe operation.
- **Contingency planning:** Communities can plan for and map several potential routes before deployment, reducing the potential for delay and cost overruns if the shuttle route unexpectedly needs to change due to external factors.
- **Evaluation metrics:** Deployers can consider service or learning objectives of the deployment project upfront and use those objectives to identify useful evaluation metrics. Once the metrics of interest have been identified, deployers can work with other stakeholders to insure that they will have access to the appropriate data to support project objectives.
- **Stakeholder engagement:** Deployers bring together leaders and representatives from a range of backgrounds (e.g., state and local governments, labor, public safety, operators, contractors, and others) who will likely be involved in project implementation or who may affect or be affected by the project. Projects may benefit from involving a broad range of stakeholders early in the planning process, as stakeholder ownership and buy-in may help with some of the financial and acceptance challenges associated with a shuttle project. Projects with early engagement can be designed with stakeholder preferences in mind rather than needing to change later on to address concerns.
- **Knowledge sharing:** Organizations participating in deployment can produce documentation and participate in activities to disseminate information on challenges, lessons learned, and research results both internally and externally (e.g., to other organizations that may be conducting similar

work). Other organizations not deploying shuttles, such as governments (local, state, or federal) nonprofit organizations, or industry associations could also provide guidance or best practices documents based on the experiences of others.

- **Training and workforce development:** Community colleges, nonprofit groups, transit agencies, or other relevant organizations could develop curricula on and provide training programs for automated shuttle operation and maintenance. In addition, some level of training may be needed for first responders, or other professionals, who may need to interact with low-speed automated shuttles (e.g., in emergency situations). Training and education of operators, riders, or other road users who may need to interact with demonstrations may also be important to ensure that individuals have reasonable expectations in terms of how shuttles will behave, where they will operate, and how deployments will affect the surrounding area.
- **Standards development:** Standards are published documents produced by standards development organizations (SDOs) that establish specifications and procedures to promote reliable and consistent performance of products and services. Development of appropriate standards for low-speed automated shuttles could help address a range of issues, such as supporting functionality, interoperability, comfort, safety, accessibility, and passenger comfort.
- **Procurement:** Foreign companies, including EasyMile, 2getthere, and Navya, have created U.S. offices and are looking to begin manufacturing shuttles domestically themselves or through partners, due in part to Buy America requirements. When appropriate, deployment communities may consider using state funds rather than federal funds for procurement.
- **Funding:** Some deployers are pursuing private and local funding to cover costs, as well as considering the use of advertising (either on-board or external) or vehicle sponsorships. Though most deployments are for research purposes and do not currently include passenger fares, some deployers are considering charging fares in future phases.
- **Further testing:** Additional pilots and demonstrations of low-speed automated shuttles may help deployers expose the public to the technology, potentially improving understanding, comfort, and acceptance. Further testing may also build internal staff capacity in understanding the steps involved in piloting a new mobility technology.
- **Public education:** Additional mitigation strategies may include training and education of operators, riders, or other road users who may need to interact with the demonstration.

Research Questions

Many questions need to be answered in order to move toward sustainable deployment of low-speed automated shuttles, and perhaps, their ultimate integration into the transportation system. Some of the research will be undertaken by shuttle developers and associated suppliers, while other research is best suited for academia and the public sector.

- **Technology research, development, and commercialization**
  - How can research and development support for the low-speed shuttle market help to “jump-start” the domestic market for automation?
  - Could research and development (R&D) funding for academic institutions and private firms lead to new mobility products and demonstrations, helping bring products closer to market?
  - What unmet conditions are needed for successful market introduction and sustainable operations of low-speed automated shuttles?
  - How can various stakeholder groups foster innovation and creativity?
- **Safety research**
  - What are best practices for safety issues, including human factors and safety certification?

  - What can be learned from other modes, such as aviation, rail, and commercial trucking to help inform future development of technical standards?
  - What safety research is needed to help academic institutions and private firms with product development?
  - What research on the safety of low-speed automated shuttles is needed to inform future development of federal guidance and regulations? Does this research also inform public perceptions by addressing common safety concerns?
  - How can safety and security be ensured for the system? What would be included in a safety and security assessment?
- **Accessibility research**
  - What are the accessibility implications of low-speed automated shuttles?
  - What potential vehicle modifications impact the passenger experience?
  - How can deployers make sure that vulnerable populations, many of whom may rely on transit, are empowered rather than disadvantaged by the implementation of automation in transit?
  - How can accessibility considerations help inform future development of federal guidance?
  - Outside of physical accessibility, how can information and communications technology enable access to services using low-speed automated shuttles?
- **Infrastructure research**
  - What infrastructure-based technologies and automation-related infrastructure maintenance can help private firms offer better products and help communities and regional governments understand the broader investments that must be made to enable automation?
- **Remote intervention research**
  - What technical standards and interfaces are needed to enable remote intervention?
  - Do remote operators need valid U.S. driver's licenses? What other requirements must they meet to ensure safe operation of shuttles (e.g., training, standard operating procedures, and licensing)?
- **Workforce research**
  - What are the likely automation-related workforce impacts (in terms of changes to required skills and workforce size in the near-, medium-, and long-term)?
  - How can an understanding of the workforce implications of automation, from both a legal and technical perspective, enable transit agencies, operators, and other deployers to hire or retrain workers with new skills?
- **Technology policy research**
  - How can insurance, liability, privacy, and other implications of low-speed automated shuttles inform how local agencies set guidelines for treatment of passenger information?
  - What policy tools are necessary to encourage local decision-makers to prioritize shared mobility services over increasing vehicle miles traveled from individual vehicles?
- **User acceptance research**
  - What is the state of user acceptance of low-speed automated shuttles, particularly in instances where there is no on-board safety operator or attendant?
  - How will user behavior change when using low-speed automated shuttles as compared to buses or other similar transportation options?

