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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP RESEARCH REPORT 220

Low-Speed Automated Vehicles (LSAVs) in Public Transportation

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2021

TRANSIT COOPERATIVE RESEARCH PROGRAM

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FOREWORD

By Dianne S. Schwager
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Interest in driverless vehicles, including low-speed automated vehicles (LSAVs), continues to expand globally and in the United States. *TCRP Research Report 220: Low-Speed Automated Vehicles (LSAVs) in Public Transportation* presents current use cases for LSAVs and provides a Practitioner Guide for planning and implementing LSAV services as a new public transportation service. The audience for this research includes public transit agencies, communities, and private mobility providers seeking to understand how to best incorporate automated vehicles—and specifically LSAVs—into public transportation service.

Research under TCRP Project J-11/Task 27, "Low-Speed Automated Vehicles (LSAV) in Public Transportation," was conducted by Mobilitye3, LLC, and the Eno Center for Transportation. The team was asked to (1) conduct scenario analyses of possible use cases for LSAVs that foster integrated urban mobility; (2) delineate vehicle, technology, and infrastructure attributes required for various LSAV use cases; (3) consider important issues relevant to the introduction of automated transportation regarding goals, safety, mobility of diverse populations (including people with disabilities), and benefit measurement; and (4) develop guidance, such as a checklist, that presents a decision-making process and rationale for the effective planning and deploying of LSAV services.

The focus of this research was LSAVs, also called automated shuttles. At present, LSAVs are typically low-floor and high-ceiling vehicles that carry four to 10 seated passengers and some standing passengers at relatively low speeds (i.e., about 15 mph). While the vehicles do not require a driver and have SAE Level 4 automation, they typically have an attendant to help passengers and oversee the safe operations of service. Generally (but not always), LSAVs currently operate in controlled environments such as office parks, campuses, and theme parks and on simple circulator routes. To date, LSAVs do not operate in complex mixed traffic or on demand. The future of LSAVs is unknown, but many of the above characteristics may change as vehicles, technology, and use cases evolve.

The research included a literature review; three detailed case studies on the lessons learned in pilots conducted in Texas, Nevada, and North Carolina; and 14 mini case studies on other LSAV projects in the United States. The research team interviewed numerous project sponsors, public agency representatives, researchers, and technology vendors.

The Practitioner Guide presents seven key stages for planning and implementing LSAV services with checklists and resources (available through hyperlinks) that address (1) program foundations, (2) feasibility, (3) procurement, (4) implementation, (5) operations, (6) monitoring and evaluation, and (7) sustainability.

CONTENTS

SUMMARY

Low-Speed Automated Vehicles (LSAVs) in Public Transportation

The automation of mobility is complex, unpredictable, and potentially transformative. Public transit agencies and private mobility providers seek to understand how best to incorporate automated vehicles—specifically low-speed automated vehicles (LSAVs)—into public transportation service. Many public and private entities have experimented with LSAVs in a range of applications. At the same time, the manufacturers of LSAVs are expanding vehicle and service types.

Vehicular automation is a dynamic topic in that technologies and policies may change rapidly. Public transit agencies wishing to explore LSAV services may consult with relevant federal, state, or local authorities on policy. This research was conducted under the direction of a panel with expertise in public transportation, mobility innovation, and research.

Research Objectives and Approach

The objectives of this research were to (1) provide public transit agencies and communities with guidance about the deployment of LSAVs as a new public transportation service and a step toward automated mobility on demand, (2) present use cases for LSAVs that may evolve, and (3) provide a checklist for planning and implementing LSAVs. Through a literature review, interviews, and project assessments, this research developed practical guidance for public transit agencies on emerging LSAV technology, lessons learned from early implementations, and considerations for LSAV projects in public transportation. The report addresses

- **LSAV service applications.** Emerging vehicle types and service models and how to consider their use in varied operating environments.
- **Guidance for developing LSAV projects.** LSAV projects in public transportation, including planning, funding, implementation, and evaluation.

LSAVs vary in speed, level of automation, size, and whether the vehicle and the service must comply with the ADA as amended (ADA 42 U.S. Code §12101 et seq.) For purposes of this study, "LSAV" refers to vehicles that reach speeds between 15 and 35 mph, are highly automated (Level 4 of 5, as defined by SAE), and operate as a shared service. LSAV types and sizes, or "form factors," are expanding with the emergence of smaller scooter-like vehicles and larger buses (along with the attendant federal regulations).

Project research identified varied LSAV use cases currently being planned and implemented by public and private entities that do not provide public transportation, as well as by public transit agencies. Two important attributes of these use cases are service models and trip purposes:

- **Service models.** The service models include fixed routes, circulators, shuttles, first/last mile feeder services, and paratransit and other on-demand mobility options. These service models may operate separately or be combined.
- **Trip purposes.** LSAV services for specific types of trips are being planned and piloted by organizations that are not public transportation providers. These trips include services for health care, employment, entertainment, recreation, retail, parking access, residential development, and senior social services. In the future, public transit agencies as well as other public and private providers may offer LSAV service to provide general mobility for any trip in the public right-of-way.

The report explains the importance of the operational design domain (ODD) for LSAVs. An ODD comprises the operating conditions under which a given driving automation system or feature is specifically designed to function. Conditions may include speed, weather, topography, time-of-day restrictions, and the requisite presence or absence of certain traffic or roadway characteristics. This research identified vehicle speed; weather; and traffic, roadway characteristics, and roadway conditions as key ODD aspects for practitioners to evaluate when considering LSAV service:

- **Vehicle speed.** As the name "low-speed automated vehicles" suggests, practitioners will need to account for posted speed and operational speed, as well as the speed of other vehicles in mixed traffic in the same right-of-way.
- **Weather.** Practitioners may find that heat, snow, and rain require mitigation or limit operations.
- **Traffic, roadway characteristics, and roadway conditions.** Depending on the design of a specific vehicle, LSAVs can travel in mixed traffic with a range of crossings (e.g., unprotected turns, controlled stops, and signalized intersections). Modifications to physical infrastructure or the addition of connected vehicle technology can mitigate the hazards these attributes present.

On the basis of a review of procurement and grant applications, as well as stakeholder interviews, this research found that a rising number of communities in the United States are exploring how LSAVs can help them achieve their transportation, mobility, and economic development goals. LSAV projects have ranged from short pilots with simple use cases to multiphase deployment strategies, in which communities are using LSAVs as a key part of the transportation system. Further, communities are deploying LSAVs in a variety of operating environments and ODDs.

This research examines U.S.-based LSAV projects that have been planned, implemented, or completed. The projects ranged between 2 and 15 months' duration; no demonstrations of shorter duration were included. Project status is defined in one of three categories:

- **Planning.** Projects in active concept development, route planning, or approvals before their official launch, including projects in testing.
- **Operational.** Projects currently operating, which generally involves transporting passengers or fulfilling the goals of the program.
- **Completed.** Projects that have finished.

Key Findings and Lessons Learned

This research on the evolution of interest in LSAV services in the United States and lessons learned from their initial planning and implementation informs findings and guidance for practitioners. Key findings address:

- **Current global and U.S. interest in LSAVs.** Global and U.S. interest in LSAVs continues to expand, along with the start up of LSAV services. To date, most LSAV service planning, development, testing, and initiation has been by public and private entities other than public transportation agencies. In most cases, LSAV services, although publicly available, serve tightly targeted trip purposes. Evidence of continued interest and support for LSAV service expansion includes the following:
  – Vendors have secured on-road testing approvals for additional vehicles.
  – At least one public transit agency has identified ways in which LSAV service can support logistics, such as moving COVID-19 testing samples.
  – NHTSA has issued Nuro a temporary 2-year exemption from the Federal Motor Vehicle Safety Standards (FMVSS). This exemption is the first issued for any automated vehicle, including an LSAV (albeit for a vehicle designed for cargo instead of passengers).
- **Objectives for planning and implementing LSAV services.** Long-range transportation plans (LRTPs) have identified improved mobility as a key objective for LSAV services, yet the objectives for most metropolitan planning organizations (MPOs), cities, and public transit agencies are to introduce and understand automated technologies and to pursue economic development.
- **Management, oversight, and funding for LSAV services.** LSAV service management, oversight, and funding throughout the United States are currently through various public–private collaborations. Since early pilots at Fort Bragg and the Smart Cities Challenge held in 2016, few sustained LSAV projects or pilots in the United States have been led directly by a public transit agency.
- **Evolution of LSAVs and services.** LSAV models and services are evolving as they are piloted. Existing vehicles are being modified, new vehicle models are being introduced, and new services are being considered and planned. Technological capabilities of LSAVs and use cases related to public transportation are intertwined. Although this research on LSAV technology and services represents a snapshot in time, it reveals that technology and use cases are evolving as LSAVs move from prototype to production.
- **Accessibility and LSAVs.** Though FTA has not issued guidance defining accessibility for LSAV models or services, it has issued an FAQ on transit bus automation.[1] To date, no LSAV models have been designed or retrofitted to include all features for customers with disabilities, such as wheelchair ramps, securement devices, and rails. Some LSAV manufacturers have begun to include ramps and wheelchair securement; others have added human–machine interfaces (HMIs) to allow customers with cognitive, visual, and auditory disabilities to communicate with the vehicle. Federal and state governments have funded prototype accessible automated vehicles through both design challenges and assistive technology initiatives.

Practitioner Guide

This research confirmed that practitioners want guidance about planning and implementing LSAV service, as well as additional research on LSAVs.

The research informed the checklists for key LSAV project stages in Chapter 5, the Practitioner Guide. The key stages are LSAV program foundations, feasibility, procurement, implementation, operations, monitoring and evaluation, and building for sustainability. Each checklist features examples or models of transportation planning, procurement, funding, safety, and operations approaches. Figure S.1 highlights the key elements.

[1] FTA, "Transit Bus Automation Policy FAQs," November 1, 2019, https://www.transit.dot.gov/research-innovation/transit-bus-automation-policy-faqs.

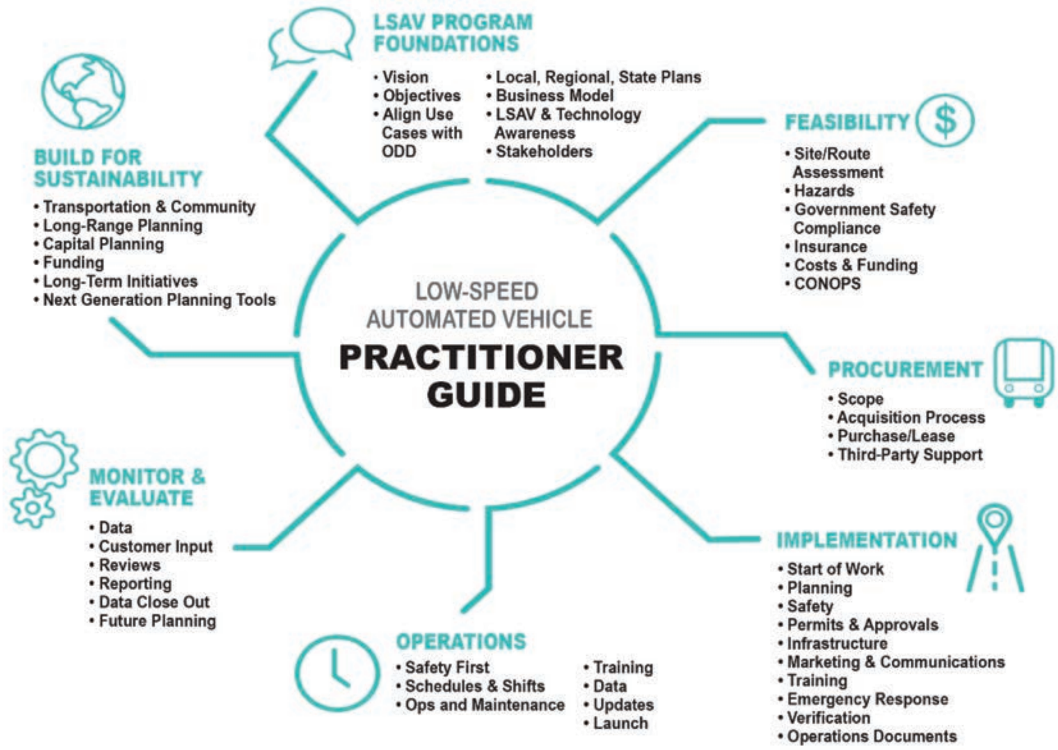

Figure S.1. Key elements of the Practitioner Guide.

Future Research

Future research in several areas could increase the transit industry's capacity for planning for and managing LSAVs. Key outcomes of further research include

- Establishing a baseline of LSAV planning and implementation in transit and related public agencies, including cities, MPOs, and state departments of transportation.
- Developing performance requirements for LSAVs, related data tools, and training for safety operators.
- Creating an inventory of strategies to maximize accessibility through ADA standards, equity of access, and universal design, including assistive technologies.
- Establishing a resource center to support ongoing collaboration on best practices.
- Identifying and validating metrics and evaluation tools for LSAV services in public transportation.

CHAPTER 1

Introduction

The development of automated vehicles is complex, challenging transportation professionals to keep up with the state of the technology and its uses; federal, state, and local policy; and best practices in planning and deployment. This research builds on the various trials of different levels of automated technology across several categories of vehicles operating at a range of speeds. In particular, the research examined low-speed automated vehicles (LSAVs) already deployed on public roads as shared mobility services. This research provided an opportunity to explore future operation of LSAVs as public transportation.

Vehicular automation is a dynamic topic in that technologies and policies may change rapidly. Public transit agencies wishing to explore LSAV services may consult with relevant federal, state, or local authorities on policy. This research was conducted under the direction of a panel with expertise in public transportation, mobility innovation, and research.

The technology for automated vehicles moves forward alongside new business and service models in the transportation portion of the sharing economy. This convergence signals the potential for accelerated deployment of shared automated vehicles in more densely populated areas, especially for vehicles operating at speeds less than 35 mph.

1.1 Study Background

In August 2018, a report by Volpe National Transportation Systems Center noted that more than 260 LSAV demonstrations and pilots—some planned, some ongoing, and some complete—had occurred in North America, Europe, Asia, Oceania, and Africa. *Low-Speed Automated Shuttles: State of the Practice* identified more than 50 suppliers of LSAVs in different stages of development; manufacturing locations included the European Union, the United Kingdom, Asia, and Australia.

This study focuses on U.S.-based LSAV projects that are (1) being piloted or deployed for sustained service of more than a few days and (2) designed to explore a transportation use case and experiment with this emerging technology. May Mobility, sponsored by Bedrock, launched the first commercial deployment of LSAVs in the United States in Detroit, Michigan, in July 2018. At about the same time, two LSAV pilots providing shared service to the public ended: one in Arlington, Texas, and the other in Las Vegas, Nevada.

Since then, more projects featuring LSAV service have started operating, and dozens more have been planned. More expansive deployments of LSAVs, sometimes supported by more expansive infrastructure, have been funded through U.S. DOT BUILD grants, including new LSAV services in Las Vegas, Nevada, Jacksonville, Florida, and Youngstown, Ohio. Dozens more entities included LSAVs in proposals submitted under U.S. DOT Automated Driving System demonstration grants.

LSAVs vary in vehicle speed, level of automation, vehicle size, and whether the vehicle and service comply with the ADA (ADA 42 U.S. Code § 12101 et seq). For purposes of this study, "LSAV" refers to vehicles that reach speeds between 15 and 35 mph, are highly automated (as defined by SAE), and operate as a shared service. LSAV types and sizes, or "form factors," are expanding with the emergence of smaller scooter-like vehicles and larger buses (along with the attendant federal regulations).

LSAVs encompass a variety of vehicle attributes, for example,

- **Levels of automation.** SAE has defined six progressive levels of automation from Level 0 to Level 5. Level 0 has no driving automation. LSAVs operate at Level 4 (High Driving Automation), which means the vehicle is capable of performing all driving functions under certain conditions. That is, the driver may have the option to control the vehicle. Level 5 (Full Driving Automation) means that human driving is completely eliminated.[2]

  Currently, LSAVs transporting humans are being operated with a safety attendant on board and, in some cases, with a remote operator. In spring 2020, the Jacksonville (Florida) Transportation Authority and Florida-based autonomous shuttle service provider Beep deployed a Navya shuttle, an LSAV, to move COVID-19 test samples. No passengers or safety operators are on board, but a follow, or chase, vehicle travels close to the Navya.
- **Vehicle size and configuration.** LSAVs include a variety of vehicle shapes and sizes. For example, some LSAVs are known as neighborhood electric vehicles (or NEVs), which can carry 4 to 10 seated passengers and some standing passengers. Other LSAVs are purpose-built low-floor shuttle vehicles with high ceilings, which can accommodate 6 to 22 passengers. Still others are purpose-built "pod cars" that carry one to six passengers and can be configured as "trains" or a platoon. LSAVs may also be retrofitted light duty vehicles such as vans or sedans. Though there is no federal definition of an LSAV, NHTSA defines a low-speed vehicle as a vehicle that has four wheels, a top speed of more than 20 mph and less than 25 mph, and a gross vehicle weight rate of fewer than 3,000 pounds.[3] All such vehicles must meet the testing requirements set out in the FMVSS.[4]
- **Vehicle speed.** Some LSAVs travel at low speeds (below 15 mph). Some vehicles programmed to operate up to 25 mph have been introduced into mixed traffic, and there are projects in the planning stages for speeds up to 35 mph.

1.2 Research Objectives

The objectives of this research are to (1) provide public transit agencies and communities with guidance about the deployment of LSAVs as a new public transportation service and a step toward automated mobility on demand, (2) present use cases for LSAVs that may evolve, and (3) provide a checklist for planning and implementing LSAVs. The research examines completed LSAV pilots as well as LSAV projects currently in planning or early-stage implementation.

The research illustrates conditions for current and future use cases, along with best practices for planning, implementing, and operating LSAVs. Whereas the use cases are rooted in public transit, other business rationales and service models suggest new mobility applications that blur the lines between public and private transit. The report presents checklists for practitioners, as well as examples of templates, forms, guides, and manuals. This report does not assess the performance of currently available technology.

[2] SAE International, "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," Document J3016, issued January 2014, revised June 2018.
[3] 49 CFR § 571.3, Definitions.
[4] 49 CFR § 571.500, Standard No. 500, Low-speed vehicles.

1.3 Methodology: Lessons-Learned Approach

The research approach included

- **Literature review.** The research team reviewed relevant published literature, including the 2018 study *Low-Speed Automated Shuttles: State of the Practice*, by the Volpe National Transportation Systems Center. The team also conducted interviews with Volpe researchers. (See Appendix A for an annotated list of the relevant published literature.) The team also reviewed unpublished documents that represent each stage of the LSAV planning and implementation process, primarily from projects profiled in the case studies or mini case studies. The Practitioner Guide also provides checklists with examples of useful reference documents for practitioners ideating, planning, and implementing LSAV projects.
- **Case studies.** Three LSAV pilots are presented as case studies to provide lessons from implemented LSAV projects in Arlington, Texas; Fort Bragg, North Carolina; and Las Vegas, Nevada (see Appendix D). The case studies include (1) interviews with key stakeholders (see Appendices B and C); (2) a review of working papers, planning documents, and procurement documents related to the pilots; and (3) a review of other existing reports related to LSAVs.
- **Mini case studies.** To supplement the three case studies, the research team reviewed 14 other LSAV projects in the United States, some in regular operation and several being planned. The research team reviewed available working papers and interviewed project stakeholders, where possible. The findings focus on key planning and operational elements summarized in two- to three-page mini case studies in Appendix E.
- **Other interviews.** In addition to interviews conducted for the case studies, the research team interviewed numerous project sponsors, public agency representatives, researchers, and technology vendors. Those interviews informed the case studies as well as the rest of the report.

CHAPTER 2

Use Cases and Operational Design Domains for LSAVs

This section focuses on use cases and operational design domains for LSAVs. The discussion on use cases describes the service models and transportation needs LSAVs address, both now and in the future. LSAV operational design domain (ODD) attributes are relevant to how both conventional and automated vehicles can operate with various road conditions, speed, weather, and other factors. For automated vehicles, such as LSAVs, the ODD is defined as either "limited" or "unlimited" under the SAE taxonomy.[5] ODDs suitable for LSAVs vary according to the vehicle; environmental, geographical, and time-of-day restrictions; and the requisite presence or absence of certain traffic or roadway characteristics.

2.1 LSAV Use Cases

LSAV services may be provided by public transportation agencies, connect to public transit, or provide shared mobility services in areas with no or limited public transportation. Many examples of LSAV services presented in this report are currently being planned and implemented by public and private organizations that do not provide public transportation. The use cases for LSAVs include two aspects of the services:

- **Service models.** The service models include fixed routes, circulators, shuttles, first mile/last mile feeder services, and paratransit and other on-demand mobility options. These models may be combined. For example, a service may operate along a fixed route where pick-up is on demand and may use a flex zone surrounding the fixed route to expand the locations served. Some service models may operate as prearranged, zone-based, or property-based services. The various service models may also operate flexibly, meaning they could change on the basis of customer requests.
- **Trip purposes.** LSAV services for specific types of trips are being planned and piloted by organizations that are not public transit providers. These include services for health care, employment, entertainment, recreation, retail, parking access, residential development, and senior social services. In the future, public transit agencies, as well as other public and private providers, may offer LSAV service to provide general mobility for any trip in the public right-of-way.

As will be discussed in Chapter 4, LSAV services operated by public transit agencies and funded by the federal government must be ADA compliant and accessible to disabled persons.

[5] SAE International, "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," Document J3016, issued January 2014, revised June 2018.

LSAV Service Models

The following LSAV service models may be offered by public transit agencies or other public and private providers. The first four models generally operate as fixed services. LSAV service models may be provided areawide or on a zoned basis. They could be more flexible than traditional on-call services in both routing and employing mobility-on-demand options and using smartphone apps, automated kiosks, or web-based bookings. This flexibility allows passengers to request pick-up and drop-off to desired destinations or door-to-door service.

Fixed-route LSAV services operate on a set path between end points with stops along the way, similar to traditional public transportation provided by bus or rail services. Vehicles may travel at different speeds in dedicated lanes or in mixed traffic. Fixed-route LSAV services can stop at all programmed points or by request. Vendors are introducing voice-activated technology, computer screens, call buttons, and other mobile device applications to allow customers to request stops from inside LSAVs. The frequency of trips or the size of vehicles can be altered to match demand.

Circulators operate within a closed loop, usually 3 mi or shorter. LSAV circulator services are particularly appropriate where people travel within a specific neighborhood or campus. In existing public transportation circulator services, stops are often closer than in fixed-route service, given the proximity of destinations in the area. Because ridership is high density and the service may represent only one leg of a multimodal trip, conventional circulator services often operate more frequently, and vehicles can be smaller.

A–B shuttles travel between two points, either on a fixed route or as a circulator. For example, an A–B LSAV shuttle could travel to and from a special event, employment destination, or parking lot. A–B LSAV services may include the capability for customers to request on-demand stops within or outside the vehicle.

First/last mile and feeder services connect customers to higher-capacity fixed-route rail or bus public transit services. The effect is to increase the catchment area of a bus stop or rail station. Typically, first/last mile services make short-distance trips and may run all day or just during morning and evening peak hours. First/last mile LSAV services may operate as fixed routes but could deviate to provide flexible routes and door-to-door service. Small LSAVs could offer frequent service from a transit stop or station and nearby destinations.

Paratransit (on-demand service) LSAVs may provide point-to-point services by customer request, which could be especially beneficial to customers with mobility, visual, or communications disabilities who need door-to-door services. These services, which may be either booked or provided on demand as driverless taxis or ride-hailing services, could be deployed as shared services that pool people headed in the same direction into one vehicle. LSAVs—whether as paratransit or general access—could be dispatched when a threshold number of people or specified wait time is reached.

LSAV Trip Purposes Served

Most LSAV services for specific-purpose trips are being planned and tested by organizations that are not public transit providers. Instead, these services are typically provided by public and private organizations that may interface with public transit providers (Table 2.1). Examples of trip purposes being served by LSAVs or being considered for future LSAV services include

- **Education.** LSAVs can provide connections to and within university and other educational campuses, expanding both mobility options and educational opportunities.

Table 2.1. LSAV project use cases.

LSAV Project Example	Trip Type	Service Model
Jacksonville, Florida	Education	Fixed Routes, Circulators, A–B Shuttles, Prearranged Route, or Zone-Based Services
Grand Rapids, Michigan	Health Care	Circulators
Youngstown, Ohio	Education, Employment, Entertainment, Health Care	Circulators
Frisco, Texas	Employment, Entertainment	Circulators
Arlington, Texas	Education, Employment, Entertainment, Recreation, Retail, Parking	Fixed Routes, Circulators, Paratransit
Doraville, Georgia	Entertainment, Recreation, Retail	Circulators
Detroit, Michigan Bedrock	Parking	Circulators
Ann Arbor, Michigan Mcity	Education	A–B Shuttles
Las Vegas, Nevada GoMed	Employment, Health Care	A–B Shuttles
Pawtucket and Providence, Rhode Island	Employment	Fixed Routes, First/Last Mile
The Villages Florida and California	Recreation, Health Care	Paratransit, On-Demand Pooled Services

- **Employment.** LSAVs can provide access to employment centers and allow mobility within such a center. (An employment center is an area where job locations are concentrated, such as an office park, downtown, mixed-use campus, industrial park, or cluster of office buildings.) Such services may decrease parking requirements and increase amenities for employees and visitors.
- **Entertainment, recreation, and retail.** LSAVs can connect customers to entertainment, recreation, and retail venues, as well as allow movement within a defined single-purpose or mixed-use district. LSAV services can help reduce parking requirements and improve accessibility, particularly for those with a mobility, visual, or cognitive impairment.
- **Health care.** LSAVs can provide service to and within a health care campus, or point-to-point service to medical and behavioral health services, to improve access to health care. LSAV services may decrease transportation time to appointments, reduce parking requirements, and increase rates of follow-up care.
- **Parking.** LSAV can shuttle employees to and from remote parking, reducing parking costs for employees and employers.
- **Property-based services.** Real estate developers often fund property-based services to attract shoppers or to provide amenities for employees or residents. LSAV services such as circulators and first/last mile services can connect residents, customers, and employees to home, shopping, and work.
- **Senior services and residential developments.** LSAVs can provide seniors fixed-route and on-demand services within campus environments and to community and human services.

2.2 Operational Design Domains

The ODD for LSAVs or any automated vehicle is the operating conditions under which a given driving automation system or feature is specifically designed to function. Conditions include, but are not limited to, environmental, geographical, and time-of-day restrictions, and the requisite presence or absence of certain traffic or roadway characteristics. Key ODD attributes for practitioners to consider include posted and operational speeds, intersections and crossings, and road conditions. The following are key aspects of ODDs related to LSAVs:

- **Vehicle speed.** As the name “low-speed automated vehicles” suggests, speed is a key consideration in assessing whether an LSAV may operate in a specific environment. Practitioners must account for posted and operational speed. “Operational speed” refers to the speed of other vehicles in mixed traffic in the same right-of-way. LSAVs’ operating environments typically have posted speeds of under 35 mph.
- **Traffic, roadway characteristics, and roadway conditions**. Depending on their specific design, LSAVs can travel in mixed traffic with a range of crossings (e.g., unprotected turns, controlled stops, and signalized intersections). On the basis of a given LSAV’s capabilities and the nature of a potentially hazardous intersection, an operator, vendor, or transportation agency may add sensors at an intersection to enhance vehicle-to-vehicle and vehicle-to-infrastructure communication. Adding fixed sensors to augment the LSAV environmental data may be especially important for unprotected left-hand turns. A signal may be phased, or a signal phase can be communicated from the LSAVs automatically. (At this time, safety operators are sometimes directed to revert to manual mode for left-hand turns.)
- **Weather.** As another key factor for providers deploying LSAVs, weather conditions that can have adverse impacts include heat, snow, and rain. The effect depends both on the intensity of the weather condition and the specific design of the vehicle.

A summary of ODD attributes pertaining to LSAVs’ interactions with other road users, crossings, and turns is presented in Table 2.2.

Table 2.2. Key ODD considerations for LSAVs.

Operational Design Domain	Description/Significance	Example Pilot or Demonstration
"Level of interaction with other road users" (or "right-of-way") determines the complexity of the operational environment for an automated vehicle. Right-of-way that minimizes interaction with other vehicles and pedestrians is generally easier to automate, given simpler programming parameters and less chance of an unexpected edge case scenario.		
Exclusive off-street guideway	Operates in dedicated guideway or path and may be governed by geofencing or physical infrastructure	Jacksonville Ultimate Urban Circulator (U2C)
Off-street multiuse pathway	No light duty vehicle traffic; pedestrians, cyclists, and scooters present	Arlington (Texas) Milo shuttle
On-street pathway with dedicated lane for LSAVs	Dedicated lane, although on a street/right-of-way with other traffic in other lanes and no physical barrier	Jacksonville Bay Street Corridor
On-street pathway with dedicated lane for LSAVs and other transit vehicles	Dedicated to specific types of vehicles and transit	Tampa downtown shuttle
On-street mixed traffic	Right-of-way/street in mixed traffic	Bedrock Detroit shuttle
"Crossings/turns" refers to how the route of the vehicle crosses other vehicles' paths.		
Unprotected left-hand turns	Vehicle must cross pathway of other vehicles	Drive AI, Arlington (Texas)

CHAPTER 3

LSAV Projects

Communities around the United States are exploring the potential for LSAVs and how these vehicles can help them achieve their transportation, mobility, and economic development goals. LSAV projects range from short pilots with simple use cases to multiphase deployment strategies in which cities are using LSAVs as a key part of the transportation system. Further, LSAVs are being deployed in a variety of operating environments or ODDs. This section aims to capture recent developments with LSAVs as they are being used across the United States (Figure 3.1).

In July 2018, the research team identified only 11 LSAV projects, of which three were completed. As of October 2019, the team identified 73 projects in the United States that are in active planning or implementation stages, including 11 completed projects. These projects are presented in Table 3.1. Table 3.1 includes projects of 2 to 15 months duration and notes one of three possible current statuses: (1) *planning*, or projects in active concept development, route planning, or approvals before the official launch, including testing; (2) *operational*, or projects currently transporting passengers or otherwise fulfilling program goals; or (3) *complete*, or projects that have finished and are no longer operating.

The research team identified nearly 50 other LSAV projects (including 25 in Canada that are listed in Appendix F), some subject to nondisclosure agreements, and others on military bases that have hosted the testing and piloting of automated ground transportation systems.

In addition to the LSAV projects identified by the research team, other community projects to deploy automated vehicles, including LSAVs, have been in discussion for the past few years. Seventy-five percent of applications to the U.S. DOT Smart Cities Challenge launched in 2015 had an automated vehicle component. The terminology in the grant applications was generic but, in context, many proposals included LSAV options. Since the challenge, many cities have developed mobility innovation plans that include LSAV taxis and shuttles, and some MPOs have included LSAV projects in their federally required LRTPs and transportation improvement programs (TIPs). Many cities are including automated vehicles (encompassing LSAVs) in new smart mobility chapters of their comprehensive plans, corridor plans, transportation master plans, and requests for proposals (RFPs) for micromobility hubs.

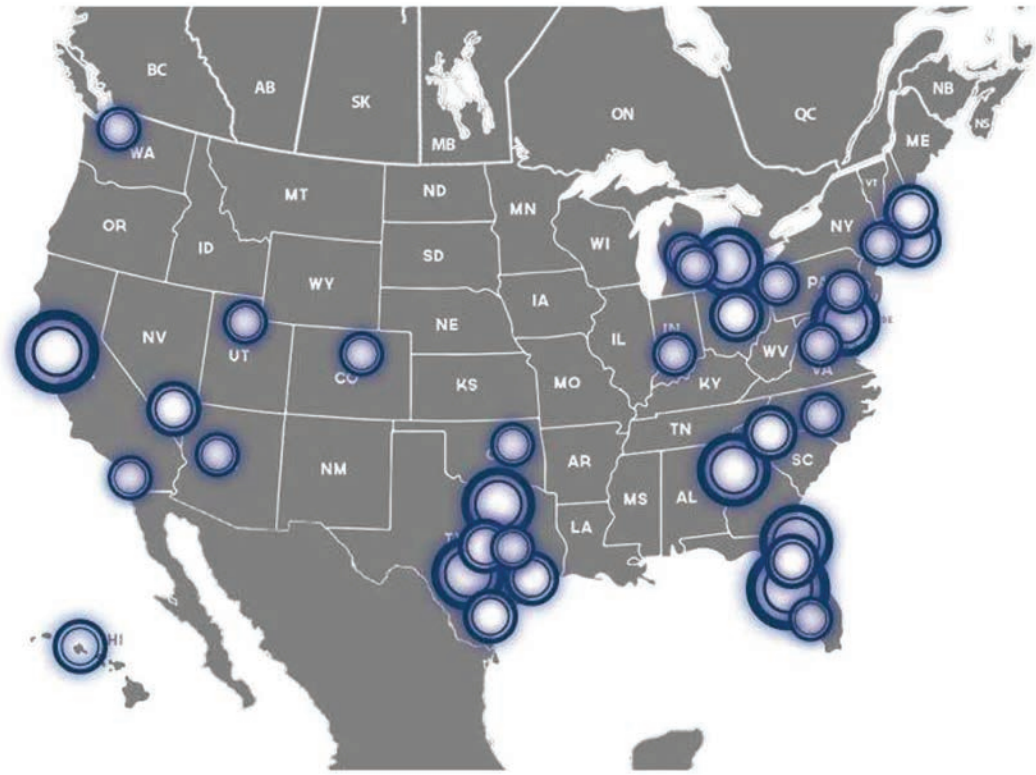

Figure 3.1. LSAV project use cases.

Table 3.1. LSAV projects in the United States (as of October 2019).

City/State	Name	Description	Status
Tempe, Arizona	ASU SAV Feasibility Study and Concept Plan	Concept plan for first/last mile shuttle/campus circulator serving Arizona State University Tempe campus and one of their light-rail transit stations.	Planning
Dublin, California	LAVTA First/Last Mile Shuttle to BART station	First/Last Mile shuttle to East Dublin/Pleasanton BART station on mixed-traffic roads.	Planning
Fairfield, California	Paradise Valley Estates Shuttle	Optimus Ride shuttle in a continuing care retirement community campus.	Planning
Miramar, California	MCAS Miramar Modern Installation Mobility	Active testing and planning for additional deployment on the military base and in surrounding areas. Launched February 2019.	Operational
Mountain View, California	VTA North Bayshore Transit Connection	Connection between VTA light rail and North Bayshore (a.k.a. Googleplex, a business park including Microsoft and other employers).	Planning
San Francisco, California	Treasure Island LSAV Taxi	San Francisco County Transportation Authority LSAV taxi project on Treasure Island.	Planning
San Jose, California	The Villages/Voyage On-Demand LSAV	Retirement community on-demand service. Phase 1 completed. Phase 2 testing.	Planning
San Ramon, California	Bishop Ranch/GoMentum LSAV Testing	Phase 1: Business park circulator to test signal prioritization/performance. Phase 2: First/last mile service. Testing began March 2018.	Planning
Denver, Colorado	61st Street AV Shuttle	LSAV shuttle connecting RTD East Line 61st and Pena Station to office park where Panasonic is located. Completed August 2019.	Complete

Table 3.1. (Continued).

City/State	Name	Description	Status
New Haven, Connecticut	New Haven Fully Autonomous Vehicle Testing Pilot Program	Fully Autonomous Vehicle Testing Pilot Program between two hospital campuses in downtown New Haven.	Planning
Washington, D.C.	The Yards	Point-to-point shuttle with Brookfield mixed-use development; pivot to meal delivery during COVID-19.	Planning
Babcock Ranch, Florida	Babcock Ranch Shuttle	On-demand LSAVs serving residential community connecting to retail and other amenities. Launched November 2017.	Operational
Clearwater, Florida	Pinellas Suncoast Transit Authority Self-Driving Shuttle	Downtown LSAV circulator serving tourist destinations.	Planning
Dunedin, Florida	Pinellas Suncoast Transit Authority Self-Driving Shuttle	Downtown LSAV circulator serving tourist destinations.	Planning
Gainesville, Florida	GAToRS AV pilot project	Fixed-route LSAV service between downtown Gainesville and University of Florida campus.	Planning
Jacksonville, Florida	Ultimate Urban Circulator Phase1	Off-street testing track for 3 automated shuttles, including public demonstrations and educational events. Launched December 2017.	Operational
Jacksonville, Florida	Ultimate Urban Circulator Phase 2	Bay Street Innovation Corridor, providing fixed-route LSAV service along one main street in downtown Jacksonville.	Planning
Jacksonville, Florida	Ultimate Urban Circulator Phase 3	Replacement of elevated people-mover system (Jacksonville Skyway) with LSAV shuttles, and extension into downtown-adjacent neighborhoods.	Planning
Lake Nona, Florida	Move Nona AV Shuttle	Community shuttle as part of Move Nona initiative run by Beep and Bestmile. Launched September 2019.	Operational
Tampa, Florida	HART Transitway AV Shuttle	LSAV shuttle route along the Marion Street Transitway, from Hillsborough Area Regional Transit Authority's main transit hub to downtown.	Planning
Tampa, Florida	University of South Florida Shuttle	LSAV campus circulator to run on off-street pathways at University of South Florida. Weeklong test conducted February 2019.	Planning
The Villages, Florida	Voyage On-Demand LSAV Taxi Service	On-demand LSAV taxi service and paratransit service for retirement community. Service moving to fully autonomous service 2020.	Operational
Atlanta, Georgia	Ponce City Market AV Shuttle	Connection between MARTA North Avenue station and Ponce City Market.	Planning
Chamblee, Georgia	Downtown Chamblee AV Circulators	LSAV circulator and first/last mile service (to MARTA) for a suburban downtown area (3–5 potential routes).	Planning
Doraville, Georgia	Assembly Yards AV Circulator	LSAV mixed-use development service, first/last mile from Doraville MARTA station.	Operational
Honolulu, Hawaii	DTS East Kapolei	LSAV fixed route that includes first/last mile connections to metro stations.	Planning
Honolulu, Hawaii	Hawaii DOT Honolulu Airport	LSAV airport shuttle to rental car facility.	Planning
Bloomington, Indiana	IU East Healthcare and Campus Circulator	LSAV shuttles to serve Indiana University Health Bloomington at the Regional Academic Health Center and campus (incorporated within Bloomington transit operational assessment).	Planning

(continued on next page)

Table 3.1. (Continued).

City/State	Name	Description	Status
National Harbor, Maryland	National Harbor AV Shuttle	Local Motors LSAV shuttle for residents, employees, and tourists on public roads; testing in conjunction with Maryland DOT.	Planning
Boston, Massachusetts	Boston Seaport District Circulator	LSAV on-demand service in a mixed-use employment and retail district and surrounding area in conjunction with Aptiv, Local Motors, and Optimus Ride. Launched 2017.	Operational
Weymouth, Massachusetts	Union Point AV Circulator	Exclusive test track for accessible LSAV first/last mile and circulator service in Union Point mixed-use development.	Complete
Ann Arbor, Michigan	Mcity AV Shuttle	LSAV shuttle on North Campus, University of Michigan, Ann Arbor. Launched June 2018.	Operational
Detroit, Michigan	Bedrock Downtown Parking Shuttle	LSAV shuttle to transport employees from parking structures to work in Bedrock-owned buildings. Launched June 2018.	Operational
Grand Rapids, Michigan	Grand Rapids Autonomous Vehicle Initiative	Downtown LSAV circulator that connects two sides of river, along route of the existing DASH West bus. Launched July 2019.	Operational
Kalamazoo, Michigan	Western Michigan University AV Campus Shuttle	Campus LSAV shuttle serving those with disabilities on Western Michigan University campus. Launched October 2019.	Operational
Rochester/ Auburn Hills, Michigan	Oakland University AV Campus Shuttle	LSAV circulator on Oakland University campus.	Operational
Fort Bragg, North Carolina	ARIBO Project	LSAV shuttle and circulator on Fort Bragg to transport veterans to medical appointments at Womack Army Medical Center. Operated January 2016–October 2017.	Complete
Las Vegas, Nevada	GoMed AV Shuttle	LSAV shuttle to connect downtown with nearby medical center district across I-15.	Planning
Las Vegas, Nevada	Las Vegas Keolis-AAA Shuttle	Downtown LSAV circulator near Fremont Street tourist area, on street in mixed traffic. Operated November 2017–October 2018.	Complete
New York, New York	Optimus Ride AV Shuttle	LSAV employee shuttle at the Brooklyn Navy Yards Industrial Park to New York City Ferry. Launched August 2019.	Operational
Columbus, Ohio	Linden Community AV Shuttles	Free LSAV shuttle service in Linden neighborhood to make jobs and services easier to reach.	Planning
Columbus, Ohio	Smart Columbus Smart Circuit	Downtown Columbus LSAV circulator that connects two sides of a river. Operated December 2018–September 2019.	Complete
Toledo, Ohio	TARTA Downtown Circulator	Downtown LSAV circulator between businesses, attractions, and residential development.	Planning
Youngstown, Ohio	Smart2 AV Shuttle	LSAV shuttle that connects downtown Youngstown with an adjacent medical campus.	Planning
Tulsa, Oklahoma	Tulsa AV Circulator	Downtown LSAV circulator.	Planning

Table 3.1. (Continued).

City/State	Name	Description	Status
Middletown, Pennsylvania	Pennsylvania DOT Middletown Shuttle	LSAV shuttle from Penn State University–Harrisburg to Amtrak Middletown station and Harrisburg airport.	Planning
Pawtucket, Rhode Island	Rhode Island DOT project: Quonset Office Park AV Shuttle	Office park LSAV first/last mile route to/from commuter rail station, for testing “Little Roady” pilot. Launched February 2019.	Complete
Providence, Rhode Island	Rhode Island DOT “Little Roady” Autonomous Shuttle Pilot Project	Connector LSAV shuttle between Olneyville (commercial district) and downtown Providence Amtrak Station. Scheduled to operate May 2019–May 2020. Report pending.	Complete
Greenville, South Carolina	Autonomous Mobility District: Phase I Verdae	Retail and residential LSAV shuttle at mixed-use Verdae development.	Planning
Greenville, South Carolina	Autonomous Mobility District: Phase II Parker	LSAV taxi service to health care services in low-income neighborhood west of downtown Greenville.	Planning
Greenville, South Carolina	Autonomous Mobility District: Phase 0 ICAR	Public–private partnership to demonstrate on-demand LSAV taxis in International Center for Automotive Research (ICAR) business park campus.	Planning
Arlington, Texas	Milo Autonomous Shuttle	Off-street LSAV shuttle from stadiums to remote parking during sports and entertainment events. Operated August 2017–August 2018.	Complete
Arlington, Texas	Drive.ai Shuttle in Arlington Entertainment District	Weekday LSAV on-demand shuttle on fixed route connecting sites within Entertainment District. Operated October 2018–May 2019.	Complete
Arlington, Texas	Phase 3 Arlington AV Pilot	On-demand LSAV shuttle serving downtown and the University of Texas at Arlington community, with potential paratransit service. The Arlington RAPID project (FTA IMI Grant-funding project in partnership with Via, May Mobility, and UTA) is in the development phase currently. Launch AV planned March 2021 five vehicle fleet, operating for 12 months.	Planning
Austin, Texas	Capital Metro Driverless Bus Pilot Project	LSAV circulator between Capital Metro downtown transit station at Convention Center and Central Library.	Planning
Austin, Texas	Austin-Bergstrom International Airport Shuttle	LSAV people-mover shuttle between terminal and rental car facility.	Planning
Bryan, Texas	Downtown Bryan LSAV Shuttle	LSAV shuttle deployment in downtown Bryan led by Texas A&M University’s Mechanical Engineering Department. Completed November 2018.	Complete
Bryan/College Station, Texas	TTI/Texas A&M University LSAV Campus Shuttle	Navya LSAV campus shuttle on Texas A&M University’s College Station campus. Launched August 2019.	Operational
Corpus Christi, Texas	RTA-TAMUCC AV Shuttle Project	Corpus Christi Regional Transportation Authority (RTA) and Texas A&M University campus LSAV circulator at Texas A&M University (Corpus Christi).	Planning
Corpus Christi, Texas	RTA Paratransit	On-demand LSAV paratransit.	Planning
DFW Airport, Texas	Dallas-Fort Worth International Airport Parking Lot Shuttle	Shuttle from remote parking lot to main parking area at DFW airport.	Complete

(continued on next page)

18 Low-Speed Automated Vehicles (LSAVs) in Public Transportation

Table 3.1. (Continued).

City/State	Name	Description	Status
Frisco, Texas	Frisco Drive.ai Shuttle	Office park LSAV circulator funded by Drive.ai for pilot service. Completed March 2019.	Complete
Houston, Texas	Houston METRO AV Shuttle Phase 2	First/Last Mile LSAV service to nearby Houston METRO light-rail station. AIM funded. Launch September 2021.	Planning
Houston, Texas	Houston Metro University District Circulator Pilot	Campus LSAV shuttle at Texas Southern University. Launched June 2019.	Operational
San Antonio, Texas	City Innovation Zones	LSAV implementation in innovation zones: Brooks mixed-use development to transport employees, visitors (expected first location); and South Texas Medical Center campus for first/last mile service for employees, visitors, and patients.	Planning
San Antonio, Texas	City Employee Shuttle	LSAV shuttle to transport employees between city buildings in downtown San Antonio.	Planning
San Antonio, Texas	Joint Base San Antonio Shuttle	LSAV shuttle to transport base employees between building locations.	Planning
Salt Lake City, Utah	Utah DOT/UTA AV Pilot Program	Series of 3- to 5-week LSAV shuttle pilots to connect to fixed-route transit in a variety of operating environments and locations. Report to be finalized December 2020.	Complete
Arlington, Virginia	Fort Myer Autonomous Shuttles	Military base LSAV circulator that connects community center, dining, health clinic, and barracks. Future phases may connect to Arlington Cemetery, Pentagon, Metro stations.	Complete
Crozet, Virginia	AV Neighborhood Use	LSAV circulator and connection service for retirement community. Launched July 2019.	Operational
Merrifield, Virginia	Mosaic District Shuttle	Shared LSAV shuttle providing first/last mile service between new mixed-use district in Merrifield and Dunn-Loring Metro station. Launched October 2020.	Operational
Reston, Virginia	Brookfield Properties Halley Rise Shuttle	LSAV providing connection between Reston Town Center Metro station and new mixed-use development. Completed October 2019.	Complete
SeaTac, Washington	Center for Advanced Transportation and Energy Solutions (CATES) AV Action Plan	LSAV shuttle providing first/last mile service to/from Tukwila light-rail station.	Planning

CHAPTER 4

Findings

This section presents key findings from this research on the evolution of interest in LSAVs in the United States and lessons learned from the initial planning and implementation of these services. Although the primary audience for this research is public transportation agencies, the findings will be useful to other public and private entities exploring the introduction of LSAV services.

The key findings address

- Current interest in LSAVs globally and in the United States,
- Objectives for planning and implementing LSAV services,
- Governance and funding for LSAV services,
- Evolution of LSAVs and services, and
- Accessibility concerns with LSAVs.

4.1 Current Interest in LSAVs Globally and in the United States

Current interest in LSAVs globally and in the United States continues to expand along with the start up of LSAV services. To date, most LSAV service planning, development, testing, and initiation has been by public and private entities, rather than public transportation agencies. In most cases to date, LSAV services, although publicly available, serve targeted trip purposes.

In some cases, planned LSAV services will connect to existing public transportation, extending its reach. Over the past year, interest has begun to translate into formal planning and implementation of public transportation LSAV services. LSAV services are now being designed as an integral part of public transportation. More specifically, this research revealed an evolution in transportation planning to incorporate LSAVs:

- More than 260 international LSAV demonstrations and pilots were recorded by August 2018; around that time, the United States saw a move from demonstrations to pilots or longer-term deployments.
- As of July 2018, 11 trials or deployments of LSAVs were active in the United States, with three larger-scale pilots completed. As of August 2019, the research team identified seven completed pilots, 45 in planning, and 18 operational. This formed the base list for the lesson learned and mini case studies. In addition, through October 2020, more than 300 projects in the United States are known to be in some stage of the pipeline. Some have not begun formal planning (although a potential funder has been identified) or are subject to confidentiality or nondisclosure agreements.

- Although most did not specifically refer to LSAVs, 75 percent of applications to the U.S. DOT Smart Cities Challenge grant competition referenced plans to test, demonstrate, or pilot the use of automated vehicles. Many flagged automated shuttles as the preferred vehicle.

During 2019, interest in LSAV services began to translate into formal planning and implementation of public transportation LSAV projects, including the collaboration between the Utah Transit Agency and the Utah Department of Transportation and a Houston Metro project in Texas.

4.2 Objectives for Planning and Implementing LSAV Services

Objectives for LSAV service vary depending on whether a project is currently being planned or implemented or is part of a longer-term planning initiative. Long-range plans identify improved mobility as a key objective for LSAV services. Nevertheless, objectives for the LSAV projects identified in Chapter 3 show that MPOs, cities, and public transit agencies have designed LSAV projects to introduce and understand automated technologies and pursue increased economic development. Many are seeking to be among the first to implement driverless transportation services to the public.

Whereas public transportation agencies have historically introduced new transportation services to expand capacity, serve new markets, or improve service quality, this does not appear to be the case with recent LSAV pilot projects. During interviews conducted for this research, no city or transit agency reported completing a market analysis of potential ridership when planning their LSAV service. By and large, LSAV services were not designed with typical ridership or market assessment objectives in mind. Innovation was reported as a priority by most interviewees.