- How can human-machine interface (HMI) design, both inside and outside the vehicle, enable use by a broad range of travelers, including older adults and those with cognitive limitations?

- **Use case and business model research**
  - Are there specific use case implications for each of the relevant modal administrations?
  - How can low-speed automated shuttles contribute to the development of innovative mobility services that are user-centric, reliable, equitable, and ubiquitous?
  - What new models and services will low-speed automated shuttles support? Is there potential for this format to support combined transportation of people and goods?
  - How will low-speed automated shuttles affect the emergence of new business models for private, commercial, and public users?
- **Societal and transportation system impacts**
  - How can existing tools and simulation models be adapted or upgraded to analyze mobility demand and to assess the impacts of low-speed automated shuttles?
  - What will the effect of low-speed automated shuttles be on cities and society more broadly?
  - How will shuttles affect access to jobs, healthcare, and recreation for people who may not be able to access them currently, such as those with disabilities or older individuals?
  - How can low-speed automated shuttles integrate with existing public transport and other active modes, such as walking and cycling?

Conclusion

This report describes current conditions in testing and deployment of this vehicle type and identifies many of the challenges that must be resolved to enable more useful services and broader deployment of automated shuttles. Key findings include:

- Substantial interest exists in low-speed automated shuttles—a variety of stakeholders have expressed interest in deploying vehicles, and many are moving forward with pilots. Several pilots are currently operating, and as deployers gain experience with operating the vehicles, they are exploring offering new or expanded services and operating in more complex environments.
- Though many of the low-speed automated shuttle models have good “fit and finish” and well-packaged sensor suites, at this point, these vehicles are undergoing frequent hardware and software updates, and they should still be considered prototypes. Many systems have somewhat limited technical capabilities and may require frequent intervention from the on-board attendant.
- Appropriate use cases for low-speed automated shuttles are still somewhat unclear. Though shuttle providers and other stakeholders have conceived of use cases, current technological constraints limit which of those use cases can be practically piloted. As a result, existing pilots typically do not fill substantial transportation gaps.
- On-board attendants are currently used on every deployment, and the path to removing attendants is unclear, particularly in more complex operating environments or for services that take on passengers. For some use case concepts, removing the operator is a key element of the business model, as the labor cost of an on-board attendant may make the automated shuttle uncompetitive with other options using manned vehicles.
- Evaluation is challenging for new deployers, but it is necessary to advance the state of the practice. Organizations deploying low-speed automated shuttles do not always have well-defined goals for their pilots, making it difficult to identify performance metrics of interest or to collect appropriate baseline data for comparison.

This document provides background on low-speed automated shuttles and potential services they may be able to provide. It discusses the deployers, their motivations, and their partners, and it has provided information on demonstrations and deployments, both international and domestic. The document also provides context on common challenges and suggested mitigations. Building on all of this information, the document identifies several research questions on topics ranging from safety and accessibility to user acceptance and societal impacts.

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Appendix A: SAE Levels of Automation

SAE's levels of driving automation are descriptive and informative, rather than normative, and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. In this table, "system" refers to the driving automation system or automated driving system (ADS), as appropriate.

Summary of Levels of Driving Automation

Level	Name	Narrative definition	Dynamic Driving Task (DDT)		DDT fallback	ODD
			Sustained Lateral and Longitudinal Vehicle Motion Control	OEDR		
Driver performs part or all of the DDT						
0	No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.	Driver	Driver	Driver	n/a
1	Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.	Driver and System	Driver	Driver	Limited
2	Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.	System	Driver	Driver	Limited
ADS ("System") performs the entire DDT (while engaged)						
3	Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	System	System	Fallback-ready user (becomes the driver during fallback)	Limited
4	High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	System	System	System	Limited
5	Full Driving Automation	The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	System	System	System	Unlimited

Source: SAE 2016

Appendix B: Working Group Participants

The Low-Speed Automated Shuttle Deployment Information-Sharing Working Group has included 19 member projects spread across 15 states. Members include transit agencies, local governments, state transportation departments, universities, and contractors.