Examples of objectives for LSAV projects that have been completed or are underway are presented below, highlighting the importance of innovation and economic development:

- The City of Arlington, Texas, designed its initial project to test and showcase LSAV technology.
- The City of Las Vegas and the Regional Transportation Commission focused on validating connected technology used in conjunction with AVs. Meanwhile, the private sector funder, American Automobile Association (AAA), focused on consumer acceptance.
- Houston METRO's deployment at Texas Southern University focused on understanding LSAV technology.
- The Jacksonville Transportation Authority initially sought to demonstrate proof of concept.

By contrast, long-term plans for LSAVs have objectives with a greater emphasis on local and regional mobility and improved public transportation. Cities across the United States, including Arlington, Texas; Austin, Texas; Portland, Oregon; and Seattle, Washington, are developing innovative mobility plans, transit development plans, and transportation district plans. Smart Cities initiatives in Columbus, Ohio; Las Vegas, Nevada; and Denver, Colorado, include LSAV projects. Additional examples of these plans include the following:

- A Bloomington, Indiana, operational study (or route optimization study) examined how to accommodate or take advantage of emerging technologies such as microtransit, transportation network companies, and LSAV shuttles.
- Hawaii's A^{2}CES (Accessible, Automated, Connected, Electric, and Shared) policy focuses on shared use, connectivity to transit, and electrification across modes.
- Honolulu Authority for Rapid Transportation's assessment of station areas and proposal for shared mobility hubs embeds LSAV planning in transit agency programmatic, design, and construction assessments.
- North Central Texas Council of Governments and Jacksonville MPO LRTPs approved projects for LSAVs in public transportation.

Two cities in the United States are now developing methods to analyze consumer preferences, and therefore market potential, for LSAV services:

- In Chicago, MIT's JTL/Transit Lab researched stated versus revealed preferences for LSAV service that connects to commuter rail or provides door-to-door service.
- In San Antonio, Poco Labs conducted market surveys and Delphi interviews to assess the market for LSAV shuttles.

4.3 Governance and Funding for LSAV Services

LSAV service governance and funding throughout the United States are through public–private collaborations. States, cities, regional planning organizations, and public transit agencies are working with real estate developers, hospitals, private employers, major insurance companies, the hospitality industry (e.g., convention centers, hotels, and restaurants), the energy sector (primarily electrical utilities), and other private entities to manage, oversee, and fund LSAV services. Many initiatives include both public and private research institutions hosting or evaluating LSAV services. Since early pilots at Fort Bragg and the Smart Cities Challenge of 2016, few sustained LSAV projects or pilots in the United States have been led directly by a public transportation entity.

Public–private collaborations for the management, oversight, and funding of LSAVs include the following specific examples:

- In Columbus, the Linden Community AV Shuttles and Smart Circuit LSAV services are funded by the Ohio DOT initiative DriveOhio and the City of Columbus. Smart Columbus, a public–private partnership, manages the two projects.
- The Contra Costa Transportation Authority partnered with Bishop Ranch, GoMentum Station, Stantec, Bestmile, Bay Area Rapid Transit (BART), First Transit, and the Bay Area Air Quality Management District in one of the early pilots.
- In Denver, the Regional Transportation District partnered with Panasonic Smart City and tapped its bus service provider, Transdev, as its LSAV operator.
- Hawaii's comprehensive approach to readiness for automated vehicles engaged varied private investors and landowners; land-use and transportation planners; and state, regional, and local planning and operational units.
- In Las Vegas, Nevada, the City's chief engineer served as a project manager for LSAV service funded by AAA.
- In Rhode Island and Utah, the respective DOTs and transit agencies are working together on LSAV pilots.

4.4 Evolution of LSAVs and Services

LSAV models and services are evolving as they are tested. Existing vehicles are being modified, new vehicle models introduced, and new services considered and planned. Technological LSAV capabilities and use cases related to public transportation are intertwined. The literature review and case studies conducted in this research represent a snapshot in time, as technology and use cases evolve and more LSAVs move from prototype to production.

LSAV technology continues to change across vehicle classifications, including small NEVs, larger purpose-built models, and low- and medium-speed vehicles compliant with the FMVSS. These new models and types are reflected in recent federal and state grant applications, including U.S. DOT Automated Driving demonstration grants. Most new LSAV models are not yet operational in public service or on public roadways.

Characteristics of updated vehicles include

- Larger and smaller passenger capacities, including full-size electric buses and pod cars;
- Higher operating speeds;
- Development of low- and medium-speed FMVSS-compliant vehicles;
- Installation of wheelchair securement and ramps in vehicles not traditionally used in public transportation; and
- Improved artificial intelligence and vehicle design.

Early adopters of LSAVs and other automated vehicle technologies are finding that the appropriateness of a particular vehicle or use case may depend on the specific technology and the operating environment. Some public agencies are addressing this by evaluating vendors over a phased program and by pilot testing across different operating environments. Other project sponsors have opted to plan for more permanent deployments of LSAVs as the technology matures. Arlington, Texas; Las Vegas, Nevada; and Tampa, Florida (in partnership with the Jacksonville Transit Authority) have—or plan to conduct—projects in phases using different technologies over an extended time period. Other approaches include the following:

- Honolulu's transportation community is pursuing a hybrid approach through a combination of private and public planning, including assessment of a low-speed network, accommodation of emerging technologies in the design of new rail system stations, and development of projects with varied use cases such as accessible automated mobility on demand, first/last mile connections, and campus-based applications.
- In Mountain View, the Santa Clara Valley Transportation Authority is planning a connector service and first/last mile application on dedicated lanes and an elevated guideway. Similarly, Youngstown, Ohio's BUILD grant-funded program includes a path for LSAV shuttle design.
- Utah DOT's collaboration with the Utah Transit Authority looks to a series of short deployments across eight to 10 ODDs, including those that are on road, off road, and for different purposes.

In the course of the research interviews, project sponsors for completed LSAV projects noted some performance limitations with vehicles. These interviewees commented that, on the basis of their experience, LSAVs had the following shortcomings:

- Limited speed ranges (9 to 11 mph) in some vehicles.
- Limitations in making unprotected left-hand turns (addressed by vehicle technology, a manual override, or both).
- Weather impacts on battery life (extreme heat/cold), air conditioning, operations in automated mode (heavy rain), and performance of drive-by-wire electromechanical systems (snow).
- Interference with autonomous mode by light debris or lack of hard edges.
- Oversensitivity to objects triggering abrupt stops.

4.5 Accessibility Concerns with LSAVs

FTA establishes many requirements for those receiving federal funds, including financial reporting, compliance with disadvantaged business enterprise reporting, Buy America provisions, life cycle maintenance, and more. Importantly, FTA regulations for public and private transportation services address the accessibility of vehicles and facilities in compliance with the ADA.[6] This research focuses on the availability of accessible LSAVs, in particular wheelchair-accessible vehicles and accessible design for adults with cognitive and communication disabilities.

[6] 49 CFR 37, Transportation Services for Individuals with Disabilities.

With the emergence of highly automated vehicles deployed in public transit, FTA has provided guidance for automated buses that also applies to buses used as shuttles.[7] Also, the U.S. Department of Justice resolved an ADA compliance review with the University of Michigan and its Mcity LSAV shuttle in 2019. The resulting settlement stipulates that the ADA requires all new vehicles operating on a fixed route to be accessible, and autonomous vehicles, pilot programs, or research programs are no exception. The Justice Department and University of Michigan agreement provides that any future highly automated vehicles that the university purchases or leases for the Mcity Driverless Shuttle program, or any other fixed-route transportation system, must be equipped with accessible features. Until all Mcity vehicles are accessible, the university must provide equivalent services to individuals with disabilities.

To date, no LSAV models have been designed or retrofitted to include all features for customers who use wheelchairs, such as wheelchair ramps, securement devices, and rails. Over time, some LSAV manufacturers have begun to include ramps and wheelchair securement; others have added human–machine interfaces (HMIs) to allow customers with cognitive, visual, and auditory disabilities to communicate with the vehicle regarding destinations and other travel information. However, the full complement of accessibility-related features needed to serve customers with disabilities does not currently exist for LSAVs.

Some adopters of LSAV technology have prioritized vehicles designed to accommodate persons with limited mobility, and at least one vendor featured universal design and an HMI to help those with communications disabilities. Specific efforts in this direction have included the following:

- The City of Arlington, Texas, required a vehicle with a ramp for its first deployment.
- Fort Bragg ARIBO (Applied Robotics for Installations and Base Operations) included evaluation of automated wheelchair access and securement.
- Las Vegas, Nevada, procured a Navya with an electric wheelchair ramp.
- Local Motors has designed the Accessible Olli but does not yet produce it.

Some communities initiating LSAVs and some vehicle vendors have engaged with stakeholders to assess how best to ensure that LSAVs are accessible:

- Jacksonville Transit Authority included wheelchair users in their assessment of accessibility and LSAVs on its fixed guideway.
- Local Motors designed the Accessible Olli prototype relying on an HMI and other tools to make its vehicle more accessible than ADA requirements.
- May Mobility partnered with a Michigan state disability advisory group to define needs and to develop a retrofit for its Polaris GEM chassis that accommodates a ramp. Further, in a deployment of five vehicles planned for March 2021 in Arlington, Texas, one with wheelchair accessibility will be available at all times the fleet is in service.

[7] Federal Transit Administration, "Frequently Asked Questions: Transit Bus Automation Policy," July 11, 2019, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/134506/transit-bus-automation-faqs_0.pdf.

CHAPTER 5

Practitioner Guide

This Practitioner Guide, as summarized in Figure 5.1, presents checklists and resources for planning an LSAV project, based on the research team's experience and interviews with more than 200 stakeholders. The guide assists public transit agencies, their partners, and stakeholders in LSAV program foundations, feasibility, procurement, implementation, operations, monitoring and evaluation, and building for sustainability. Checklists lay out key considerations and are intended to be illustrative, not exhaustive. LSAV transportation is dynamic and technologies and policies may change rapidly. Public transit agencies wishing to explore these services may consult with relevant federal, state, or local authorities on policy. A resources box in each section links to examples of relevant documents and secondary material.

5.1 LSAV Program Foundations Checklist

This checklist provides core considerations for formulating an LSAV program, including defining vision, outcomes, objectives, use cases, and service models.

✔ **Stakeholders.** Engage key stakeholders such as elected officials, transportation, economic development, human service, public safety agencies, community groups, and private interests (landowners, developers, etc.).

- Convene stakeholders to gain a common understanding of the program vision, objectives, and LSAV technology implementation.
- Develop and implement a sustained stakeholder communication plan to relay program performance, key results, milestones, and next steps after program completion.

✔ **Vision.** Articulate a vision for the LSAV program that includes desired outcomes.

✔ **Objectives.** Define objectives of the LSAV program, such as

- Showcase LSAV technology and related innovations,
- Expand mobility service to mobility deserts or those underserved by public transit,
- Evaluate user acceptance of LSAV-like technologies,
- Increase travel options,
- Promote economic development,
- Evaluate ways to integrate into high-capacity transit,
- Define the business case for LSAV service, and
- Enhance safety, efficiency, and accessibility.

✔ **Use Cases.** Determine the transportation use cases, including private and public transit use cases and service models. Start with defining the trip purpose and then align the purpose with the appropriate service model and vehicle type.

✔ **Alignment of Use Cases with Operating Environment.** Assess the alignment of the use cases using key factors in the operating environment such as speed, intersections/crossings,

5.1 Program Planning Resources

DRPT Statewide Integrated Mobility Plan

U.S. DOT Grant Narrative: Jacksonville U2C Program

U.S. DOT Grant Narrative: Downtown Youngstown

Click on the item to access the resource.

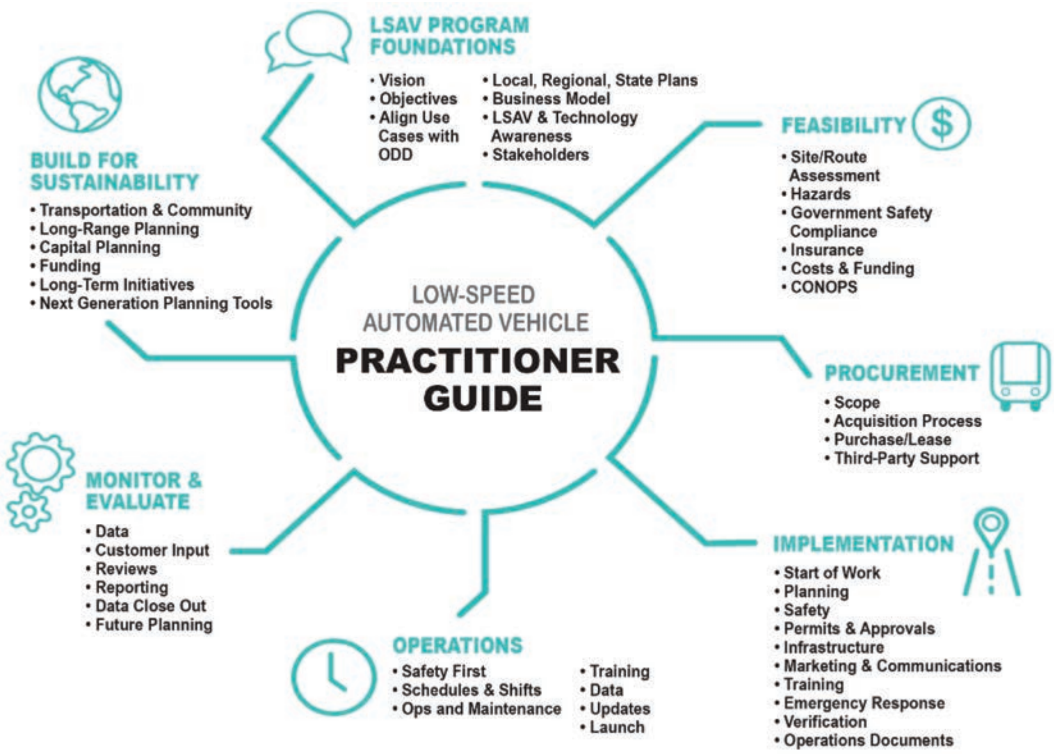

Figure 5.1. Practitioner Guide overview.

and road conditions (as discussed in Section 2.2 on operational design domains). These factors need to be taken into consideration in assessing potential hazards and preparing a mitigation plan.

✔ **Local, Regional, and State Plans.** Consult appropriate plans such as local comprehensive plans, transit-oriented development plans, technology plans, and state and regional LRTPs, TIPs, and regional transportation priority plans.

✔ **Business Model.** Identify a business model for sustained operations and maintenance over short-, medium-, and long-term time frames.

✔ **LSAV and Technology Awareness.** Establish a baseline of stakeholder knowledge about LSAV technology, current LSAV capacity and availability, trends in LSAVs over time (1, 2, and 5 years), and availability and integration of related technologies.
- Include related technologies such as connected technologies, mobility on demand, and assistive technologies.
- Consider assistive technology such as haptics (technology that stimulates touch through motion), HMI to support those with communications limitations, augmented and virtual reality for wayfinding, and virtual and augmented reality tools.
- Conduct a workshop featuring technology development and deployment experts, suppliers, and researchers, as well as transit agency staff, local and regional stakeholders, and public and private partners.

5.2 Feasibility Study Checklist

This checklist for the feasibility study encompasses assessing the site or route and associated hazards, considering government compliance requirements, estimating costs and identifying funding, and developing a concept of operations for the project.

5.2 Feasibility Resources

Mountain View Feasibility Study

Chamblee Feasibility Study

Jacksonville Benefit–Cost Analysis

CONOPS Next Generation Integrated Transportation

CONOPS Worksheet

Click on the item to access the resource.

✔ **Site/Route Assessment.** Assess a site or route to evaluate and document physical attributes, technology performance requirements, and transportation needs. Focus principally on the operating environment and safety considerations to determine the alignment between the technology, operational considerations, and the operating designing domain.

- **Route Mapping.** Document the route in a GIS format on the basis of a physical assessment informed by relevant planning materials. Video of operating conditions on the route and Google Earth reviews, along with existing maps, are useful resources. Include the following key elements:
  - Adjacent land-use and development plans;
  - Appropriate venues for charging, storage, and maintenance of LSAVs;
  - Crash data;
  - Existing active (bike and pedestrian) transportation facilities;
  - Existing and planned transit service;
  - Intersections with and without controlled stops and signals;
  - Opportunities for dedicated right-of-way;
  - Parallel and angled on-street parking;
  - Public or private roadway type;
  - Roadway condition, including surface and grade;
  - Posted speed and operating speeds;
  - Structured and surface parking facilities; and
  - Traffic volume.
- **Transportation Needs.** Review planning data and residential developers, human services providers, employers, and community groups to assess
  - Housing, employment, entertainment, retail, health, educational, and other destinations along the route and in the catchment.
  - Population and demographics data in the catchment.
  - Transportation demand based on modeling and market assessments.

✔ **Hazards Assessment.** Assess hazards and develop a mitigation plan.

✔ **Compliance with Public Safety Requirements.**

- Ascertain federal, state, and local requirements, if any, including permits, waivers, and approvals.
- Coordinate with law enforcement and other emergency responders, transportation agencies, and legal departments.

✔ **Accessibility.** Assure compliance with ADA requirements.

✔ **Insurance.** Determine insurance requirements.

✔ **Costs and Funding.** Calculate project cost and secure public and private funding from federal, state, and local agencies and nonprofit and commercial partners, such as

- Economic development agencies,
- Federal and nonprofit research grants,
- Downtown development authorities or business improvement districts,
- Hospital systems or campuses,
- Real estate developers, and
- State transportation innovation funds.

✔ **CONOPS.** Develop a project concept of operations, or CONOPS, which describes in plain language

- The current situation,
- The purpose of the LSAV project and how it will be used,
- Recorded goals and objectives,
- General system requirements (detailed system requirements generally follow the CONOPS), and

- A project plan to capture and organize key concepts, collaboration, performance metrics, and feasibility outcomes into a guide for procurement, implementation, launch, and operations.

5.3 Procurement Checklist

This checklist provides considerations specific to LSAV service procurement. This checklist augments, rather than supplants, public procurement processes and is premised on the research findings that LSAV projects are most often the product of public–private collaborations.

✔ **Scope.** Develop a scope of work to address
- Vehicle and system requirements;
- Accessibility requirements to design for wheelchair and securement and inclusion of HMIs that allow those with communications-related disabilities to interact with the AV through visual panels, touch screens, voice communication, and more;
- Performance requirements, data sharing and privacy accessibility, and reporting;
- Outcomes;
- Risk management, including hazard assessment and risk mitigation, safety operation compliance, and vehicle performance monitoring;
- Insurance and related liability assignment;
- Emergency management planning and coordination with public safety stakeholders; and
- Vehicle safety standards.

✔ **Acquisition.** Align acquisition to the type of money allocated (public, private, or a combination of both). Public transportation entities may
- Issue individual RFPs,
- Tap state or regional contracting to prequalify vendors,
- Provide a regional brokerage or statewide sole source, and
- Use local or state on-call or task order contracts.

✔ **Purchase or Lease.** Structure acquisition for purchase or lease of vehicles, operations, or a combination of both.

✔ **Third-Party Support.** Determine whether marketing, communications, storage, and charging (or some combination of these) will be provided by third parties, including private landowners, facility owners, and nonprofit organizations.

5.3 Procurement Resources

Tampa RFP

Columbus RFP

Texas RFP (prequalify vendors)

Arlington Phase 2 RFP

Gainesville RFP

Rhode Island RFP

DCTA MaaS RFP (Documents tab)

RTD Contract Modification

Click on the item to access the resource.

5.4 Implementation Checklist

This checklist highlights key activities relevant to implementing an LSAV project.

✔ **Start of Work.** Conduct a "start of work" meeting with stakeholders and suppliers to
- Confirm roles and responsibilities and identify key personnel;
- Establish working groups and key participants (e.g., local police and first responders, utilities, other key groups that could intersect with pilot operations);
- Identify and assign required deliverables to include plans, standardized checklists, and documents; and
- Finalize LSAV project evaluation criteria and key measures.

✔ **Planning.** Develop program plans to include
- Standard operating procedures (SOPs),
- Functional plans defining roles and responsibilities,

- Manuals and training plans,
- Communications plans,
- Data management plans, and
- Management tools identified in the CONOPS.

✔ **Safety.** Develop a safety approach for the program to include
- Safety plans,
- Safety operations,
- Safety standards, and
- Emergency management plans, including coordination with local and state emergency managers, training that includes tabletop exercises, and crisis communications plans.

✔ **Permits and Approvals.** Obtain required permits from state and local authorities and approvals, as needed, from NHTSA.

✔ **Infrastructure.** Plan and install infrastructure improvements to include both permanent and temporary changes, digital and physical infrastructure elements, and signage. These may include
- Design, construction, and designation of paths on private property and off-road paths such as sidewalks and walking and bike trails.
- Intersection improvements, design and construction of dedicated lanes, and elevated guideways.
- Kiosks for information, ticketing, and mobility-on-demand tools.
- Painted or temporary lane markings with cones or bollards.
- Signs noting LSAV operations and stops.
- Temporary or permanent traffic signals and roadside units (RSUs).

✔ **Marketing and Communications.** Create marketing and communications tools to include printed, electronic, and web-based messages, updates, and surveys or other mechanisms to collect participant input.

✔ **Training.** Conduct required training for on-board and remote operators as well the service and maintenance team.

✔ **Emergency Response.** Brief emergency responders and law enforcement personnel and conduct tabletop exercises.

✔ **Verification.** Schedule and carry out an LSAV operational shakeout and safety verification to include operations as described in the CONOPS and SOPs.

✔ **Operations Documents.** Supply all standardized procedures, instructions, checklists, forms, and other required documentation on board each LSAV, within the monitoring center, and in all service areas.

5.5 Operations Resources

JTA Safety Checklist

CCTA AV Shuttle Safety Outline

Mcity Operations

Mcity Signage Example

Las Vegas UNLV Rider Survey

Smart Columbus Safety Plan

Click on the item to access the resource.

5.5 Operations Checklist

This checklist highlights key operational activities, beginning with safety, from hazards assessment and mitigation to continuous improvement.

✔ **Safety.** Execute and ensure compliance with a comprehensive safety operations program that includes
- Hazards assessment and mitigation,
- Safety operations protocols,
- On-board diagnostics,
- Initial and refresher safety operator training plans,
- Emergency preparedness plans, and
- Continuous improvement processes to ensure vigilance and up-to-date safety practices throughout the project.

✔ **Schedule and Shifts.** Document and monitor service hours, shift schedules, service times, and daily opening and closing procedures.

- ✔ **Operations and Maintenance.** Ensure operating and maintenance procedures are current and accessible for operations staff.
- ✔ **Training.** Train personnel on their roles and responsibilities, SOPs, safety, and emergency-response protocols. Provide LSAV familiarization training.
- ✔ **Data.** Confirm procedures and tools are in place for data collection, storage, analysis, and reporting in accordance with the data management plan.
- ✔ **Updates.** Provide timely and accurate updates to all program personnel, stakeholders, and the public, according to the communications plan.
- ✔ **Launch.** Prepare for program launch to
  - Determine whether the launch will be partial or full-scale operations.
  - Determine whether the launch event will include a formal ribbon-cutting ceremony with distinguished visitors, formal proceedings, and other official activities.
  - Present planned communications, media, and other engagement activities to inform and invite the public to participate in the launch and pilot operations.
  - Conduct a dress rehearsal within 24 hours before launch to work out final operational and technological bugs.

5.6 Monitoring and Evaluation Checklist

This checklist highlights core monitoring and evaluation activities over the course of planning, operating, and closing out the project.

- ✔ **Data.** Collect data and information, both qualitative and quantitative, to monitor and evaluate performance in accordance with specified metrics. Align metrics with the objectives of the project. Example metrics include
  - Amount of time a vehicle operated in autonomous mode;
  - Community and stakeholder engagement in planning, execution, and evaluation;
  - Customer acceptance;
  - Information on capability of a specific technology; and
  - Performance of LSAV services in a particular operating environment or ODD.
- ✔ **Customer Input.** Gather qualitative customer satisfaction and community acceptance data to evaluate against previously established baselines and comparable operations.
- ✔ **Reviews.** Plan and facilitate after-action reviews at key milestones or incidents, if any, with the core project team and stakeholders.
- ✔ **Reporting.** Provide regular reporting on the program, including a closeout report if appropriate.
- ✔ **Data Closeout.** Finalize data collection, analysis, reporting, and transfer to long-term storage per the data management plan.
- ✔ **Future Planning.** Create a business plan or model for sustainable LSAV service.

5.6 Monitoring Resources

AAA National Polling on AV Acceptance (May 2019)

AAA NorCal Customer Satisfaction Survey on Las Vegas LSAV

Arlington Milo Shuttle Survey Results (on page 3 of Closeout Report)

AVS Symposium Briefing on User Acceptance of AVs

Denver RTD 61AV Final Report

UDOT/UTA Survey Questions

Click on the item to access the resource.

5.7 Sustainability Checklist

This checklist reflects key factors, activities, and tools critical to building sustainable approaches toward including LSAV service in public transportation.

- ✔ **Transportation and Community.** Integrate LSAV projects into transportation and community planning.
  - Adapt existing tools such as LRTPs and TIPs.
  - Create new approaches, including mobility innovation plans and innovation challenges.

5.7 Sustainability Resources (Part 1)

Preparing Communities for Autonomous Vehicles, APA

APA AV Knowledge Base*

APTA Research Page on Autonomous and Electric Vehicles*

CTAA Statement of Principles for Automated Vehicles

NACTO Blueprint for Autonomous Urbanism (second edition 2019)

National League of Cities Autonomous Vehicles: A Policy Preparation Guide

National League of Cities Autonomous Vehicle Pilots Across America (2018)

NCTCOG Automated and Connected Vehicles Planning Page*

Miami-Dade TPO Connected-Autonomous Vehicle Program*

Click on the item to access the resource.

*updated periodically

✔ **Long-Range Planning.** Incorporate LSAV projects into existing regional and state long-range plans and evaluate potential projects to be placed in constrained plans, such as
- Capital and operating budgets,
- Constrained LRTPs,
- Transit development plans, and
- TIPs.

✔ **Capital Planning.** Review and update state, municipal, and transit agency capital planning documents and budgets.

✔ **Funding.** Create a funding matrix of public and private grant, contract, and innovation investment funds.

✔ **Long-Term Initiatives.** Integrate the LSAV service into longer-term projects, including
- Curbside management studies,
- Digital infrastructure,
- General public transit improvement plans,
- Human services plans,
- Land-use studies,
- Lane reallocation and complete streets initiatives,
- Local and regional corridor transportation plans,
- Municipal capital planning,
- Parking studies, and
- Sign codes and signage.

✔ **Next-Generation Planning Tools.** Develop and adopt next-generation operational planning tools, including
- Capacity management through pricing, geofencing, and data from infrastructure and vehicle sensors;
- Cross-sector technology planning;
- Data-based planning and operations tools;
- Land use;
- Mobility innovation and smart city plans;
- Public–private partnerships;
- Scenario planning; and
- Simulations and visualization.

✔ **Mobility Hub Plans.** Design adaptive mobility hubs at transit stations, taking into consideration:
- Multimodal passenger and delivery services,
- Support for amenities and adaptive or future-proofed infrastructure design,
- Designated pick-up and drop-off areas,
- Bike and pedestrian infrastructure,
- Universal access through design and operation,
- Electric charging and communications facilities, and
- Strong sense of placemaking including key retail services.

✔ **Curbside Management Plans.** Develop and implement strategies to manage curbside as a terminal for AV drop-off and pick-up for passengers and goods, including
- Dynamic pricing and geofencing;
- Smart zones for loading;
- Policies relating to managing micromobility including smaller, automated electric vehicles on the sidewalk; and
- Enhanced accessibility for people with disabilities at the curb.

✔ **Flexible Land-Use Zoning.** Assess and adopt zoning approaches that reflect variable travel demand, e-commerce, and residential densities, including
- Parklet,
- Parking requirements,
- Right-of-way management off roadway, and
- Build codes.

5.7 Sustainability Resources (Part 2)

Mobility Hub Typology Study (Prepared for Portland DOT) 2020

San Diego Forward, Regional Mobility Hub Plan; Mobility Hub Features Catalog; Oceanside Mobility Hub Simulation (SANDAG)

Curbside Management Practitioners Guide, Institute for Transportation Engineers (2019)

A Framework for Hawaii's AV Future: Accessible, Autonomous, Connected, Electric and Shared (Ulupono Initiative, 2020)

Planning for the Advent of Connected and Autonomous Vehicles in Champaign-Urbana Using Scenario Planning

Click on the item to access the resource.

CHAPTER 6

Areas for Further Research

Further research in several areas could increase the transit industry's capacity to plan for and manage LSAVs. This research could help facilitate planning and implementation for more automated services; provide insight into the evolution and deployment of LSAV service; capture best practices, including those for maximizing accessibility and equity; and illuminate how best to monitor and evaluate LSAV services.

6.1 Baseline Survey of LSAV Planning and Implementation

Given the apparent increasing interest in LSAVs among public transit agencies, a baseline survey of transit agency planning and implementation would be useful. Surveys would document both the interest in LSAVs and the state of play. To gain a broader perspective, cities, MPOs, and state departments of transportation should be surveyed to capture how each is incorporating LSAVs in planning and funding activities.

6.2 Performance Requirements for LSAVs

Given that neither ODDs nor technology is static, research is required to assess appropriate minimum performance standards for LSAVs in public transportation. Vehicle technologies vary and their capabilities can change with shifts in the operating environment or sensor degradation. Research to inform safe operations could therefore include the development of vehicle or performance standards relevant to varying ODDs, assessment of data recorders and data analytic tools (e.g., on-board diagnostic tools), and training for operators in assessing technology and ODD considerations.

6.3 Accessibility, ADA Standards, Equity, and Universal Design

Research is needed to inventory LSAV sponsors' and operators' strategies to comply with the ADA, to understand how well these strategies are achieving equivalent levels of accessibility, to identify approaches that address design and assistive technology for persons with mobility and communications disabilities, and to expand on-demand transportation to all users of paratransit. This research could also extend to equity of access for LSAVs and other automated public transportation services. Considerations include socioeconomic factors, environmental justice, and underserved communities. Both public and private providers and operators should be examined. Best practices may be identified through a review of initiatives undertaken by industry, states, and U.S. DOT to stimulate barrier-free vehicle design and related infrastructure, as well as to expand access.

A survey, along with interviews, could help LSAV providers and other related transportation practitioners understand strategies to improve accessibility, adapt vehicles to ADA standards, ensure equity of access, and promote universal design of vehicles and related infrastructure. In the short term, LSAV manufacturers and operators would benefit from more access to online training materials and other training opportunities. These would guide providers in planning wheelchair-accessible services or HMIs to improve access for those with a cognitive, visual, and/or auditory impairment.

6.4 Resource Centers for Best Practices and Research

With estimates that each LSAV generates up to 20 terabytes of data daily, project partners have little guidance on what data are relevant to understanding and assessing this new technology. Most public agencies seek data about incidents, ridership, and consumer acceptance, but vendors vary in their responsiveness to these requests. There are no national standards governing what LSAV data must be shared.

Transit agencies and other public transportation providers need further guidance about and access to data sharing, insurance, accessibility, regulatory standards, risk management and safety practices, procurement and contracting, and related planning initiatives for LSAV and other automated transit projects. A research entity or a transit association should establish a curated knowledge management resource center featuring best practices for LSAV studies and plans across a range of topics.

6.5 Measurement and Assessment of LSAV Services

This research yielded several ideas relating to valuation of LSAVs as either a public or a private transportation service. Further research is needed to determine whether, when, and how LSAV projects can become shared-use services that are sustainable and help communities achieve their objectives. Research topics could include

- Effective ways to assess the accessibility and mobility benefits provided by LSAVs.
- Potential ridership of LSAVs and the ridership impacts on existing higher-capacity transit services.
- Whether and how to compare LSAV service with other modal and service options in alternatives analyses.
- Assessment of methodologies to evaluate customer satisfaction and consumer acceptance of an LSAV service.
- Assessment of LSAV operating costs and potential cost savings from areas such as reductions in property loss, mortality, and morbidity.
- Assessment of best practices and benefits related to effective LSAV security practices, including cybersecurity.
- Assessment of effective performance and evaluation metrics for LSAV projects.

6.6 Infrastructure Improvements for More Effective LSAV Applications

Research could define how infrastructure (physical and digital) can improve the efficacy of LSAV applications. LSAV projects are often premised on the need for limited modification of physical infrastructure; reliance on connected infrastructure; and vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), and vehicle-to-anything (V2X) applications. Topics could include

- Best curbside management practices for wayfaring, accessibility, congestion management, and accessible pick-up and drop-off.
- Maintenance on existing infrastructure to facilitate automated vehicle technology capabilities.
- Opportunities to allow higher operating speeds and enhanced safety through dedicated lanes and elevated guideways.
- Potential to enhance LSAV efficiency, speed, and safety through connected technologies.
- Value and best practices in the use of existing or new multimodal paths or trails for mixed- or single-mode use.

Acronyms and Glossary

Acronyms

ADS	automated driving system
ARIBO	Applied Robotics for Installations and Base Operations
AV	automated vehicle
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CONOPS	concept of operations
DDT	dynamic driving task
DOT	Department of Transportation
DSRC	dedicated short-range communication
FMVSS	Federal Motor Vehicle Safety Standards
HMI	human–machine interface
LiDAR	light detecting and ranging
LRTP	long-range transportation plan
LSAV	low-speed automated vehicle
MPO	metropolitan planning organization
NEV	neighborhood electric vehicle
ODD	operational design domain
RFP	request for proposals
RSU	roadside unit
SAE	SAE International
SOP	standard operating procedure
TIP	transportation improvement program
V2I	vehicle to infrastructure
V2V	vehicle to vehicle
V2X	vehicle to anything

Glossary

Automated driving system (ADS): The hardware and software collectively capable of performing an entire dynamic driving task on a sustained basis, regardless of whether the task is limited to a specific operational design domain. This term is used specifically to describe a Level 3, 4, or 5 driving automation system.[1]

In contrast with "ADS," the generic term "driving automation system" refers to any Level 1 to 5 system or feature that performs part or all of the DDT on a sustained basis. Given the

[1] As defined in SAE International, "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," Document J3016, issued January 2014, revised June 2018.

similarity between the generic term "driving automation system" and the Level 3-, 4-, and 5-specific terms, this research uses highly automated vehicles for Levels 3 and above.

Automated vehicle (AV): SAE has defined six levels of automation from Level 0 to Level 5. Level 0 has no driving automation. In Level 1 (Driver Assistance) and Level 2 (Partial Driving Automation), except for the assistance areas specified, the driver remains in control of all driving tasks. At Level 1, some driver-assistance features are included in the vehicle design. Level 2 has combined automated functions, such as acceleration and steering. Level 3 (Conditional Driving Automation) is the lowest tier of an ADS; vehicles at this level can make informed decisions but still require that the driver be ready to take control of the vehicle at all times with notice. Level 4 (High Driving Automation) means the vehicle is capable of performing all driving functions under certain conditions; that is, the driver may have the option to control the vehicle. In Level 5 (Full Driving Automation), human driving is completely eliminated.[2]

Conventional vehicle: A vehicle designed to be operated by a conventional driver during part or all of every trip.[3] A conventional vehicle may be equipped with one or more Level 1 or 2 driving automation system features that support the driver in performing a DDT but do not perform the complete DDT, as well as Level 3 and 4 ADS features that require a conventional driver to operate the vehicle during portions of each trip. That is, a conventional driver is required for at least part of every trip.

Dynamic driving task (DDT): All real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding strategic functions such as trip scheduling and selection of destinations and waypoints.[4]

Fallback: The response by the user to either perform a DDT or achieve a minimal risk condition after the occurrence of a DDT performance–relevant system failure or on ODD exit, or the response by an ADS to achieve minimal risk condition, given the same circumstances.[5]

High driving automation: Level 4 in the SAE levels of 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.[6]

LiDAR: Light detection and ranging, a surveying method that measures the distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor.

Low-speed automated vehicle (LSAV): LSAVs include vehicles such as highly automated vehicle shuttles (SAE Level 4) that can accommodate six to 22 passengers and pod cars that can carry one to six passengers. The vehicles may also be retrofitted conventional vehicles, either NEVs or light duty vehicles such as vans. Other LSAVs are purpose-built low-floor shuttle vehicles with high ceilings, which can carry four to 10 seated passengers and some standing passengers. Some LSAVs travel at speeds of 15 mph, but vehicles programmed to operate up to 25 mph have been introduced into mixed traffic. Projects are in the planning stage for LSAVs capable of speeds up to 35 mph.

[2] Adapted from SAE International, J3016.
[3] As defined in SAE International, J3016.
[4] As defined in SAE International, J3016.
[5] As defined in SAE International, J3016.
[6] As defined in SAE International, J3016.

Neighborhood electric vehicle (NEV): FMVSS Standard 500 defines low-speed vehicles as any four-wheeled motor vehicle that has a top speed greater than 20 mph, but not greater than 25 mph. This group includes neighborhood electric vehicles. The standard further defines NEVs as any four-wheeled electric vehicle whose top speed is not greater than 25 mph.[7]

On-demand service (shared): From an LSAV service model standpoint, an on-demand service is a shared service that pools multiple people headed in the same direction into one vehicle. Usually, a vehicle is dispatched when a threshold number of people has been reached or an individual's wait reaches a certain time limit. Transportation network company services like UberPool, Lyft Line, and personal rapid transit are examples of on-demand shared services. LSAVs could effectively serve in this role as well, with an automated booking and dispatch system such as for paratransit.

Operational design domain (ODD): The operating conditions under which a given driving automation system or feature is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and the requisite presence or absence of certain traffic or roadway characteristics.[8]

Paratransit: Comparable transportation service required by the ADA for individuals with disabilities who are unable to use fixed-route transportation systems.[9]

Shuttle: Shared vehicles that connect passengers from a common origin or destination to areas such as public transit, health care, retail, hospitality, or employment centers.[10]

[7] 49 CFR § 571.500, Standard No. 500, Low-speed vehicles.
[8] As defined in SAE International, J3016.
[9] 49 CFR 37, Transportation Services for Individuals with Disabilities.
[10] Adapted from SAE International, J3016.

APPENDIX A

Literature Review and Survey

Literature Review

Alessandrini, A., R. Alfonsi, P. D. Site, D. Stam. Users' Preferences Towards Automated Road Public Transportation: Results from European Surveys. *Transportation Research Procedia* 3 (2014): 139–144. July 2014. This academic paper includes results and econometric analysis from a stated preference survey on riding collective automated road transport systems versus minibuses. The researchers surveyed users in 12 European cities and found a slightly higher preference for automated options among males rather than females, and that people with higher education levels are more likely to prefer automated options. They also found that users care more about travel time than technology type when choosing transport options.

Automotive Information Sharing and Analysis Center. "Automotive Cybersecurity Best Practices." 2017. The Automotive Information Sharing and Analysis Center (Auto-ISAC) is a community of international original equipment manufacturers, suppliers, and commercial vehicle companies that share information, analysis, and resources relating to automotive cybersecurity. This website gives general information about Auto-ISAC objectives and best practices in the area of automotive cybersecurity.

Autonomous Vehicle Working Group. Draft Report of the Massachusetts Autonomous Vehicles Working Group v4.0. September 12, 2018. This draft report from the governor-mandated Massachusetts AV Working Group includes a connected and automated vehicle (AV) technology overview, governance considerations, and policy considerations. It mostly focuses on non-LSAV AVs but does contain a chart with a few examples of where LSAVs have been legislated or regulated and notes the examples of deployment in Minnesota; Las Vegas, Nevada; and Gainesville, Florida. The document also has a list of working group members, national and international AV initiative examples, and lists of resources.

Bansal, P., K. M. Kockelman, and A. Singh. "Assessing Public Opinions of and Interest in New Vehicle Technologies: An Austin Perspective." *Transportation Research Part C: Emerging Technologies* 67: 1–14. 2016. This academic paper on public opinion in Austin, Texas, of general AV technologies aims to help transportation professionals develop smarter and more sustainable travel options that the public will adopt. The study looks at the impact of demographics, built-environment variables, and travel characteristics on the willingness to pay for adding SAE International Level 3, 4, and 5 technologies to personal vehicles. It does not focus on shared vehicles or LSAVs but is one of the few objective, quantitative studies available to assess public opinion. Results show a willingness to pay $7,253 to add Level 4 automation to a personal vehicle.

California Department of Motor Vehicles. Title 13, Division 1, Chapter 1. Title 13, Division 1, Chapter 1 of the California Department of Motor Vehicles regulations includes Article 13: Testing of Autonomous Vehicles. The article includes definitions relating to AV testing, requirements for a manufacturer's testing permit, requirements for a certificate of self-insurance, proof of financial responsibility, and other requirements.

Dong, X., M. DiScenna, and E. Guerra. "Transit User Perceptions of Driverless Buses." *Transportation*: 1–16. 2017. This academic study includes results from a stated preference survey of transit bus riders in Philadelphia about their willingness to ride driverless buses. The researchers use mixed-logit modeling to examine the relationship between passenger types and willingness to ride driverless buses with or without an on-board safety attendant. Overall, younger riders and males are more willing to ride a driverless bus. Of the entire sample, two-thirds expressed willingness to ride with an attendant on board but only 13 percent expressed willingness without anyone on board.

EasyMile. Site Assessment Report. Client: City of Arlington. Site: Convention Center to AT&T Stadium. September 2017. This document is a slide set of the site assessment by the vehicle manufacturer (EasyMile) for the off-road path LSAV testing in Arlington, Texas. The document consists primarily of maps, drawings, and charts and an overview, requirements, and analysis of the chosen site and path for the vehicle in the City of Arlington pilot project.

Eno Center for Transportation. Beyond Speculation 2.0: Automated Vehicles and Public Policy. January 2018. This report from a transportation policy think tank covers the state of the practice in and recommendations for AV policies at the federal level. The report does not focus on LSAVs but includes general recommendations for policies related to automated transportation options, including needs relating to operational, infrastructure, and security.

FTA. Strategic Transit Automation Research Plan. FTA Report no. 0116. January 2018. This 2018 FTA plan for the future of transit incorporation of automated technologies outlines FTA's research plan for automated technologies. The plan specifically notes Level 4 automated shuttle applications, including the use cases of a circulator bus service and a feeder bus service. It also specifies the use of mobility-on-demand services for use cases that shuttles could also contribute to, such as first mile/last mile, ADA paratransit, and on-demand shared rides. Transit agencies could use the FTA plan to help align their plans and goals with national plans and goals.

Fraade-Blanar, Laura, Marjory S. Blumenthal, James M. Anderson, Nidhi Kalra. Measuring Automated Vehicle Safety. Rand Corporation. 2018. This Rand report on AVs and safety outlines a framework for safety for automated vehicles. It discusses how safety can and should be measured for AV technologies. The report does not focus on low-speed vehicles or shuttles but impresses upon the fact that LSAVs have very specific and limited operational design domains and use cases.

FHWA. Traffic Calming ePrimer—Module 2. February 2017. FHWA has a publicly available eight-0module primer online as a resource for traffic-calming practices and information. This is module two of these FHWA materials on safety, focusing on traffic-calming to reduce speeds. Module two is basic information of definitions, reasoning behind traffic-calming, and traffic-calming in context of other transportation issues. This resource backs up the importance of using low-speed vehicles in certain situations.

Government Accountability Office. Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges. GAO-18-132. This study addresses the need for national policy supporting the development and planning for automated vehicles, including SAE levels 1 through 5 technologies and both passenger and freight movement. The GAO study recommendation is for the U.S. DOT to develop a comprehensive plan for AVs, which they complied with in the federal automated vehicle policy, Automated Vehicles 3.0: Preparing for the Future of Transportation, preceding and supporting documents. The document does not specify shuttles and low-speed vehicles or their common use cases.

Governors Highway Safety Association. Preparing for Automated Vehicles: Traffic Safety Issues for States. August 2018. This report outlines GHSA recommendations to states for planning for AVs, specifically vehicles with level 3–5 capabilities. The report includes recommendations to incorporate consideration for automated driving systems in the areas of management, traffic laws, and AV testing and deployment. It also includes examples of state policies and relevant resources. The report does not focus on or discuss LSAV applications.

Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation. "ITS Research 2015–2019: Connected Vehicles." 2018. ITS JPO at U.S. DOT awarded three pilot projects a collective $45 million in 2015 to test connected vehicle dedicated short-range communications technologies. There are reports and updates for each project, as well as general information about applications of connected transportation technologies. This resource is just about connected vehicles, not automated vehicles, and includes research on both vehicle-to-vehicle communication and vehicle-to-infrastructure communication.

National League of Cities. Autonomous Vehicle Pilots Across America: Municipal Action Guide. 2018. The National League of Cities developed this guide to help cities take action in regulating, tracking, and participating in automated vehicle testing, pilots, and demonstrations. The report outlines local governance issues associated with AVs and gives examples of AV pilot programs and what goes into implementing them. It also includes recommended strategies for city leaders. The report outlines planning for and implementing AV pilots in cities in the context of new technologies, transportation and land-use trends, and state and federal policy frameworks. One of the examples highlighted in the report is the Arlington, Texas, LSAV shuttle.

NTSB. Reducing Speeding-Related Crashes Involving Passenger Vehicles. 2017. The NTSB conducted a seminal study on the risks associated with high-speed vehicle travel. In particular, the study examined the causes of and trends in speeding-related passenger vehicle crashes. From 2005 through 2014, vehicle speed was the cause or contributing factor in 31 percent of traffic fatalities. The NTSB found speed to increase both the likelihood of being involved in a crash and the severity of crash injuries. The study recommended five countermeasures for speeding, including (1) speed limits, (2) data-driven approaches for speed enforcement, (3) automated speed enforcement, (4) intelligent speed adaptation, and (5) national leadership. LSAVs were ignored as a direct potential solution. This report emphasizes the implications of implementing low-speed service. See also **Elvik, Rune. The Power Model of the Relationship Between Speed and Road Safety. 2009.**

Navya Safety Report: The AUTONOM Era. January 2019. Navya submitted its Voluntary Safety Self-Assessment (VSSA) to U.S. DOT in January 2018. The document is similar to other VSSAs, including basic information about the company, the technologies they use in their vehicle, safety technologies and testing methodologies, and relevant policies. The VSSA includes an entire section on operational design domain, including the variables that must be assessed and the requirement of a site feasibility study before implementation.

Nielsen, T. A. S., and S. Haustein. "On Skeptics and Enthusiasts: What Are the Expectations Towards Self-Driving Cars?" *Transport Policy* 66: 49–55. 2018. This academic study includes a survey of Danes on perceptions of AVs and vehicle sharing. The results of the survey of 3,040 people separate the respondents into three categories: 38 percent fell into the category of "skeptic," 37 percent "indifferent stressed drivers," and 25 percent "enthusiasts." This study found, consistent with other studies, that the enthusiasts are more likely to be young, highly educated, urban-dwelling males. Skeptics are more likely to be older, car reliant, and live in less dense areas. Personal ownership of AVs was preferred over shared fleets.

Nuro. Delivering Safety: Nuro's Approach. 2018. This is the U.S. DOT–recommended Voluntary Safety Self-Assessment form from Nuro, an LSAV manufacturer whose vehicles are designed to carry only goods and no passengers. The VSSA includes standard elements of the company's vision, vehicle specifications and technologies, safety testing methods, the operational design domain specifications, and high-level policy considerations. In 2020, NHTSA granted Nuro a temporary exemption from the Federal Motor Vehicle Safety Standards (85 FR 7826, February 11, 2020).

Pettigrew, S., Z. Talati, and R. Norman. "The Health Benefits of Autonomous Vehicles: Public Awareness and Receptivity in Australia." ***Australian and New Zealand Journal of Public Health*****. 2018. http://doi.org/10.1111/1753-6405.12805**. This was an academic study surveying Australians about AV acceptance, salience of AV health benefits, and prompted awareness of these health benefits. Quantitative and qualitative data were generated using an online survey targeting Australians 16 years and older. Results indicated neutral levels of receptiveness towards AVs and very low salience of health benefits. However, there were more substantial levels of prompted awareness of positive health benefits. The study implied Australians' likelihood to accept AVs when understanding the associated health benefits. The study did not focus on low-speed vehicles.

SAE J3016™ Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, Publication Date June 2018. This is an SAE Recommended Practice describing motor vehicle driving automation systems that perform part or all of the dynamic driving task.

SAE J3163™ Taxonomy and Definitions for Terms Related to Shared Mobility and Enabling Technologies, Publication Date September 2018. This is an SAE Recommended Practice providing a taxonomy and definitions for terms related to shared mobility and enabling technologies.

Securing America's Future Energy. America's Workforce and the Self-Driving Future. June 2018. The report commissioned by SAFE supported academic economists' research on the impact of AVs on the United States workforce. Implications of automated vehicle technologies affecting the workforce are still unknown, as the capabilities and applications of the technology are still in development, but the research suggests that while there may be shifts in workforce skill needs, the overall number of jobs will not change much over time as the transportation sector adopts automated technologies. Simulations in this study show that impacts on the workforce from AVs would be felt starting in the early 2030s but would only increase the national unemployment rate by 0.06–0.13 percentage points at peak impact sometime between 2045 and 2050 before a return to full employment. The report does not look specifically at LSAVs but notes the possibilities of shared fleets.