Organization(s)	Project Location
Valley Metro	Phoenix, AZ
Contra Costa Transportation Authority (CCTA) and Central Contra Costa Transit Authority (CCCTA)	Contra Costa County, CA
San Francisco County Transportation Authority (SFCTA) and San Francisco Municipal Transportation Agency (SFMTA)	San Francisco, CA
Santa Clara University	Santa Clara, CA
City and County of Denver	Denver, CO
City of Gainesville and Florida Department of Transportation (FDOT)	Gainesville, FL
Hillsborough Area Regional Transit Authority (HART)	Tampa, FL
Jacksonville Transportation Authority (JTA)	Jacksonville, FL
City of Atlanta	Atlanta, GA
City of Boston	Boston, MA
University of Michigan (Mcity)	Ann Arbor, MI
Minnesota Department of Transportation (MnDOT)	Twin Cities, MN
U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC)	Fort Bragg, NC
City of Las Vegas	Las Vegas, NV
City of Columbus	Columbus, OH
Pennsylvania Department of Transportation (PennDOT)	Middletown, PA
Rhode Island Department of Transportation (RIDOT)	Providence, RI
Greenville County	Greenville, SC
City of Arlington	Arlington, TX

Appendix C: Use Cases

As low-speed automated shuttles are part of an emerging and rapidly evolving industry, a cohesive set of vehicle and service characteristics has not yet been defined. In order to develop a framework for the analysis presented in this paper, the project team developed four use cases that represent a potential evolution of vehicle capabilities and the needs that these vehicles are positioned to meet (see Table 5). These use cases are presented in increasing order of automated driving capability.

Table 5: Summary of Low-Speed Automated Shuttle Use Case Characteristics

	Use Cases			
	Private Circulator	**Group Transit Shuttle**	**Automated Paratransit Service**	**Automated Urban Delivery**
Operating Environment	Private Roads	Public/Private Roads	Public Roads	Public Roads
Specialized Infrastructure	Yes	No	No	No
Maximum Speed	25 mph	25 mph	25 mph	25 mph
Waypoints/Stops	Fixed Makes All Stops	Fixed Stops On Demand	Dynamic	Dynamic
Route	Fixed	Dynamic	Dynamic	Dynamic
Service Type	Passengers	Passengers	Passengers	Freight

Private Circulator

Shuttles provide passengers with rides along fixed routes between fixed waypoints on a fixed schedule, and are unable to deviate from these parameters. The shuttle operates on private, restricted roads, which may include specialized infrastructure like markings or alterations to physical infrastructure (e.g., modification or addition of dedicated pathways, signage, landscaping, and vertical features) to help guide the vehicle. Operating environments could include federal lands, parks, zoos, amusement parks, tourist attractions, and other closed campuses. A shuttle can detect individuals waiting at stops, but cannot differentiate between those waiting to board and other pedestrians, so it stops at each of its predefined waypoints, even if no one is waiting to board. Because the shuttle operates on a fixed schedule, it does not accept ride requests from passengers. Variations on this concept include an urban automated people mover and shuttles for indoor use (e.g., at airports or museums). While these variations may differ somewhat from the general concept, they are similar enough that most of the implications explored in this paper will still hold true.

Group Transit Shuttle

Shuttles provide passengers with rides between fixed, high-demand waypoints such as transit stops, retail centers, and office parks. The shuttle operates on public roads, but may also operate in restricted environments, such as service roads or busways. No specialized infrastructure is required for this use case. While the shuttles serve fixed waypoints and operate on a few certified routes, they do not follow a fixed-route or schedule, and may adjust their operation to better serve demand. Riders can request rides using stationary kiosks at waypoints or touchscreens mounted in the shuttles, though a smartphone application could also allow users to make ride requests. Shuttle speed is limited to 25 mph to ensure safe operation on public surfaces, though shuttles may travel at lower speeds depending on the complexity of the environment. Variations include airport shuttles or transit connectors (e.g., service between bus stops and train stations).

Automated Paratransit Service

Shuttles provide passengers with rides between variable waypoints (addresses) within a predefined service area or ODD. Shuttles have variable routes and variable schedules, adjusting their operation to serve demand. This service is intended to primarily serve those with mobility limitations that may otherwise prohibit them from using traditional public transit services, though the service may be extended to other groups as well. Rides with similar origins and destinations, or that have significant overlap in route and timing, may be combined as shared rides. Because the paratransit service must be able to operate on public roads in suburban and rural areas, the shuttle would be able to operate at speeds greater than 25 mph. Riders can request rides using a smartphone application, a website interface, or a ride request hotline. Ride requests may be entered in advance or made in real time. Variations include taxi/transportation network company (TNC) service or first/last-mile connectors providing rides between high-demand transit stations and individual addresses.

Automated Urban Delivery

Shuttles deliver groceries and other retail items from stores or warehouses to variable waypoints (recipient addresses) within a service area. Shuttles have variable routes and variable schedules, adjusting their operation to serve the delivery schedule. Deliveries with similar origins and destinations may be combined on the same shuttle. Deliveries may be stored in lockers to be opened by the recipient who must come to the street to pick up delivered items, or the shuttle may carry smaller delivery robots that carry items to the recipient's front door. Because the delivery service operates on public roads, the shuttle would be able to operate at speeds greater than 25 mph. Variations include circulating stores (for impulse purchases), anticipatory shipping, and urban freight deliveries (to industrial or commercial buildings).