Swigart, Sarah. AAA Survey Summary. 2018. As a sponsor of the Las Vegas Phase I LSAV pilot project in downtown Las Vegas, AAA distributed a survey to riders. The survey asked riders how many stars they would give the experience, if they would recommend it to friends, their perceptions of AVs before and after riding, and gave space for additional comments. The document indicates an overwhelmingly positive response. AAA did not survey people who chose to not board the vehicle or participate in the pilot experience.

University of Michigan. Mcity Driverless Shuttle: A Case Study. 2018. This document provides an overview of the Mcity driverless shuttle testing on the University of Michigan campus. The testing included studies on human behavior and AV technologies. The project included pilots with a Navya LSAV on the University of Michigan campus. The report also includes recommendations for others interested in deploying comparable services. The identified lessons learned are (1) set specific project goals; (2) engage stakeholders early; (3) explore legal, regulatory, and insurance options; (4) identify operational environment constraints; (5) conduct your own testing; (6) train safety conductors thoroughly; (7) anticipate challenges; (8) develop an incident-response plan; and (9) establish data needs early.

U.S. DOT. Automated Driving Systems 2.0: A Vision for Safety. September 2017. NHTSA released the first version of their Federal Automated Vehicles Policy Statement (FAVP) in September 2016 and replaced the document the following year with a second version, *Automated Driving Systems: A Vision for Safety* (2.0 ADS). The statements were written in consultation with industry stakeholders, including automakers, technology firms, state government officials, and experts in the field, with incorporation of feedback from public comments. The 2.0 ADS provides information for the industry on AVs. It provides guidance to manufacturers testing and developing AVs on public roads, clarifies the roles of the federal and state governments in regulating operations, and outlines NHTSA's existing and potential enforcement mechanisms. The 2.0 ADS encourages manufacturers to publish their VSSA and does not specifically address low-speed or transit applications of AV technologies.

U.S. DOT. Automated Vehicles 3.0: Preparing for the Future of Transportation. October 2018. This document is the updated federal guidance for AV development and testing. It builds off the federal guide Automated Driving System 2.0, adding to and not replacing the 2.0 guidance. The document expands on transit applications of AVs and the FTS's role in providing technical assistance for AV applications in transit. It also includes a full section on "considerations for public sector transit industry and stakeholders" and a shorter section on recommendations for the private sector transit industry. The document also notes the potential use cases and existing pilots for LSAVs.

Volpe National Transportation Systems Center. Low-Speed Automated Shuttles: State of the Practice. 2018. Volpe National Transportation Systems Center in conjunction with the Intelligent Transportation Systems Joint Program Office conducted research on the state of the practice both domestically and abroad of the use of LSAVs. Their research spanned from August 2015 to September 2018. It included the review of multiple LSAV demonstrations and pilots, examination of vehicle designs and transportation service provided, and the governance behind the various programs examined. The Volpe team also convened a working group for agencies involved in LSAV demonstrations and pilots for project insight and to provide a platform for technical exchange between agencies.

World Economic Forum. Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston. June 2018. A study on AV and urban mobility by WEF and Boston Consulting Group culminated in this report. The authors used the City of Boston as their study ground. Findings included intuitive possible outcomes of reduced vehicle ownership, but possible increased vehicle miles traveled if shared AV fleets absorb enough mode share; shared AV fleets could reduce parking demand; and that shared AV fleets could replace trips in both personal vehicles and public transit options. A global survey deployed to urbanites by the researchers found that respondents were most enthusiastic about AVs to eliminate the need to manually search for and execute the parking task, and overall about 60 percent of respondents said they would be likely or very likely to ride in an AV. The report mentions "autonomous minibuses," which are akin to LSAVs, and notes that many German cities and other cities around the world are implementing LSAV pilots.

WSP and AECOM. Draft MnDOT Autonomous Bus Pilot Project: Testing and Demonstration Summary. June 2018. To prepare for the operations of an automated shuttle bus in mixed general traffic and cold weather climate conditions, the Minnesota Department of Transportation (MnDOT) conducted an Autonomous Bus Pilot project. The project aimed to safely demonstrate AV technology to stakeholders and capture public interest. Testing focused on identifying challenges and solutions for operating AVs on the MnDOT transportation system. The demonstration of the automated shuttle bus was conducted by EasyMile, a vendor chosen by MnDOT, with oversight from WSP and AECOM. First Transit and 3M also partnered with MnDOT for operational support. Demonstrations occurred on a 2.5-mi closed low-volume loop. Winter weather testing found snowfall and snowbanks alongside vehicle routes were often detected as obstructions, causing the vehicle to slow down or stop completely. When core temperatures of the shuttle dropped significantly, operations were negatively impacted and charging times increased. Dry pavement conditions and salt spray from treated sections of roadway did not alter shuttle performance. Overall, survey data from the demonstrations showed the public in favor of the Autonomous Bus Pilot project.

A Feasibility Study to Explore the Potential for Running Autonomous Vehicles Trails in Cambridge Utilizing the Unique Aspects of Guided Busway. n.d. It is unclear who conducted this feasibility study for AV testing in Cambridge, UK, regarding sharing existing busway right-of-way with autonomous driving systems. The report focuses on the interaction between transportation, land-use, and economics, and the potential for new technologies to increase access and mobility. The report touches on LSAV applications, noting the added expense of dedicated right-of-way, which is sometimes, but not always, necessary. The report includes a feasibility analysis and various options for possible programs in Cambridge, including LSAV programs.

49 U.S.C. § 5323(j). 49 U.S.C. §5323(j) requires that federal tax dollars used to purchase steel, iron, and manufactured goods in a transit project are produced domestically in the United States. This includes rolling stock purchases and capital leases. For rolling stock purchases for which the average cost of the vehicle is more than $300,000, the cost of steel or iron produced in the United States and used in the rolling stock frames or car shells may be included in the domestic content calculation, regardless of where it is produced. FTA's Buy America regulations apply to third-party procurements by FTA grant recipients. LSAVs used for public transit and receiving federal funding must abide by the Buy America law. If the minimum percentage content quote is not met, any FTA funding would be withheld unless a waiver is justified by the FTA. LSAVs not using federal funding do not have to abide by the Buy America laws.

49 U.S.C. § 30114. NHTSA issues the FMVSS; compliance with these standards allows vehicles to operate on public roads. This part of the United States Code allows exemptions to the FMVSS. The FMVSS includes provisions regarding minimum safety specifications for vehicle design, construction, and performance.

42 U.S.C. § 12101 et seq. Public transit agencies (and many private providers) must follow the federal law, the Americans with Disabilities Act (ADA), which includes requirements for transit stations, vehicles, and services. Before any agency or company implements service with LSAVs, they must bring the infrastructure, vehicles, and service into compliance. However, there are no currently available vehicles that meet the specifications of the ADA. The most common shortfall is the lack of securement for a wheelchair inside the vehicle, but some vehicles do not include ramps, a bar to hold on to for stability, or designated areas for people with disabilities.

Literature Survey

In reviewing the published literature on LSAVs as of 2018, many transit agencies have expressed and demonstrated interest in specific use cases for LSAVs, but few formal studies have been conducted to increase knowledge in the field of LSAVs.[1] Understanding how LSAVs operate, their limitations, and their potential is important for transit agencies deciding whether or how to integrate them into their networks. This section examines the limited existing literature

[1] Cregger, Joshua, Machek, Elizabeth, et al., "Low-Speed Automated Shuttles: State of the Practice Final Report." Intelligent Transportation Systems Joint Program Office. FHWA-JPO-18-692. 2018, https://rosap.ntl.bts.gov/view/dot/37060.

on LSAVs and LSAV testing and reflects the information as of the publication of the referenced documents. Topics include the following:

- Infrastructure requirements and operational design domain
- Vehicle specifications
- Safety
- Cybersecurity
- NHTSA "Temporary Importation of a Motor Vehicle or Equipment Under Box 7 on the HS-7 Form"
- Law enforcement
- Liability
- Accessibility for people with disabilities
- Connectivity
- Workforce
- User acceptance
- Stakeholders from the private, public, and research sectors have shown interest in and have paid attention to the short- and long-term tests of LSAVs.[2]

According to the FTA's Strategic Transit Automation Research report, AV demonstrations can lead to a better understanding of several important issues, including

- Transit operations and maintenance
- Fuel and emissions
- Service quality
- Safety
- Passenger experience, comfort, and acceptance
- Accessibility
- Travel options and mode choice
- Fare collection
- Cost-effectiveness[3]

Infrastructure Requirements and Operational Design Domain

ODD defines the physical and temporal conditions under which AVs can operate, including roadway types (interstate, local, etc.) on which the ADS is intended to operate safely; geographic area (city, mountain, desert, etc.); speed range; environmental conditions in which the ADS will operate (weather, daytime/nighttime, etc.); and other domain constraints.[4] The low-speed shuttles currently or recently deployed generally operate on dedicated or limited access right-of-way and with minimal environmental complexity. Sometimes the added complexity involves only portions of the ODD that are in mixed right-of-way or crossings with vehicular traffic.[5] LSAVs require specific infrastructure elements that both support the dynamic driving task by any means of operations (such as clear right-of-way), and that support automated systems. Infrastructure allows the LSAV sensors to understand the environment and inform proper steering, acceleration, and braking.

[2] Ibid.
[3] U.S. DOT, FTA, "Strategic Transit Automation Research Plan." FTA Report no. 0116. January 2018, http://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf.
[4] U.S. DOT, "Automated Driving Systems 2.0: A Vision for Safety." September 2017, www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf.
[5] Cregger, Joshua, Machek, Elizabeth, et al., "Low-Speed Automated Shuttles: State of the Practice Final Report." Intelligent Transportation Systems Joint Program Office. FHWA-JPO-18-692. 2018, https://rosap.ntl.bts.gov/view/dot/37060.

As of 2018, the literature review indicated that LSAV pilots and demonstrations have largely occurred on existing limited access right-of-way.[6] A dedicated right-of-way for AVs eliminates risks from mixed traffic or from unprotected left-hand turns. In developing LSAV projects, project managers need to account for interactions with other vehicle types, including higher-speed transit vehicles and bicyclists or pedestrians (for example, at intersections or on mixed-use paths).[7]

Literature shows that state agencies are beginning to examine various aspects of the operational environment. The Commonwealth of Massachusetts AV Working Group established multiple classifications of environmental conditions with various degrees of complexity in order to permit vehicle testing based on the appropriate environment, starting in a closed course and graduating to open public roads.[8] At least one, MnDOT, has conducted a test of an EasyMile vehicle in snowy and rain-inclement weather. MnDOT found environmental factors such as snow or rain cause increased localization issues and wheel slippage for the EasyMile vehicle.[9]

Levels of Automation

The SAE-established levels for ADS automation levels 0–5, with Level 0 (No Driving Automation) and Level 5 (Full Driving Automation). While this classification system does not include many nuances in advanced driver-assistance systems, it provides a standard framework to consider various types of vehicle automation.[10] In a January 2018 report, the FTA states that LSAVs can perform SAE Level 4 capabilities under certain, carefully planned, ODD and contextual circumstances.[11]

In 2015, FAST required a GAO study on automated vehicle policy, which outlines the basic state of the practice for automated driver-assistance systems and recommends further planning by U.S. DOT to accommodate new technologies, such as implemented in the recent U.S. DOT AV guidance document. The study focused on passenger vehicles and light duty trucks and does not specifically mention shuttles such as LSAVs but notes that standards for vehicles and infrastructure will change and DOT must respond accordingly.[12] Under current law, vehicles operating on public roads are required to adhere to the FMVSS, which have been developed by NHTSA, unless they qualify for an exemption. In 2020, NHTSA granted Nuro a temporary exemption from the Federal Motor Vehicle Safety Standards (85 FR 7826, February 11, 2020) and initiated rulemaking with regard to Occupancy Protection Standards in Vehicles with Automated Driving Systems (84 FR 24433, May 28, 2019).

[6] University of Cambridge, "A Feasibility Study to Explore the Potential for Running Autonomous Vehicles Trails in Cambridge Utilizing the Unique Aspects of Guided Busway"; see also EasyMile, "Site Assessment Report," Sept. 2017, on behalf of the City of Arlington for a site between the Arlington Convention Center and AT&T Stadium.
[7] Ibid.
[8] Autonomous Vehicle Working Group, "Draft Report of the Massachusetts Autonomous Vehicles Working Group" v4.0. September 12, 2018, http://www.mass.gov/files/documents/2018/09/12/DraftReport_AV_WorkingGroup.pdf.
[9] WSP and AECOM, "MnDOT Autonomous Bus Pilot Project: Testing and Demonstration Summary." Draft. June 2018, http://www.dot.state.mn.us/automated/bus/finalreport.pdf.
[10] Eno Center for Transportation, "Beyond Speculation 2.0: Automated Vehicles and Public Policy." June 2019, http://www.enotrans.org/events/webinar-beyond-speculation-2-0/.
[11] U.S. DOT, FTA, "Strategic Transit Automation Research Plan." FTA Report no. 0116. January 2018, http://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf.
[12] GAO, "Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges." GAO-18-132, Nov. 2017, http://www.gao.gov/assets/690/688676.pdf.

LSAV Characteristics

According to research by the Volpe National Transportation Systems Center, LSAVs have the following characteristics:

- Fully automated driving (SAE Level 4 or 5, intended for use without a driver).
- ODD (restricted to protected and less-complicated environments).
- Low operating speeds (cruising speeds around 10–15 mph).
- Shared service (typically designed to carry multiple passengers, including unrestrained passengers and standees).
- Share the right-of-way with other road users, either at designated crossing locations or along the right-of-way itself.[13]

LSAVs are not a specific vehicle class. Some are NEVs, which are subject to guidance by NHTSA as well as state and local law. Others are purpose-built vehicles. A third category includes retrofitted vehicles such as the Cushman 6 deployed at Fort Bragg and the Polaris GEM used by May Mobility and Optimus Ride, as well as pod car.[14]

As recommended by the GAO in 2017, U.S. DOT did indeed refine guidance for AVs in its 2018 document, *Automated Vehicles 3.0: Preparing for the Future of Automation*. The document includes multiple references to ongoing LSAV testing, while cautioning local governments to maintain expectations that are "realistic about their limitations," presumably meaning that agencies understand the necessity of the on-board safety attendant, including to operate the vehicle, the maintenance needs, and varied battery draw.[15]

Some LSAVs currently on the roads in the United States are imported and have been operating with the issuance of an HS-7 waiver from the FMVSS. These vehicles qualify by virtue of the fact that the vehicles are imported and used for research, investigations, demonstrations or training, or competitive racing.[16] However, if transit agencies using federal funding decide to adopt the vehicles for service, the Buy America requirements could lead to the required use of American-made vehicles that will have to comply with FMVSS regulations.[17] U.S. DOT specifies in its recent AV guidance that they will be updating the FMVSS to account for automated technologies, which could further influence the landscape for procurement and operation of vehicles.[18] According to the FTA in its Strategic Transit Automation Research Plan, LSAVs are subject to speed and operational environment limitations and low passenger capacities, so are not yet suitable for broad adoption by the transit industry for higher-capacity services.[19]

Safety

Research indicates that the largest contributor to deaths and serious injuries on the roadway is vehicles traveling at high speeds. Therefore, a significant safety benefit of LSAVs is that they operate at lower speeds. There is a direct relationship between speed and the probability of serious

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[13] Cregger, Joshua, Machek, Elizabeth, et al., "Low-Speed Automated Shuttles: State of the Practice Final Report." Intelligent Transportation Systems Joint Program Office. FHWA-JPO-18-692. 2018, https://rosap.ntl.bts.gov/view/dot/37060.

[14] Carolinas Alliance 4 Innovation, Website, http://ca4i.com/projects.html. Accessed February 12, 2019.

[15] U.S. DOT, "Automated Vehicles 3.0: Preparing for the Future of Transportation. October 4, 2018, http://netchoice.org/wp-content/uploads/DOT-Guildelines-v3.0.pdf.

[16] NHTSA, "Importation of Motor Vehicles and Motor Vehicle Equipment Subject to Federal Motor Vehicle Safety, Bumper, and Theft Prevention Standards." http://www.nhtsa.gov/sites/nhtsa.dot.gov/files/hs7_r.v.7.pdf.

[17] 49 U.S.C. §5323(j)

[18] U.S. DOT, "Automated Vehicles 3.0: Preparing for the Future of Transportation. October 4, 2018, http://netchoice.org/wp-content/uploads/DOT-Guildelines-v3.0.pdf.

[19] U.S. DOT, Federal Transit Administration, "Strategic Transit Automation Research Plan." FTA Report no. 0116. January 2018, http://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf.

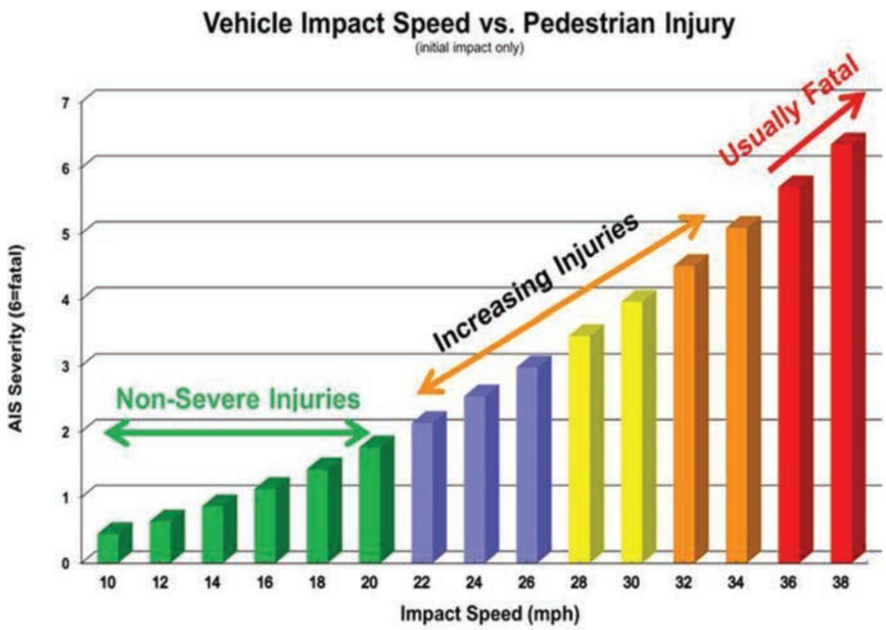

Figure A.1. FHWA speed/pedestrian injury severity correlation.

injury or fatality in a crash, for pedestrian safety as seen in Figure A.1. The escalation of risk with the increase of speeds holds for vehicle crashes with other vehicles as well.[20]

There is no standard definition of "safety" in the specific context of AVs, including LSAVs.[21] A 2018 Rand report explores definitions of safety, safety measurement, and communication about safety, limiting the discussion to highly automated vehicles, or vehicles operating under SAE automation Level 4 or 5. Rand divides safety measures into two types: leading and lagging. Leading measures include behavior such as following traffic laws that may prevent crashes, whereas lagging measures measure actual safety outcomes. Figure A.2 shows the proposed measures and when to implement them.

Measures such as the proposed Rand measures could play a role in future safety certification for vehicles.

Public education and communication around safety may have an impact on willingness to adopt and utilize automated vehicle technologies. Documents such as the voluntary safety self-assessments outlined in the Federal Automated Vehicle Policy 3.0 inform the public on automakers' approach to safety and the technologies they use.[22] As of the date of this review, the only manufacturer of an LSAV that had submitted a Voluntary Safety Self-Assessment is Nuro, who develops vehicles exclusively for the transport of goods, and not passengers.[23] On February 11, 2020, the NHTSA granted a temporary exemption to Nuro from the FMVSS, the first granted to any AV manufacturer (85 FR 7826).[24]

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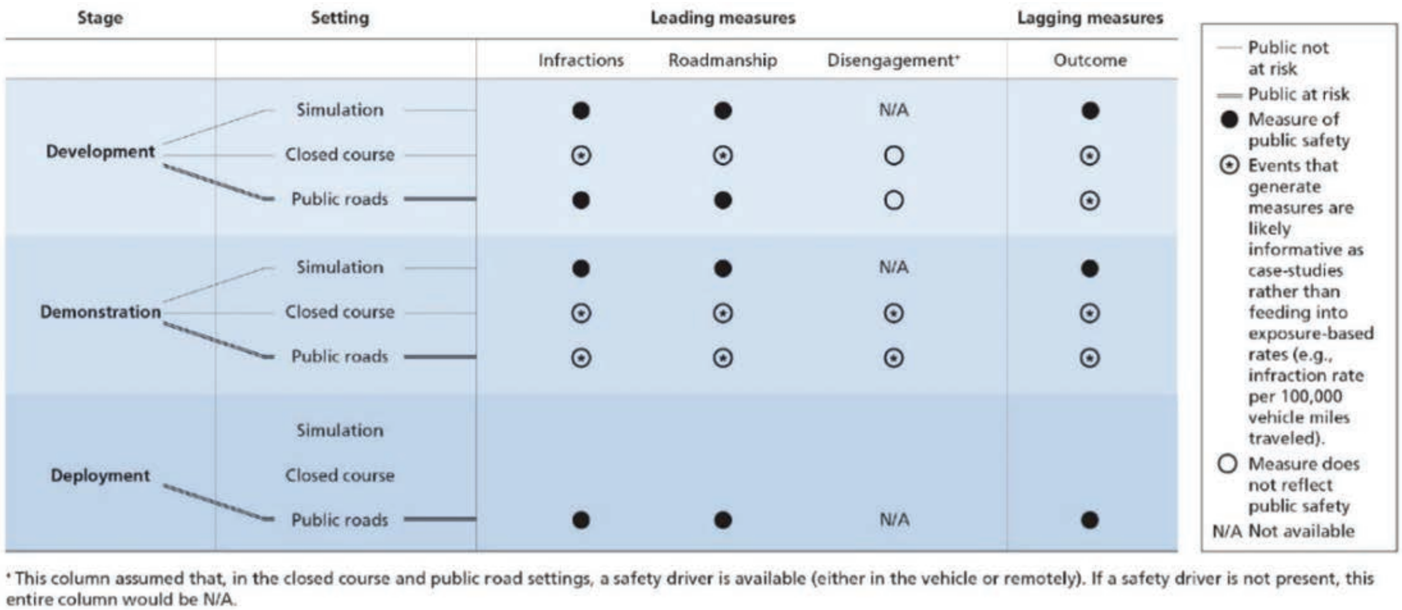
[20] NTSB, "Reducing Speeding-Related Crashes Involving Passenger Vehicles." NTSB/SS-17-01, 2017, http://www.ntsb.gov/safety/safety-studies/Documents/SS1701.pdf; Elvik, Rune. "The Power Model of the Relationship between Speed and Road Safety." TOI Report: 1034/2009. Norwegian Centre for Transport Research, Oct. 2009, ISBN 978-82-480-1001-2.

[21] Fraade-Blanar, Laura, Marjory S. Blumenthal, James M. Anderson, Nidhi Kalra, "Measuring Automated Vehicle Safety." Rand Corporation. 2018. ISBN: 978-1-9774-0164-9.

[22] Ibid.

[23] U.S. DOT, "Automated Vehicles 3.0: Preparing for the Future of Transportation." October 4, 2018, https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf.

[24] Nuro, Delivering Safety: Nuro's Approach. 2018; Nuro, Temporary Exemption from the FMVSS, 85 FR 7826.



Source: Fraade-Blanar et al., "Measuring Automated Vehicle Safety." Rand Corporation, 2018.

Figure A.2. Integration safety framework.

Federal Motor Vehicle Safety Standards

NHTSA has a legislative mandate under Title 49 of the United States Code, Chapter 301, Motor Vehicle Safety, to issue FMVSS and Regulations to which manufacturers of motor vehicles and items of motor vehicle equipment must conform and certify compliance. Under these standards, vehicles must include standard features; vehicles that do not conform to standards make seek a waiver of FMVSS from NHTSA.[25]

Law Enforcement

Studies agree that states and cities must develop law enforcement policies around AVs, including for issues around operations and data sharing and access.[26] The state of California, which has some of the most stringent laws for AV testing, requires that manufacturers certify that there is a process to hand over operator information to law enforcement in the event of a crash or "any reason." California also requires manufacturers to inform law enforcement and other first responders of the ODD and protocols to interact with the vehicle and requires that law enforcement interaction plans are reviewed annually.[27] Case studies in Appendix D and Appendix E provide further examples of collaboration with law enforcement.

Accessibility for People with Disabilities

Public transit agencies (and many private providers), must follow the ADA, which includes requirements for stations, vehicles, and services. In implementing LSAV service, public and private providers must ensure that infrastructure, vehicles, and services are compliant with

[25] 49 U.S.C. § 30114.
[26] Governors Highway Safety Associations, "Preparing for Automated Vehicles: Traffic Safety Issues for States." August 2018, http://www.ghsa.org/sites/default/files/2018-08/Final_AVs2018.pdf.
[27] California Department of Motor Vehicles. Title 13, Division 1, Chapter 1.

applicable laws.[28] The regulations vary depending on many factors, and little has been written about the topic. The 2018 report on LSAVs conducted by Volpe did not fully address the issue of ADA compliance because of the levels of complexity and rapid changes in the levels of compliance.[29]

U.S. DOT's recent Notice of Funding Opportunity for Automated Driving Systems stated that AVs in public transit should include, at a minimum, a ramp and securement. In addition, U.S. DOT is now requiring an input/output interface to allow communication between the vehicle and those who have a vision, hearing, or cognitive impairment.

The U.S. Attorney's Office for the Eastern District of Michigan (as a component of the U.S. Department of Justice) and the University of Michigan reached an agreement in November 2019 related to the university's autonomous transportation services (as further described in mini case study E.7, Mcity Driverless Shuttle, in Appendix E).[30] The agreement was predicated on the lack of accessible features on two vehicles purchased by the university for its autonomous transportation system, which operates on a fixed route during business hours. Title II requires that all new vehicles operating on a fixed route be accessible and there are no exemptions for autonomous vehicles, pilot programs, or research programs. The agreement included the following elements:

- Any future highly automated vehicles (HAV) that the university purchases or leases for the Mcity Driverless Shuttle program or any other fixed-route system must be equipped with accessible features as set forth in 49 CFR, Part 38, and 49 CFR 37.7 (a) including, but not limited to, securement devices and lifts, ramps, and other means of access to vehicles. These must be maintained to be in compliance with 49 CFR 37.161.
- Additional requirements for development of policies, procedures, and training materials.
- Until all HAVs are accessible the university must provide equivalent services to individuals with disabilities.
- Convene a research group to evaluate the accessibility of the autonomous transportation services.

As of January 2019, some vehicles have a ramp, one has securement, and one prototype included a human–machine interface. The National League of Cities highlighted the Arlington, Texas, LSAV pilot project, attributing their partnership with the vehicle manufacturer EasyMile to the wheelchair ramp included in the design.[31] MnDOT also chose to use an EasyMile vehicle with a ramp.[32] The Navya AUTONOM vehicle also has a ramp. May Mobility expects to begin production of a vehicle with ramp and securement later in 2019.[33] Local Motors and Perrone Motors each produce vehicles with securement and ramps.[34]

Connectivity

LSAVs, like all automated vehicles, depend on loaded maps as well as sensors such as camera, radar, and LiDAR read-ins to navigate the ODD. Some vehicles also communicate with other

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[28] Americans with Disabilities Act of 1990. Pub. L. 101-336. 26 July 1990. 104 Stat. 328.

[29] Cregger, Joshua, Machek, Elizabeth, et al. "Low-Speed Automated Shuttles: State of the Practice Final Report." Intelligent Transportation Systems Joint Program Office. FHWA-JPO-18-692. 2018, https://rosap.ntl.bts.gov/view/dot/37060.

[30] Ackerman, Shannon M., United States Attorney's Office Eastern District of Michigan, U.S. Department of Justice, "Letter of Resolution D.J. No. 204-37-328, ADA Compliance Review of the University of Michigan's Driverless Shuttle Program." Received by C. Ndu Oor, University of Michigan, November 12, 2019.

[31] National League of Cities, "Autonomous Vehicle Pilots Across America: Municipal Action Guide." 2018, https://www.nlc.org/sites/default/files/2018-10/AV%20MAG%20Web.pdf.

[32] WSP and AECOM, "MnDOT Autonomous Bus Pilot Project: Testing and Demonstration Summary." Draft. June 2018, http://www.dot.state.mn.us/automated/bus/finalreport.pdf.

[33] Alysin Malek, interview by research team, May 10, 2019.

[34] Gina O'Connell, interview by research team, April 9, 2019; Paul Perrone, interview by research team, April 7, 2019.

vehicles and/or with the physical infrastructure via several communications technologies, including DSRC and 5G cellular. Vehicle to vehicle and V2I communication can take many technological routes, including dedicated short-range communication (DSCR) and cellular vehicle to anything (CV2X) technologies. U.S. DOT has established a robust connected vehicle program to test DSRC technology, and many universities also research connected vehicles.[35] However, CV2X is still a nascent technology and much testing is needed to assess capabilities.[36]

LSAV pilots have shown that without DSRC V2I communication, AVs need extensive visual cues such as additional signage, decoration, and identifiable objects.[37] As LSAVs on the road today have an on-board attendant/operator present, communication can also occur between people operating the vehicle and people in other vehicles or exterior to the driving domain without CV2X or DSRC technologies enabled.[38]

Workforce

Implications of automated vehicle technologies affecting the workforce are still unknown, as the capabilities and applications of the technology are still in development. In the short term, LSAV pilots and demonstrations will likely boost workforce opportunities. LSAVs currently require on-board attendants, will continue to need mechanics and technology development staff, and they do not replace existing transit services.[39]

In the long run, research has suggested that while there may be shifts in workforce skill needs, the overall number of jobs will not change much over time as the transportation sector adopts automated technologies.[40] LSAVs specifically require a manufacturing workforce, maintenance workforce, operations specialists, and on-board liaisons/drivers. With the potential elimination of the human driving feature, on-board attendants still fill the role of education, safety oversight, and assistance, including for people with disabilities.

Volpe notes the unclear path forward with on-board attendants and states that they will be present for the time being. Their report further notes that some technology is not ready to operate without an attendant present. In instances in which the technology advances or operations can be handled remotely, the attendant position may be eliminated. Alternatively, an attendant may remain to assist passengers, for security, and for other duties unrelated to driving the vehicle.[41] U.S. DOT plans to further study the impacts of automated vehicles on the workforce as outlined in AV 3.0. The document announced a study to be conducted by the Departments of Labor, Commerce, Health and Human Services, and Transportation.[42]

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[35] U.S. DOT, Intelligent Transportation Systems Joint Program Office, "ITS Research 2015–2019: Connected Vehicles." 2018, http://www.its.dot.gov/research_areas/connected_vehicle.htm.

[36] Federal Communications Commission, "Press Release: FCC Allocates Spectrum in 5.9 GHz Range for Intelligent Transportation Systems Uses." 1999; 47 CFR § 2.106, NG160.

[37] EasyMile, "Site Assessment Report." Sept. 2017. On behalf of the City of Arlington for a site between the Arlington Convention Center and AT&T Stadium; see also WSP and AECOM, "MnDOT Autonomous Bus Pilot Project: Testing and Demonstration Summary." Draft. June 2018, http://www.dot.state.mn.us/automated/bus/finalreport.pdf.

[38] U.S. DOT, FTA, "Strategic Transit Automation Research Plan." FTA Report no. 0116. January 2018, http://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf.

[39] EasyMile, "Site Assessment Report," Sept. 2017, on behalf of the City of Arlington for a site between the Arlington Convention Center and AT&T Stadium.

[40] Securing America's Future Energy, "America's Workforce and the Self-Driving Future." June 2018. https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/SAFE_AV_Policy_Brief.pdf.

[41] Cregger, Joshua, Machek, Elizabeth, et al., "Low-Speed Automated Shuttles: State of the Practice Final Report." Intelligent Transportation Systems Joint Program Office. FHWA-JPO-18-692. 2018, https://rosap.ntl.bts.gov/view/dot/37060.

[42] U.S. DOT, "Automated Vehicles 3.0: Preparing for the Future of Transportation." October 4, 2018, https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf.

User Acceptance

There are no peer-reviewed studies published on consumer acceptance of LSAVs specifically. There are polling studies that consistently indicate that AVs generally do not enjoy high levels of consumer confidence. Some studies focusing on the acceptance of AVs in general reveal wider acceptance among younger people, males, and urbanites.[43] Although very few studies have examined acceptance in the context of transit, those also show younger users and males as having a higher propensity toward willingness to ride in a driverless bus.[44] JTL/Transit Lab has recently completed a study of stated versus revealed preferences of rides for different types of use cases.[45] Researchers at the University of Michigan have been surveying LSAV users to gauge consumer attitudes and plan to publish findings.[46]

To date, evaluations have been based on anecdotal observations and rider surveys, including collection of Net Promoter Scores. Pilots, such as in the City of Las Vegas, report people waiting in line for the opportunity to ride in a vehicle. AAA commissioned the University of Nevada, Las Vegas, to conduct a survey that revealed overwhelmingly positive feedback by people who chose to use the service (they did not survey nonusers).[47] May Mobility queries riders on whether they would recommend the service to a friend or colleague and calculates a Net Promoter Score. NPS is a standard consumer survey technique that allows for a comparison between consumer products and services.

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[43] Bansal, Prateek, et al., "Assessing Public Opinions of and Interest in New Vehicle Technologies: An Austin Perspective." *Transportation Research Part C: Emerging Technologies*, 67: pp. 1–14, June 2016, http://www.sciencedirect.com/science/article/pii/S0968090X16000383?via%3Dihub; Pettigrew, Simone, et al., "The Health Benefits of Autonomous Vehicles: Public Awareness and Receptivity in Australia," *Australian and New Zealand Journal of Public Health*, 2018, https://doi.org/10.1111/1753-6405.12805; Nielsen, Thomas, and Haustein, Sonja. "On Sceptics and Enthusiasts: What Are the Expectations Towards Self-Driving Cars?" *Transport Policy*, 66, pp. 49–55, 2018, https://doi.org/10.1016/j.tranpol.2018.03.004.

[44] Dong, Xiaoxia, et al., "Transit User Perceptions of Driverless Buses," *Transportation*, 46, pp. 1–16, May 2017, https://link.springer.com/article/10.1007/s11116-017-9786-y.

[45] Attanucci, John, and Salvucci, Frederick, Personal Interview, JTL Transit Lab, MIT, 2018.

[46] University of Michigan, "Mcity Driverless Shuttle: A Case Study," 2018, https://mcity.umich.edu/wp-content/uploads/2018/09/mcity-driverless-shuttle-case-study.pdf.

[47] Swigart, Sarah, AAA Survey Summary, 2018.

APPENDIX B

Interviews and Roundtable Discussions

Over the course of the research, there were extensive interviews related to the lessons-learned exercises. In addition, the team conducted interviews with transit agencies, vendors, and others, as well as roundtable discussions with campus owners and transportation agencies and investors.

Lessons-Learned Case Study: Arlington, Texas

- North Central Texas Council of Governments
- City of Frisco
- City of Arlington, Office of Strategic Planning
- First Transit
- EasyMile

Lessons-Learned Case Study: Las Vegas, Nevada

- Regional Transportation Commission of Southern Nevada
- City Engineer, City of Las Vegas
- Keolis
- Navya
- AAA NCNU

Lessons-Learned Case Study: ARIBO, Fort Bragg, North Carolina

- Project manager, TARDEC (United States Army)
- Program lead, TARDEC (United States Army)

Mobility Service Providers and Fleet Management Companies

- VIA
- MV Transit
- Keolis Transit America
- Transdev North America
- Roberts
- First Transit
- Transdev
- Lyft
- Uber
- Roberts
- Transloc
- Chariot
- Downtowner
- eFrog

Transit Agencies

- Corpus Christi Regional Transportation Authority
- Houston METRO
- CAT/Austin
- Jacksonville Transit Authority
- Tampa HART
- Chicago Transit Authority
- County Transit/Contra Costa Transit
- Bloomington Transit
- Honolulu HART
- City and County Department of Transportation Services, Honolulu, HI
- LA METRO
- JAUNT Albemarle County
- Denton County Transportation Authority
- Blacksburg Transit
- Valley Transportation Authority (VTA)
- BART
- San Francisco MTA
- Foothill Transit
- LVTA
- Santa Clara VTA
- MARTA
- Regional Transportation Commission of Southern Nevada

Other Public Agencies (City and State)

- District of Columbia Department of Transportation
- Denver Regional Transportation District
- New York City Metropolitan Transportation Council
- New York City Department of Transportation
- Chicago Department of Transportation
- Virginia Department of Transportation
- Virginia Office of Innovation, Office of the Secretary of Transportation
- Arlington County, VA
- Fairfax County, VA
- City of Fairfax, VA
- Montgomery County, MD
- Florida Department of Transportation
- Rhode Island Department of Transportation
- Hawaii Department of Transportation
- City of Frisco
- City of Austin
- City of Atlanta
- City of Arlington
- City of Greenville
- County of Greenville
- City of Las Vegas
- MnDOT
- ODOT/DriveOhio
- Utah Department of Transportation
- Utah Transit Agency

- Office of Planning, Montgomery County
- Rhode Island Department of Transportation
- Indian Nation Council of Governments
- Chicago Metropolitan Area Planning
- City of Allen
- City of Richardson
- City of Denton
- Houston-Galveston Area Council
- City of Detroit
- Michigan Economic Development Commission
- DriveOhio Alliance
- North Central Texas Council of Governments
- Oahu MPO
- Metropolitan Washington Council of Governments

AV Manufacturers

- EasyMile
- May Mobility
- Navya
- Voyage
- 2getthere
- Coast
- Robotic Research
- Waymo
- Aptiv
- Aurrigo
- EnVO EV
- Perrone Motors
- Cruise

Bus Manufacturer

- Proterra

Campus Owner

- Private Developers
  - LStar Ventures
  - Babcock Ranch
  - Verdae Development Inc.
  - D.R. Horton
  - JBG SMITH
  - Vornado Realty Trust
- University Campuses
  - University of South Carolina
  - Texas Southern University
  - George Mason University
  - University of South Florida
  - University of Rhode Island
  - Texas Transportation Institute
  - University of Texas Austin
  - North Texas State University
  - Texas Women’s University

SMEs/Proving Grounds

- Robotic Research
- Steve Shadlover
- Courtney Ehrlichman
- MIT Transit Lab/JTL
- Shared Use Mobility Center
- SAE
- TTI
- AARP
- University of Texas Arlington
- University of Hawaii
- University of California–Davis
- University of California–Berkeley
- National Federation for the Blind
- University of Wisconsin
- Intel
- Mobileye
- TRC
- GoMentum
- American Center for Mobility
- Virginia Tech Transportation Institute
- University of South Florida
- Andrew Smart
- Munich Re
- AV Program, AAA Norcal
- RAND Corporation

Roundtable Discussions Hosted by

- APTA
- VTA
- Urban Land Institute
- Texas Innovation Alliance
- Tysons Business Partnership
- American Planning Association
- Munsch & Hart
- City of Fort Worth (Transportation and Public Works Department)
- DriveOhio
- Automated Vehicle Alliance
- Autonomous Vehicle Symposium
- CityTech and Office of the Mayor–City of Chicago

APPENDIX C

Interview Outline

The outline for interviews is as follows:

1. **Setting the Scene:** Please describe the project briefly and your role in it. What was the route, and how was it funded? How long did it take to get off the ground?
2. **Planning:** What did you learn from planning the project, and was this a part of the traditional transportation planning process? How did you assess feasibility of the route and what were some of the challenges identified (regulatory, infrastructure, cybersecurity, etc.)?
3. **Measuring Performance:** What was the original purpose or goal of the project, and how well did the project meet these performance standards? Any recommendations/insights that you could give others? What data were received over the course of operations?
4. **Transportation System Integration:** How was this project integrated into other transportation modes, and what was the primary use case for travelers? What were the infrastructure requirements and who was responsible to make any necessary changes?
5. **Equity in Access and User Acceptance:** What data do you have about the demographics of potential users and actual users? Were vehicles wheelchair accessible? How did human factors and user acceptance play a role?
6. **Public Safety and Law Enforcement:** How were law enforcement/emergency responders involved? How did other road users interact with the vehicle and any recommendations for improvement?
7. **Next Steps:** What are the plans or next steps for AV deployments in your community and/or at your company/agency?
8. **Any Other Lessons Learned You Would Like to Share with Us:** Do you have any other documents that would be useful for other communities considering a similar pilot service?

APPENDIX D

LSAV Case Studies

Appendix D presents three case studies of completed LSAV pilots. These LSAV services operated in a different operational design domain at speeds of under 15 MPH. The three cases studied are the following:

- **City of Arlington, TX**, Milo LSAV shuttle, that was available to the public and used a multiuse pedestrian and bicycle path through a city park.
- **Fort Bragg, NC** (Applied Robotics for Installations and Base Operations), where the LSAV traveled on roadways with mixed traffic, pedestrian pathways, and parking lots on a closed military base and provided service to/from medical appointments.
- **Las Vegas, NV**, AAA Self-Driving Shuttle, which was available to the public and traveled in mixed traffic on downtown streets, crossing eight intersections. Cones marked a curbside lane or path.

The case studies include interviews with the key stakeholders responsible for setting up these services. Each case study covers the transportation context, the planning process, the funding and procurement process, and what the project leads learned during operations. More specifically,

- **The City of Arlington, TX**, case study was informed by more than 40 conversations with city staff, the North Central Texas Council of Governments (NCTCOG), First Transit, planners at Dallas Area Rapid Transit (DART) and the City of Frisco, Drive.ai, Via, May Mobility, Houston-Galveston Area Council (H-GAC), City of Arlington Tech Team Challenge members, University of Texas Arlington researchers, and others.
- **The Fort Bragg, NC**, case study is primarily based on discussions with the Robotics Research team (the lead robotics experts who converted and operated the vehicle), the project lead from the United States Army Tank Automotive Research, Development, and Engineering Center (TARDEC), and the project manager who oversaw technology development and planning of the deployment, who is also technology deployment advisor to the research team.
- **The Las Vegas, NV**, case study was based on interviews with six people involved in the planning, operation, and assessment of the LSAV project. These six interviews were augmented by discussions with the sponsor of the project, the technology deployment specialist (who is a member of the research team), the operational point of contact at the Regional Transportation Commission of Southern Nevada (RTC), a review of police reports and National Transportation Safety Board reports, and an unpublished paper with regard to law enforcement and public safety considerations of the pilot.

Figure D.1.1. Milo LSAV shuttle service.

D.1 City of Arlington, TX, Milo Case Study[1]

Project Profile

From August 2017 to August 2018, the City of Arlington, TX, piloted a low-speed shared automated vehicle (LSAV) shuttle service, known as "Milo." (Figure D.1.1). This was the first low-speed automated shuttle providing regular service to the public in the United States.

The City's twin goals were

1. Better understand the technology and
2. Expose residents and visitors to LSAV technology.

The route is depicted in Figure D.1.2.

The City of Arlington's Office of Strategic Initiatives led the planning, project development, procurement, implementation, operation, and evaluation for the pilot. First Transit, a transit and mobility service provider, oversaw regular operation of the vehicle, which included training and supervision of on-board attendants. Two EasyMile EZ10 Gen-1[2] vehicles were selected for the pilot. The vehicles are capable of SAE Level 4 (High Driving Automation) travel and were operated with an on-board attendant and monitored from a central operations center. EasyMile also provided technical support and training.

From August 2017 to August 2018, the shuttle operated for more than 100 events, including 78 events at AT&T Stadium and Globe Life Park (football, baseball, and concerts), 17 public demonstrations for interested citizens, and 18 demonstrations for special-interest groups (e.g., schools, local engineering groups, interested companies).

The Office of Strategic Initiatives reported that the project's goals had been met without significant safety incidents. See the Milo project overview in Table D.1.1.

Geographic Context

With a population of 396,394, Arlington, TX, forms the geographical center of the Dallas-Fort Worth metroplex. The climate in Arlington is a subtropical humid climate with summer temperatures of around 95°F (35°C). The heat combined with high humidity makes walking outside uncomfortable for many and difficult for some with limited mobility.

[1] All photos and graphics in this case study reprinted with the permission of the City of Arlington. The City of Arlington is not an author or sponsor of this case study.
[2] The EZ10 was deployed in Arlington. Since 2017, EasyMile has replaced the EZ10 Gen-1 with second- and third-generation systems. All observations reflect this older technology.

Figure D.1.2. Milo route map.

As of 2015, over 14 million visitors come to Arlington each year, most of them going to the Entertainment District. The Entertainment District is an area with over 15,000 jobs along with the Dallas Cowboys Stadium (AT&T Park), Texas Rangers Stadium (Globe Life Field), a Six Flags amusement park, a major convention center, hotels, and other regional attractions. The University of Texas (UT)–Arlington is in the nearby College Park District. Most of these attractions, along with several office buildings, are located together in the northern part of the city. Access to these destinations is almost exclusively by car. The Entertainment District has more

Table D.1.1. Milo LSAV shuttle overview.

Topic	Milo LSAV Shuttle Overview
Use Case	Shuttle (off-street) connecting remote parking during special events
Route Description	3 Fixed Routes, with 5 distinct stops (1 shared stop at south end)
Route Lengths	(1) South: ¾ mi; (2) North: ½ mi; (3) Public demo: ½ mi
Vehicle Capacity	15 passengers, seated and standing (based on specs)
Speed	15 mph maximum speed, 8 mph average operating speed
Operator	First Transit
Vehicle Provider	EasyMile
Vehicle Type	EZ10 Gen-1
Project Manager	City of Arlington, TX
Next Phase	Drive.ai on-demand shuttle in Entertainment District

than 30,000 parking spaces in both surface and structured parking. For large events, some of the remote parking lots are located over one-half mi away from travelers' destinations.

Milo shuttle operated in two routes alongside Johnson Creek and Mark Holtz Lake between AT&T Park, Globe Life Field, and the Arlington Convention Center. The route was primarily north to south in the Richard Greene Linear Park and crossed under East Randol Mill Road with fixed stops along the route to connect the destinations with their respective parking lots.

The Milo operations were on an off-street on a geofenced multiuse path without other motorized vehicles. The path was approximately 10 ft wide and used by both bicyclists and pedestrians. The typical operating speed was 8 mph because the route was on a multiuse pathway. This is below normal operating speeds of the EZ10.

Transportation Context

Arlington is the largest city in the United States without regular scheduled fixed-route transit service. While Dallas Area Rapid Transit (DART) is expanding an extensive light-rail system nearby, Arlington is not a part of that network. The Trinity Railway Express (TRE) also runs adjacent to the city to the north. In 2013, the City of Arlington contracted with DART to operate the Metro Arlington Express (MAX) commuter bus service between UT-Arlington and the TRE DFW/Centreport station. In 2017, the City of Arlington terminated that service although it provided the only shared service on that corridor.

Shortly after the termination of the MAX, the City of Arlington initiated the Milo project in the Entertainment District and began a separate on-demand rideshare service provided by the private company Via. Via also provides an on-demand platform for transportation in Arlington, which will facilitate the dispatch of paratransit service in the future. The City of Arlington planned to transfer operations of this paratransit service, known as Handitran, to Via in late 2019.

Arlington's LSAV shuttles and on-demand services are both designed to provide connections within and to key activity centers in the city. Phase 1 Milo service provided connection to event venues. The next phase was with Drive.ai (as described under Planning for Subsequent Initiatives); that service provided connections to hotels, the convention center, offices, and the stadiums. The City of Arlington planning team has also assessed routes and use cases on the UT-Arlington campus and adjacent residential areas, as well as the route now served by Via. City leaders are discussing how Via could use its platform and/or its operational service to provide on-demand LSAV service.

Planning

The Milo pilot was the first phase of the City of Arlington's LSAV pilot, and the Office of Strategic Initiatives led the planning, project development, procurement, implementation, operation, and evaluation over an 18-month period.

The planning of the Milo pilot took place as the City of Arlington wanted to promote mobility innovations to meet key transportation needs. At the same time, the regional metropolitan planning organization, the North Central Texas Council of Governments (NCTCOG), pioneered efforts in regional AV/LSAV planning. Three things occurred during this time:

In the fall of 2016, the City of Arlington appointed a Transportation Advisory Committee (TAC) to develop a city mobility innovation plan. The TAC developed its recommendations over a multi-month time period and published its final report in September 2017. AV shuttles were a key recommendation in this plan.

Also, in 2016, the NCTCOG designated a lead for automated vehicle planning (which encompasses LSAV) and began coordinating with the Texas Innovation Alliance on its Automated

Vehicle Proving Ground efforts. NCTCOG sponsored related pilots, incorporated a technology chapter in its 2045 Regional Long-Range Plan, included automated vehicle pilots in its TIP, and constructed a first-of-its-kind automated vehicle strategy and deployment initiative due to be launched in 2020.

As the TAC continued its stakeholder and community meetings in 2017, the City of Arlington moved forward with an LSAV pilot. In January of that year, it decided to pursue an automated vehicle pilot to become more familiar with the technology. In February, the City of Arlington identified the EasyMile technology, and in August it launched a pilot service in the Entertainment District. In a similar time frame, the City of Arlington also looked for an on-demand solution to replace a 6-mi route connecting the Trinity Railway Express to the business core of Arlington.

Mobility Innovation Plan Development

The Arlington City Council established a stakeholder/citizen committee, the TAC, to craft a mobility innovation plan to strengthen Arlington's transportation network, to provide transportation amenities for its residents and visitors, and to promote innovation. The TAC examined currently available and emerging transportation technology, gathered stakeholder input, and recommended which modes would work for Arlington's current and future needs. The September 2017 strategic report, "Connect Arlington: A Transportation Vision Connecting People and Places," provided a strategic plan for new transportation investments and explained how on-demand platforms and automated shuttles could enhance the city's mobility system. Connect Arlington set priorities for both new fixed-route and on-demand services, including identifying how automated vehicles could be best implemented to serve local transportation needs. The report calls for

- Bus rapid transit/high-intensity bus (with a dedicated lane)
- Demand-response rideshare (e.g., Microtransit services like Via)
- Personal rapid transit
- Rubber-tired automated shuttle service, either at grade or on an elevated guideway

The report identified six key corridors for public transportation improvements, which could incorporate automated vehicles, on-demand service, and/or bus rapid transit. The six corridors are listed here and shown in Figure D.1.3:

Corridor 1: Centreport TRE Station to Entertainment District
Corridor 2: Entertainment District to South Arlington, along Cooper Street
Corridor 3: Entertainment District to Tarrant County College, along Route 360
Corridor 4: Interstate 30 Corridor
Corridor 5: Interstate 20 Corridor
Corridor 6: Pioneer Parkway/Highway 303

In addition, the Connect Arlington document envisions services that connect to the high-speed corridors (corridors 4, 5, and 6) such as the commuter rail line, the TRE, and corridors along freeways. In addition to these transit growth strategies, the City of Arlington has pursued a variety of options to provide shared service to, from, and within the city. As previously mentioned, a commuter bus service called MAX was contracted from DART and connected to the TRE Centreport Station. However, during its four years of operation, the MAX had low ridership, averaging just 240 one-way rides per day.[3] As previously indicated, the City of Arlington canceled its contract and replaced it with on-demand service provided by Via in 2017. The City

[3] Cadwallader, Robert, "Time Running Out for Arlington's Three-Bus Public Transit Service." *Fort Worth Star-Telegram*, July 1, 2016, http://www.star-telegram.com/news/local/community/arlington/article87143757.html.

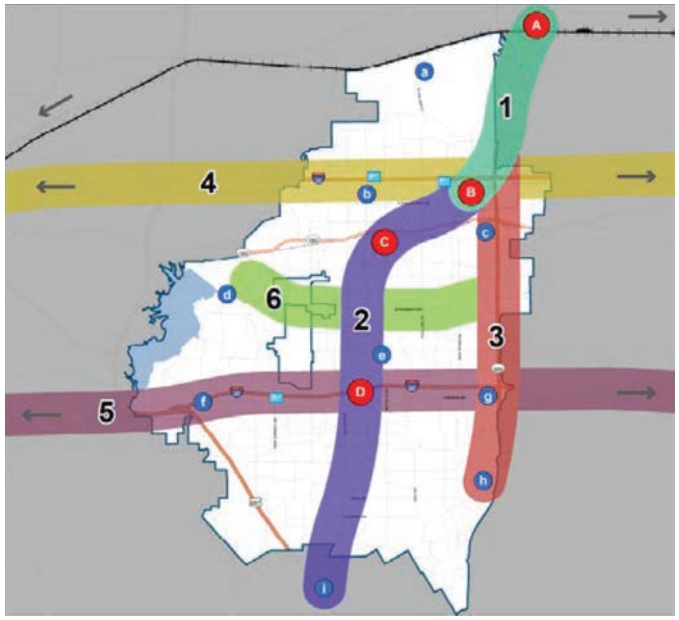

Figure D.1.3. Key new mobility corridors.

of Arlington envisions that automated shuttles will represent a larger part of the core transportation network, as local connectors and as part of the Via demand-response microtransit platform.

Regional AV Planning

The Milo project was not included in the region's long-range plans at the time of its inception. NCTCOG's leadership supported the effort through its two-person AV planning unit and complementary programming through the Texas Innovation Alliance. Additional work is being coordinated with the Texas Automated Vehicle Proving Grounds, organized by the Texas A&M Transportation Institute (TTI), the University of Texas–Austin, and the Southwest Research Institute. After the start of Milo, NCTCOG made AV pilot projects eligible for Congestion Mitigation and Air Quality (CMAQ) funds in its TIP. The City of Arlington tapped this CMAQ funding for Phase 2 of its AV pilots. In May 2018, NCTCOG adopted the 41-city area's 2045 regional transportation plan, which identifies goals that align with the Milo pilot and establishes a more comprehensive framework for AV planning and implementation in the region.[4]

Project Planning for Milo

In early 2017, the Arlington City Council instructed city staff to identify a route, preferred technology, and operational requirements for a shuttle pilot. The regulatory environment in Texas has been encouraging of automated vehicle deployments, and City of Arlington staff did not need to receive permission from the State of Texas before the project's start. The project also did not require an FMVSS waiver because the vehicle did not operate on public roads. Rather, the Milo operated on off-street pathways on city-owned land.

City staff launched the service in August 2017, after 7 months of site assessment, modest infrastructure enhancements, and development of operational and safety protocols (in conjunction with EasyMile and First Transit). During those 7 months, city staff also worked on procurement, contracting, safety attendant training, and coordinating with law enforcement.

[4] North Central Texas Council of Governments, Mobility 2045. http://www.nctcog.org/trans/plan/mtp/2045.

Planning for Subsequent Initiatives

In October 2018, the City of Arlington began Phase 2 of its AV effort with on-street services provided by Drive.ai. This time, it chose its vendor through an RFP for turnkey operations and tapped CMAQ funds allocated by NCTCOG. This was Drive.ai's second deployment in North Texas; the first was a short self-funded pilot within a business park in nearby Frisco. Drive.ai's service ended on May 31, 2019, as a result of Apple purchasing the company. A total of 765 automated trips was provided during the length of the pilot.

Separately, NCTCOG approved a three-part initiative providing a total of $30 million for automated vehicle deployments (including LSAVs). These funds would support its member cities in managing deployments, planning initiatives, and developing strategies for AV readiness, including management of revenue, parking, and curbside impacts.

Procurement and Preparation

For the Phase 1 Milo shuttle, the City of Arlington required that the LSAV shuttle have a wheelchair ramp. Staff determined that EasyMile had the only commercially available LSAV at the time that included an automated ramp, justifying a sole-source contract. The City of Arlington then used general funds to contract with EasyMile to lease two EasyMile EZ10 Gen-1 vehicles for a total of $265,213. The cost of the shuttle's operations was funded with the Convention and Event Services account using tourism-derived revenues. This funding source reflected the City of Arlington's goal to become a technology leader in the Dallas-Fort Worth region, which has demonstrated widespread community interest in automated vehicles.

With City Council approval, the Office of Strategic Initiatives contracted with EasyMile for the vehicle and software as a 6-month lease, with an option for a 6-month extension.

The City of Arlington had initially planned to operate the vehicles themselves upon receiving them from EasyMile and getting the relevant training. However, the City of Arlington staff realized that this would be an unsustainable model and decided to contract with First Transit to handle regular operations at a stipulated number of events and to provide daily service. Arlington's Convention and Visitors Bureau issued the operations contract.

Insurance

The City of Arlington self-insured the project with backing from its government insurance risk pool. In addition, it required additional coverage by EasyMile. Within the EasyMile contract, the City of Arlington stipulated that the vendor secure appropriate general liability insurance to cover passenger service operations, and EasyMile indicated that this could be covered by its general umbrella policy. Later, the city's risk management staff determined that this level of coverage was inadequate and requested additional insurance from the vendor. This was readily resolved by EasyMile and largely resulted from differences in insurance requirements in the United States versus those required in France.

Site Assessment

Before the vehicles arrived on site, one of EasyMile's engineers identified and documented potential risks and mitigation strategies along the proposed route. This information aided in the development by the EasyMile engineer of a Site Assessment Report, which summarized EasyMile's requirements and recommendations as well as the scope and conditions of the operations on this specific site. EasyMile completed the assessment in May 2017 as a predicate to completing operational planning and launching the service in August.[5] In other projects, these

[5] The process for EasyMile's Site Assessment was described in interviews with project stakeholders.

Table D.1.2. Required infrastructure changes (excerpt EasyMile assessment).

Infrastructure Changes Required	Reason
Concrete crossing turnouts	The existing multiuse pathway is not wide enough for two vehicles to pass.
Rocks along lake edge	This gave the vehicle additional reference points to minimize risk associated with localization deviation. This path followed a small lake that had insufficient reference points for the EasyMile vehicle.
Birdhouses along path	These provided fixed reference points for the vehicle to identify its location when clear edges are not available.
Tree/grass trimming	This kept the path clear for the EZ10 shuttle and ensured that grass clippings/branches would not be interpreted as obstacles that slowed the operation of the vehicle.
Signage and path marking	This is for users of the path and shuttle riders, to help them go to the right location and to share the path with the EZ10.

steps typically occur before procurement and are an aid to defining technology requirements. In this instance, the site assessment was conducted by EasyMile and can be seen in Table D.1.2; it focused on how to adjust the proposed route (as seen in Figure D.1.4) to meet the vehicle's requirements, namely

- Impediments to vehicle localization; and/or
- Issues that could cause the vehicle to unnecessarily perform emergency stops, like the clearance of surrounding plants, bridge structures, open fields, and the steepness of the grade.

Infrastructure Requirements

In its Site Assessment Report to the City of Arlington, EasyMile recommended a series of changes to the physical infrastructure. EasyMile did determine that the digital infrastructure was sufficient to deploy the service as the vehicle had been designed so it could operate on existing 4G networks and GPS service. Further, the City did not include testing of dedicated short-range communications (DSRC) and related RSUs as part of this pilot. Note that this route did not include traffic signals.

Infrastructure modifications are summarized in Table D.1.2.

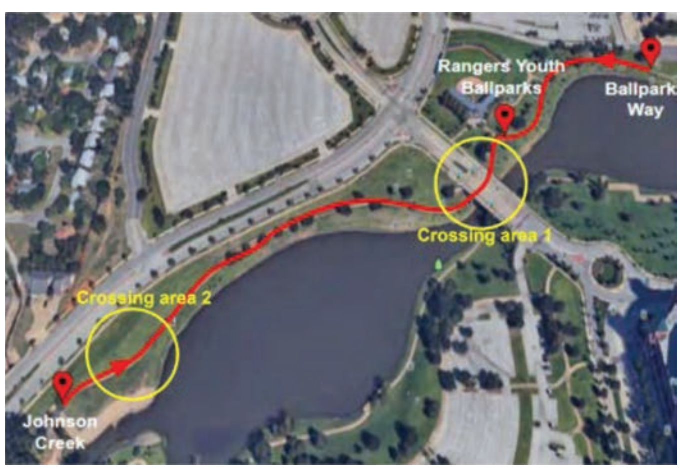

Figure D.1.4. Milo route map.

Operations

As stated, First Transit was contracted to provide regular operations support for the shuttle. As the operator, First Transit developed operating and safety protocols including[6]

- Developing roles and responsibilities for an operations team.
- Creating a daily operational schedule.
- Developing a service and maintenance plan (based on guidance from EasyMile).
- Setting emergency guidelines and protocol (based on guidance from EasyMile).
- Developing and conducting operator training and certification (based on guidance from EasyMile).
- Operating the service (based on guidance from EasyMile).
- Reporting key performance indicators.

For daily operations, First Transit dispatched the two vehicles, operated them during the stipulated hours during events at the Entertainment District, and performed regular preventative maintenance. Consistent with EasyMile guidance, First Transit performed a graffiti/vandalism check, cleaned inside surfaces with Lysol, and sprayed down the vehicle on a regular basis. First Transit also hired and trained safety attendants to monitor operations in the vehicle during regular service.

First Transit and City of Arlington operators manually logged passenger counts, the number of soft and emergency stops, and errors/disengagements in a Google Form that could be accessed by EasyMile, the City of Arlington, and First Transit. Each of the project partners could log in and access the data when necessary. Separately, the vehicles had a black box that recorded software error information, which could be accessed by EasyMile. The City of Arlington did not receive this LSAV performance information.

EasyMile provided technical support for the City of Arlington and First Transit, especially at the start of the pilot. It provided the vehicle specifications, instructions on operation and maintenance, and offered certification courses and training documents for safety attendants. The First Transit operations manager used these materials from the vendor to provide a 5-hour training course for new safety attendants.

The City of Arlington arranged storage and electric charging for the vehicles. One vehicle was kept at the convention center and one was kept at Globe Life Park. In both locations, the vehicles were charged on wall outlets at no additional cost to the city. The City of Arlington also secured the use of their park maintenance vehicle to provide a portable hose to wash down the vehicles in the parking lot next to where they were stored. Additionally, a City of Arlington planning department employee was trained as a certified operator to provide backup and demonstrate the technology to other stakeholders.

Safety and Safety Training

EasyMile provided detailed specifications and instructions on how the EZ10 Gen-1 vehicle worked. First Transit adapted best practices from its rail operations, including standardized protocols that followed checklists, dispatching, and maintenance. The City of Arlington provided oversight with an emphasis on safety.

Texas has no specific requirements for AV safety operators. At the direction of the City, First Transit developed and executed safety training for the operators. Before commencing service, the First Transit manager for this project, who was also their Lead Automated Vehicles Operations

[6] EasyMile noted in its interviews that it provides guidance to First Transit.

Manager, completed a 4-day training course with EasyMile. Based on that information, she then prepared a training program for the operators, which was adapted from other transit manuals. During this training, operators were taught how to perform normal operations. This included starting the vehicle in manual mode, switching from manual to automatic and vice versa, and getting sign-off from the lead operator. They were also taught how to evacuate riders in an emergency and call security.

Coordination with Law Enforcement, Public Safety, and Emergency Responders

Before the launch of the Milo service, planning staff briefed law enforcement, the fire department, and other first responders. The briefing included familiarization with the vehicle and information on incidents particular to electric vehicles, such as a fire with the electric motor. During operations, no incident occurred requiring contact with law enforcement or other safety or emergency personnel.

Information was obtained that a group of attendees of a baseball game shook the vehicle while passengers were inside. (Some would refer to this as "robot bullying"). The Lead Automated Vehicles Operation's Manager (as the on-board safety attendant) exited the vehicle and defused the situation. She indicated that this incident was not unlike events that occur on rail and bus in regular daily operations on rail systems. She did not contact law enforcement.

Incidents

First Transit logged all incidents and shared that information with the City of Arlington. According to the incident log reviewed by the research team, there were interruptions involving the automated driving feature, though none resulting in serious injury. The typical incidents related to loss of localization, especially under a bridge, challenges navigating a section of path with limited clearance, and interference from debris in the path.

In one incident, the vehicle failed to maintain speed along a stretch of steep incline. EasyMile engineers were dispatched to review the vehicle's operation, and after that incident, they recommended that only 10 passengers be included in future shuttle rides to reduce weight and facilitate higher speeds.

Project Evaluation

The Milo shuttle was intended to be an innovative transportation project, showcasing automated technology to a wide variety of regional residents and visitors to the Entertainment District. In the City of Arlington's words, the specific goals were to (1) test automated vehicle technology in a real-world setting and (2) educate the public and raise awareness of automated vehicle technology. The City of Arlington determined that the pilot met these goals over the course of the year-long operation and estimated that over 1,600 rides were provided across more than 110 events.

Key quantitative indicators collected included

- Number of Rides
- Number of Passengers
- Number of Disengagements
- Number of Events Served

User Acceptance

The City of Arlington aimed to expose residents and visitors to automated technology in order to both gain familiarity with automated technology and to understand how riders experienced the service. The City of Arlington conducted surveys of riders during the year-long pilot. Among those who rode the Milo shuttle, 99 percent enjoyed their experience and felt safe. 97 percent of riders who were surveyed support the use of AV technology more broadly. Other comments noted that the experience had changed their perception of automated technology and expressed a desire for the City of Arlington to expand the service area. The City of Arlington did not survey nonriders.

Automated Technology Performance

The City of Arlington reported that overall performance of the LSAV technology met its goals. First Transit and the City of Arlington indicated that there were frequent vehicle stops and disengagements caused by grass trimmings and other obstacles on the path. Further, when Milo passed under the AT&T bridge, the vehicle would lose GPS localization, which sometimes resulted in the operators shifting to manual operations.

Transportation System Integration

Milo was a 1-year pilot project in an off-street campus environment, with a clearly defined use case and a public educational mission. The City of Arlington did not charge fares and did not integrate the Milo service with other regional transportation services. In the future, its staff anticipates integrating automated shuttle services with other on-demand options (e.g., Via) in a single platform/app.

Rider Accessibility/Universal Design

The City of Arlington selected the EasyMile EZ10 Gen-1 shuttle because the vehicle has an automated wheelchair ramp, allowing it to accommodate wheelchair users. The vehicle did not have tie-downs. The vehicle also did not include assistive technology such as a human–machine interface allowing for people to communicate directly with the vehicle through haptics, display screens, or voiced communications from Milo. An attendant was available to answer passenger questions.

Lessons Learned

The City of Arlington identified a series of lessons learned:

A contract with a third-party operator for operation of low-speed automated vehicles is crucial. Given that the City of Arlington had no transportation operations services, it recommends a turnkey operation with one contract for vehicles and for operations.

Staff continuity in on-board attendants can be difficult for event-based service with irregular hours. The City of Arlington experienced high turnover among on-board attendants. This may be attributable to the irregular hours, combined with relatively low pay. Operators can prepare for this in their training and service plans.

Site assessment and mapping are required before initiating service. The site or route assessment will reveal any requirements for infrastructure modification. In the case of Arlington, EasyMile noted that the absence of firm edges typically provided by the built environment, whether curbs or buildings, was not present. Accordingly, Arlington installed landscaping features to help with localizations.

Practitioners need to plan for maintenance and repair of vehicles. Staff from the City of Arlington recommended ensuring that parts are available locally and having towing equipment available if vehicle repairs are needed.

Off-street, event-based shuttles can operate in an off-street operating environment. The City of Arlington found that the EZ10 functioned satisfactorily for event-based services on the

Source: K. E. Schaefer, A. N. Foots, and E. R. Straub, "Applied Robotics for Installations and Base Operations: User Perceptions of a Driverless Vehicle at Fort Bragg," Presented at U.S. Army Research Laboratory, January 2018.

Figure D.2.1. ARIBO Fort Bragg LSAV shuttle.

off-street paths of the Entertainment District. Residents and visitors experienced the technology. Arlington reported that the pilot demonstrated value in transporting people from the stadium to remote parking. The service was particularly valuable for those susceptible to Arlington's more extreme heat in the summer.

D.2 ARIBO Program at Fort Bragg Case Study

Project Profile

The Applied Robotics for Installations and Base Operations (ARIBO) project was first conceived in 2011. The ARIBO program introduced automated ground vehicle systems into a semi-controlled environment. Pilots were selected based on a high potential for the automated ground system to perform a task safely and reliably as well as to add quantifiable value to the selected installation. The objectives for ARIBO include

- Socializing users and nonusers with automated systems.
- Identifying operational challenges and mitigation strategies, and generating empirical data including, but not limited to, performance, reliability, and maintenance.

Collaboration with Industry and Other Federal Agencies

ARIBO was intended to accelerate the practical use of automated vehicles. ARIBO became the first significant implementation of automated vehicles to provide transportation services in the United States. The program started early demonstrations to stakeholders in 2014 using Cushman-Robotic Research shuttles (depicted in Figure D.2.1) and was led by the United States Army (Army) and the Army's Tank Automotive Research, Development and Engineering Center (TARDEC). The Fort Bragg project was the first full implementation, in which "Wounded Warriors" were transported to their medical appointments at Womack Army Medical Center (WAMC) (see route map in Figure D.2.2). "These frequent, short-distance door-to-door trips between the medical barracks and appointments at the medical center provided an environment to better understand the systemic impacts of driverless vehicle integration."[1]

[1] Schaefer, Kristin, et al., "Applied Robotics for Installations and Base Operations: User Perceptions of a Driverless Vehicle at Fort Bragg." Army Research Laboratory, Jan. 2018, https://apps.dtic.mil/ditch/tr/fulltext/u2/1044446.pdf.

Figure D.2.2. ARIBO Fort Bragg route map.

This implementation site was a roughly 1-square-mile area. The route included five pick-up/drop-off locations. The ARIBO Fort Bragg project overview is in Table D.2.1.

Geographic Context

Fort Bragg is an Army base in North Carolina. It has an on-base residential population of 29,183, and 50,000 active duty personnel work there, making it one of the largest bases in the world. It is home to several departments and groups with diverse mobility needs. Notably, it is the site of a Warrior Transition Battalion, one of nine used by the Army, which aided the transition of injured soldiers to subsequent opportunities. The area is a humid subtropical climate. Winters tend to be mild, though some snowfall occurs. Summers, however, can be quite hot with July average temperatures in the 90s with high humidity. The base covers 251 square miles with on-base transportation primarily being individual automobiles.

ARIBO at Fort Bragg represents a confluence of military research and development into automated vehicles and systems (such as the DARPA Grand Challenge) and the increasing traffic problems at military bases. TARDEC led the development of this program to further commercialize and use applied robotics to solve real challenges for the military.

Table D.2.1. ARIBO LSAV shuttle overview.

Topic	Applied Robotics for Installations and Base Operations (ARIBO) Fort Bragg Project
Use Case	Paratransit (on-demand route)
Route Description	Defined routes with on-demand service with 5 stops inside a military base
Vehicle Capacity	3, but ridership was 1 passenger normally + safety attendant
Speed	Max speed 25 mph, average speed 8–10 mph
Operator	Robotic Research
Vehicle Provider	Robotic Research
Fort Bragg Project Team	Army, Fort Bragg Transportation, WAMC, TARDEC, DOT ATTRI, Comet, UMTRI, University of MI SMART
ARIBO Project Team	Army, TARDEC, Induct/Navya, NASA, Stanford, SLAC, DOE, DOT, West Point, Comet, UMTRI, University of MI SMART, UTARI, TTI

Photo courtesy of *Northwest Florida Daily News*.

Figure D.2.3. Military-base-related congestion in NW Florida.

Transportation Challenges at United States Military Bases

In the United States, military bases are closer in scale to small cities with correspondingly high population densities. They have the same problems of traffic congestion (Figure D.2.3) and parking constraints that exist in other cities.[2]

One of the goals of ARIBO was to explore how automated transportation could decrease the need for individual vehicles on base. The approach was to add more travel options so that individuals could explore public transit options such as shared vans and other carpooling. ARIBO was intended to introduce the shared mobility concept to a military base and accelerate shared usage in the future.

Better Management of Vehicle Fleets Through Sharing

The Army has an extensive fleet of vehicles, over 50,000 in total. Most of these are passenger vehicles. Expanded sharing of these assets has been discussed to make this fleet more efficient. Automated shuttles and vehicles were suggested to facilitate that process—another reason for implementing ARIBO at Fort Bragg.

Economic Development and Innovation

ARIBO was also considered to bolster innovation and economic development in high-growth industries. Proponents argue the program could spark the development of new markets and facilitate advanced manufacturing in batteries, automated technology, and vehicle platforms.[3, 4]

Planning

Fort Bragg was selected for the first ARIBO implementation because of its distinct transportation needs and use cases. As noted previously, Fort Bragg is the site of one of the largest of nine Warrior Transition Battalions. The WAMC and the barracks associated with the Warrior

[2] A 2011 report highlighted worsening traffic congestion as a significant issue inhibiting military efficiency.
[3] Clothier, Corey, "ARIBO Robotic Vehicle CPS Test-Beds in 2014," https://smartamerica.org/wp-content/uploads/2014/05/ARIBO.png.
[4] Defense Advanced Research Projects Agency (DARPA), "The DARPA Grand Challenge: Ten Years Later," Mar. 13, 2014, https://www.darpa.mil/news-events/2014-03-13.

Transition Battalion are close in proximity, but still too far for some people to walk (especially those with mobility challenges). Additionally, traditional shuttle service results in long travel and wait times for the Warrior Transition Unit service members. As a result, service members missed medical appointments, costing the Warrior Transition Battalion money and time while the service members lost the opportunity for much-needed care.

Planning, Permitting, and Procurement

Phase 1 of the ARIBO project started in May 2016, with Phase 2 initiated in January 2017. Procurement was handled through military contracts, primarily making use of appropriated research and development dollars. The planning for the ARIBO project was unique regarding the permitting process. Military bases are given wide latitude to modify their physical environment at the discretion of the Installation Commander. Further, common U.S. DOT regulations, local land use, and municipal codes do not apply. As a result, ARIBO was not required to follow the approval processes of typical civilian agencies or private landowners.

There were some specific requirements for implementing ARIBO at Fort Bragg. Permission had to be obtained from multiple organizations on Fort Bragg (transportation, hospital, legal) and ultimately the Installation Commander had to approve the ARIBO pilot.

Insurance was provided by the automated vehicle vendor with support of the ARIBO team identifying an insurance company. One outcome of the project was to accelerate the development and issuance of commercial automated vehicle insurance by identifying and partnering with a reputable insurance company to issue a policy.

ARIBO procured a set of Cushman-6 shuttles and contracted with Robotic Research, an automated technology vendor to outfit the shuttles with automated driving sensors and software.

Site Assessment

The ARIBO team worked with Fort Bragg planners and leaders to assess and determine the optimal route to meet the ARIBO objectives and provide the most benefit to Fort Bragg stakeholders. The selected route covered the distance between the medical barracks and the WAMC. The route included

- A mix of private roads and parking lots and a signalized interchange.
- Stops (5 in total) ⅓- and ¾-mi intervals at designated routes between the barracks and the WAMC.
- Pedestrian sidewalks.
- A crossing of a four-lane divided road, which had several blind spots.
- Traffic circles at the WAMC entrances.

Infrastructure Requirements

Stationary LiDAR sensors were installed to cover the blind spots and augment the perception sensors on the shuttles. No major physical infrastructure changes were made.

Operations

Program operations were planned and managed by Army personnel. A TARDEC consultant led initial operations and planning in conjunction with the University of Michigan's Connected Vehicle Proving Center and Transportation Research Institute SMART (Sustainable Mobility & Accessibility Research & Transformation) teams.

Regular operations for the program were from Monday to Friday between 8:00 a.m. and 3:30 p.m. The operations team stored and charged vehicles in the parking structure next to the Warrior Transition Battalion barracks.

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Accessibility

Many of the passengers were injured and needed a vehicle that could accommodate their mobility limitations. As a result, the vehicles were wheelchair accessible. Human–machine interaction deployed to aid accessibility were discussed to include screens showing vehicle and route status.

Safety Testing and Automated Development

Before the pilot was operational, extensive testing was carried out for the project to ensure all requirements were met and program goals could be safely executed. Project leaders decided to phase in the self-driving features over time to build trust in the safety of the automated systems.

Phase 1 of the project was a human-driver-operated shuttle service using the Cushman-6 shuttles. During this phase, vehicle data and driving data were collected for testing the underlying architecture and autonomy algorithms. This was described as having a dual purpose. First, because a trained human driver operated the vehicle, ARIBO staff was able to evaluate the performance of the sensing and control systems in real-world conditions without increasing risk to any passengers. Second, they were able to not only evaluate the vehicle's performance against real-world conditions but also compare performance and decision making against the human-driven baseline using a recording scheme and automated analysis based on researcher-defined upper and lower limits of acceptable performance. Results of the analysis provided data for the decision to proceed to the next phase of the project.

Phase 2 of the ARIBO project transitioned the role of the driver to a safety operator. The role of the safety operator was to intervene with the vehicle's autonomy only in case of an emergency or potential vehicle error. The comparison of the human-operated system versus the automated system found that the system reliability was comparable and that AVs adhered to the rules of the road at a level comparable to human drivers. The vehicle was subsequently developed further for the commercial market.

Project Evaluation

The main goals for the project were demonstration of the technology as a viable form of transportation and further development of the automated technology. There was limited ridership, with only 112 riders during Phase 1 of the program and only 15 riders during Phase 2, but data were collected, analyzed, and reported.

User Acceptance

A survey of users of the vehicle demonstrated the following:

- 88 percent were positive on the vehicle's perceived intelligence
- 85 percent were positive on perceived autonomy
- 81 percent were positive on perceived trustworthiness
- 77 percent were positive on perceived safety
- 69 percent were positive on perceived usefulness

Automated Technology Performance

The automated control software performed well, and participants were generally satisfied with the vehicle's ability to follow traffic laws and navigate through parking lots and intersections. No incidents occurred during the pilot as a result of the AV technology or external factors impacting the shuttle.

Transportation System Integration

The ARIBO on-demand shuttle operated independently of other transportation systems on base and focused solely on transporting people to/from/within the WAMC and nearby barracks. It continued to operate in this capacity through the duration of the ARIBO pilot.

Rider Accessibility/Universal Design

The customized design of the Cushman-6 shuttle by the vendor provided an accessible design and wheelchair accessibility as a central objective. The vehicle operated as fully wheelchair accessible. However, more than one person mentioned that there was insufficient legroom in the second row for tall passengers or those with serious injuries.[5]

Lessons Learned

The initial ARIBO pilot at Fort Bragg tested a use case for LSAVs that is applicable to military bases and civilian contexts. The processes, research, and lessons learned formed the basis for additional pilots, early safety operational practices and standards, development of an automated vehicle data recorder and analytics tool, and led to the creation of an automated vehicle insurance product.

Further, the Army and other ARIBO partners made the following observations about lessons learned from this project:[6]

Users believed that the automated capabilities of the ARIBO vehicle were acceptable or would be in the future. Those who doubted safety had only a minimal level of understanding of the system's operations, suggesting further education would help increase trust.

Design features to improve passenger comfort for wounded soldiers would improve comfort and safety for all riders. These improvements include improving seats, extending legroom, safety belts, and effective communication of safety features and options.

Additional alerts or warnings would improve pedestrian safety. This includes verbal (auditory) acknowledgment when the vehicle is paused for a pedestrian, sounding a horn to let pedestrians know the vehicle is waiting for them, or providing signs explaining that this is a driverless vehicle.

Discrete design modification could increase passenger trust or confidence. These changes would communicate in multiple ways that a vehicle is driverless. This could include changes to vehicle size, color, and signage that allow the vehicle to communicate with other road users.

The vehicle system would benefit from a user display. This display would communicate vehicle awareness and actions, including navigation-specific feedback (e.g., estimated arrival time, changes in behavior or routes), error reporting (e.g., ability to report issues or errors, count of errors), and a means to communicate to a human monitor.

The ARIBO program developed automated vehicle technology across the country. Members of the team have consulted widely, including pilot projects in seven states across the United States and sites in two other countries. The project has also influenced the SAE Automated Vehicle Safety Consortium, impacting standards development. The project has led to the development of automated vehicle performance measuring tools and influenced the development of the first automated vehicle insurance product. In addition, the introduction of automated shuttles into the U.S. market (e.g., Navya, EasyMile, and Local Motors) began with ARIBO's demonstrations on military bases.

[5] Schaefer, Kristin, et al., "Applied Robotics for Installations and Base Operations: User Perceptions of a Driverless Vehicle at Fort Bragg." Army Research Laboratory, Jan. 2018, p. 16. https://apps.dtic.mil/dtic/tr/fulltext/u2/1044446.pdf.
[6] Ibid.

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Figure D.3.1. AAA self-driving shuttle.

D.3 Las Vegas AAA Free Self-Driving Shuttle Case Study

Project Profile

Beginning in 2017, the City of Las Vegas (City) and the Regional Transportation Commission of Southern Nevada (RTC), along with Keolis North America (Keolis) and the American Automobile Association Northern California, Nevada and Utah (AAA), operated the nation's first public transit AV service in mixed-use traffic on a downtown loop. A single Navya ARMA low-speed automated vehicle (Figure D.3.1) provided rides to residents and Las Vegas visitors in mixed-use right-of-way and transit-like driving conditions. The shuttle operated for 1,515 hours and had an overall ridership of 32,827 during the pilot.[1]

AAA's main goals for the pilot were

1. Gauge the public's satisfaction and acceptance of automated vehicles.
2. Gather relevant rider feedback for the service itself.

In addition, The City focused on how DSRC, connected vehicle, and infrastructure technology that was under development for the Las Vegas Valley would be relevant in the case of shared AV service. The City and AAA shared the objective of implementing a regular service geared for the general public to gain real-world experience of the technology. Both the City and AAA report that their goals were met.

Geographic Context

With a population of over 600,000, Las Vegas forms the center of a metro area of more than 2 million people. At least 42 million people visited the Las Vegas Valley (Valley) in 2019,[2] making it one of the most popular tourist destinations in the United States. The Las Vegas Strip to the south attracts most of the Valley's tourists with its well-known entertainment and resort locations. In recent years, the City rebranded its downtown as an Innovation District and undertook revitalization efforts centered on Fremont Street. The City hopes to leverage Zappos' headquarters to develop a more vibrant tech economy downtown. The City also looks to enhance its other efforts to build the district with innovative transportation technology, including automated vehicles.

The AAA Free Self-Driving Shuttle operated in a 0.6-mi fixed route (Table D.3.1) in downtown Las Vegas near Fremont Street, with three fixed stops and no fare. The shuttle ran in a

[1] Bell, Maurice, Personal Interview. Keolis North America. Dec. 2018.

[2] Las Vegas Convention and Visitors Authority, "Las Vegas Visitor Statistics." https://www.lvcva.com/stats-and-facts/visitor-statistics/.

Table D.3.1. AAA LSAV shuttle overview.

Use Case	Shuttle (on-street)
Route Description	1 fixed route on a closed loop, 3 stops
Route Lengths	0.6 mi
Vehicle Capacity	15 (11 seated; 4 standing)
Speed	15 mph max speed, 8 mph average operating speed
Operator	Keolis
Vehicle Provider/Vendor	Navya
Project Managers	City of Las Vegas
Next Stage	GoMed shuttle, funded by U.S. DOT BUILD grant

loop along Fremont, South 8th Street, East Carson Avenue, and South Las Vegas Boulevard and crossed eight intersections, of which six had signals (Figure D.3.2). The shuttle typically operated at speeds of less than 10 mph.

Except for very hot days in the summer, interest was high and there was usually a line to ride in the shuttle, with ridership consisting primarily of visitors to Las Vegas.

The City has a subtropical desert climate, with extremely hot summer days. Furthermore, heat affected LSAV performance, particularly the battery life, which was diminished significantly by air conditioning constantly running on high.

Transportation Context

The City and RTC have been planning for years to improve public transportation in the Las Vegas metropolitan area, especially in the congested corridor along the Las Vegas Strip and around downtown Las Vegas. Downtown Las Vegas is currently accessible by I-15 and I-515, as well as numerous other surface streets. Since 2004, RTC has been expanding a system of bus rapid transit lite express services (known as MAX), with enhanced shelters, limited stops, and transit

Figure D.3.2. AAA LSAV shuttle route.

signal priority. It is currently undergoing a transit planning process called OnBoard, asking for input from the community on future service.

In the past few years, during January when Las Vegas hosts the Consumer Electronics Show, Las Vegas has become the center of the transportation technology world. At this large-scale event, Las Vegas has hosted numerous demonstrations of AV technology.

The AAA Free Self-Driving Shuttle project represented the convergence of an active and willing private sponsor and an interested local government that had already been working with a transport operator (Keolis) and automated shuttle vendor (Navya). Las Vegas was an appealing location to hold the pilot given the large number of tourists who would be exposed to the service as well as a state and local government eager to test the technology and demonstrate its value in a real setting.

The next phase of the City and RTC's LSAV pilots, branded "GoMed," will be a 4.5-mi shuttle to connect downtown Las Vegas and a nearby medical campus (Figure D.3.3). This project was awarded federal funding through a BUILD grant of $5.3 million in December 2018 and dubbed the Las Vegas Medical District Automated Circulator and Pedestrian Safety Project. The project includes enhanced stop shelters and pedestrian improvements, as well as automated vehicle service. Four vehicles will serve the shuttle route providing both a downtown circulator and point A to B shuttle between downtown and the medical campus across I-15.

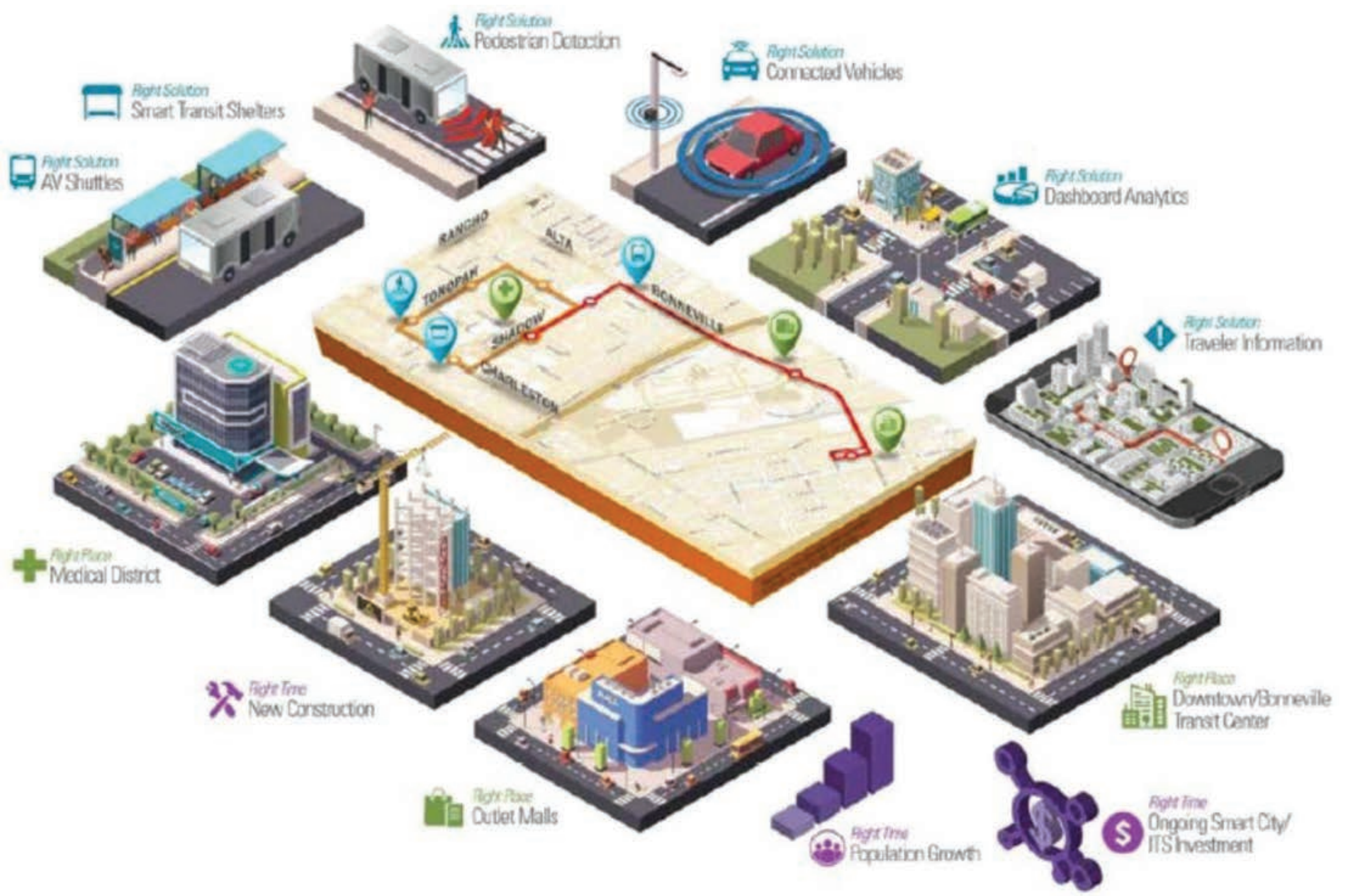

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Figure D.3.3. GoMed schematic.

The project's goal is to connect residents "to healthcare, employment, education, and other vital services."[3]

In addition to the GoMed shuttle project, the Las Vegas area is also hosting a robo taxi project jointly done by Lyft and Aptiv. Aptiv is providing BMW vehicles modified with its automated software to be placed on Lyft's platform. This project started in January 2018 and remains ongoing, surpassing 50,000 total rides as of June 2019.[4]

Planning

The State of Nevada, the RTC, and the City of Las Vegas have each engaged in a multiyear planning and policy effort to advance smart mobility, including LSAVs. The Department of Motor Vehicles by statute has immediate regulatory oversight of all types of AV deployments and has created a permitting/licensing process for AVs. Nevada has special licensing and Research and Development plates for registered vehicles.[5]

As part of an economic development effort, the Department of Commerce and a special advisor to the Governor are charged with promoting smart mobility initiatives to accelerate advanced technology in Southern Nevada.

Metropolitan Transportation and Mobility Planning

The RTC serves as the Las Vegas MPO, leads the traffic engineering system, and manages public transit operations in the urbanized area. RTC and the City have been investing in connected vehicle infrastructure in line with state policies to promote AVs. The RTC has reflected AV technology in its long-range transportation plan. Adopted in 2017, Access 2040 mentions the potential impacts of AVs on the regional transportation system and includes AV mode share as a 2040 transportation system indicator under the secondary strategy of innovative planning and emerging technologies. In its maintenance program, RTC calls for maximizing pavement quality, improving lane markings, and lane narrowing (potentially) in preparation for automated vehicles.[6]

The City and RTC are also working in the short term to improve the regional transportation system and bolster the deployment of AVs. Within the region, there are three main transportation programs to bolster innovation:

- DSRC regional network: The City has equipped over 70 intersections in downtown Las Vegas with this technology. Clark County, in partnership with Aptiv, outfitted an additional 43 intersections along the Las Vegas Strip with DSRC.
- Automated vehicles: RTC and the City seek to expand AV piloting to enhance mobility, especially downtown and between key activity nodes.
- Other transportation improvements: RTC is implementing bus rapid transit expansion along key corridors.

[3] Regional Transportation Commission of Southern Nevada, "RTC, City of Las Vegas Receive $5.3M Federal Grant for Downtown Autonomous Circulator Project." *Mass Transit*, Dec. 11, 2018, https://www.masstransitmag.com/alt-mobility/autonomous-vehicles/press-release/21036657/regional-transportation-commission-of-southern-nevada-rtc-rtc-city-of-las-vegas-receive-53m-federal-grant-for-downtown-autonomous-circulator-project.

[4] Korosec, Kristen, "Aptiv's Self-Driving BMWs Have Made More Than 50,000 Rides on the Lyft App in Las Vegas." *TechCrunch*, June 3, 2019, https://techcrunch.com/2019/06/03/aptivs-self-driving-bmws-have-made-more-than-50000-rides-on-the-lyft-app-in-las-vegas/.

[5] Nevada Department of Motor Vehicles, "Autonomous Vehicle Testing Registry Application." https://www.dmvnv.com/pdfforms/obl326.pdf.

[6] Regional Transportation Commission of Southern Nevada, "Access 2040: Enhancing Mobility for Southern Nevada Residents." Feb. 9, 2017, p.15.

In addition, the City has established an innovation district branded as "Innovate Vegas." This initiative has focused on economic development and exploring new AV options to bring people to destinations and employment in the vicinity.

Project Planning

By mid-2017, the City sought to expand from demonstrations to a longer-term pilot of AVs. At the same time, AAA wanted to find a city to sponsor an AV shuttle project designed to study the public's perception after they gained firsthand, real-world experience with AV technology. AAA's objective in sponsoring a public "self-driving" shuttle was to demonstrate the potential for automated driving technology to improve traffic safety and potentially reduce the more than 37,000 traffic fatalities annually. AAA, Keolis, and the City joined together in a public–private partnership to plan the shuttle in a loop route downtown. Keolis and the City executed a contract for the shuttle operations.

AAA hired technology deployment specialists to identify the use case, transportation market, and technology partners. Keolis was hired to develop a concept of operations and to run the year-long pilot. The City Engineer served as the overall project manager from the City, and the RTC played a coordinating role given its operational responsibilities for the transit system and traffic engineering system.

AAA had key requirements for this pilot project; these included that the service needed to be permitted per local regulations, and the project had to have support from a local agency and sponsor. To boost visibility and ridership, the technology also had to meet the requirements of the site, which was in an area of high foot traffic. All of AAA's considerations were met by the City, and the Navya vehicle was well suited to the busy downtown district, which had large numbers of tourists who would be introduced to the technology.

The City and RTC wanted the service to be tested with the new DSRC network to inform their future investments in support of automated vehicle deployment.

Procurement and Preparation

AAA Northern California, Nevada, and Utah funded the project. The City contracted with Keolis to provide a 1-year pilot service along the downtown loop to demonstrate this technology, using one Navya ARMA shuttle vehicle (now rebranded as AUTONOM).

Permitting and Waivers

Navya required two levels of permission—federal and state—for its vehicle to operate on public roads and to provide rides in Las Vegas. Navya sought approval from NHTSA to operate on public roads.[7] Keolis and Navya also were required to register and license the vehicle with the state of Nevada.[8]

Navya's AUTONOM shuttle does not have side mirrors, a brake pedal, and a driver's seat as required by FMVSS. Navya completed an FMVSS gap analysis, explaining which specific sections the vehicle does not meet, and demonstrating how they can still meet an equivalent level of function and provide an equal level of safety. For example, the eight LiDAR sensors provide much

[7] National Highway Traffic Safety Administration, "Importation of Motor Vehicles and Motor Vehicle Equipment Subject to Federal Motor Vehicle Safety, Bumper, and Theft Prevention Standards." https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/hs7_r.v.7.pdf.

[8] Nevada State Legislature, Nevada Revised Statutes Chapter 482A—Autonomous Vehicles. https://www.leg.state.nv.us/NRS/NRS-482A.html.

more information about road and traffic conditions than the human eye. (LiDAR is a surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor.) The HS-7 waiver, originally intended for exotic sports cars and auto shows, had been used until recently to facilitate research through temporary trials and pilots.

Keolis and Navya met state-level requirements in Nevada in order to operate on public roads. They filed for a state permit and acquired two sets of special AV license plates for the Navya vehicle. There are no licensing requirements for the safety attendants. The City had no permitting requirements for the Las Vegas project, but law enforcement and emergency responders needed to be notified that the shuttle was operating (more in Safety Training and Coordination with Law Enforcement section).

Insurance

Insurance on the Navya vehicle was provided by three main companies:

- Zurich American for general commercial liability
- RLI for automotive vehicle liability
- Westco for workers compensation liability

Site Assessment

In this project, Navya performed the site assessment. Keolis deemed the ODD appropriate for the operation proposed for the Navya AUTONOM. The route was in mixed traffic, in a lane separated by cones. There were eight intersections of which six were signalized and two were stop-controlled. Navya further identified “a large amount of pedestrian traffic.” Average traffic speeds were low, typically below 10 mph.

Infrastructure Requirements

The main infrastructure requirement by the project team was the inclusion of DSRC RSUs. These RSUs were procured and installed by the City. There were six DSRC units along the LSAV route, and the RTC had a lead role in ensuring information technology robustness and cybersecurity.

Operations

During the trial period, the AAA Free Self-Driving Shuttle generally operated between 11:00 a.m. and 7:00 p.m. During the summer, Keolis adjusted the schedule to between 1:00 p.m. and 9:00 p.m. to avoid the heat. The extreme heat necessitated constant air conditioning, compromising battery performance and adversely impacting peoples’ willingness to wait for the shuttle outside. In August 2018, Keolis suspended operations entirely because of excessively high heat. During the period when Keolis suspended service for excessive heat, their vehicles were sent back to Navya and were retrofitted with equipment to mitigate range degradation caused by the heat. Keolis resumed service in September and October of 2019.

Mobility Service Provider

Keolis operated the AAA Free Self-Driving Shuttle. Keolis, a mobility/transit service provider operating bus and rail transit service in the United States and Europe, recruited, trained, and supervised all safety attendants during the pilot. Keolis also oversaw storage and charging of the vehicles in a city-contracted facility. Keolis also provided AAA, Navya, RTC, and the City information on ridership, trips, and battery utilizations. Separately, Keolis provided Navya with technical disengagement reports and other logs. Neither the City, RTC, nor the project sponsor AAA received these reports on disengagements or other incidents.

Operational Challenges

Keolis and AAA reported that, generally, operations ran smoothly. AAA noted that it was often a challenge to keep the stop locations free of transportation network company vehicles (e.g., Uber/Lyft). If there were other vehicles in the shuttle stop, the automated control algorithm would not be able to decide on another stop location, and the operator would have to shift into manual mode.

Reported wait times during peak periods often were up to 30 to 40 minutes. During periods of high heat, the air conditioning significantly affected battery range and impacted the feasible hours of operation.

Development of Safety Protocols

Navya provided specifications and other information on how the ARMA shuttle worked. Keolis developed a detailed safety operations protocol for the AAA Free Self-Driving Shuttle, based on its extensive experience in other transit systems. The RTC followed its own safety protocols with respect to transit.

Safety Training and Coordination with Law Enforcement

Keolis and AAA identified safety as a key concern for the pilot. This was reflected in the selection and training of the shuttle's in-vehicle attendants. Keolis developed an extensive training program to provide a detailed understanding of the technology and its capabilities. The company noted that this allowed the attendants to be ambassadors for the technology and to provide an additional layer of safety. AV operators received certifications upon completion of the training.

Keolis briefed law enforcement officers and first responders at a workshop on the vehicle's technology as well as planned operations before the launch of the service. The workshop focused on what to do in the case of crashes and whom to contact in the case of an incident. It involved training the fire department on how to respond to an electrical vehicle fire, including whether to use water. Keolis explained how police could get footage from the vehicle in case it was needed for investigation.

A later review by the City indicated that training should be extended to other law enforcement personnel who might cooperate in a joint emergency response. The need for this training was made clear during the response to the attack on the Route 91 Harvest music festival in October 2017, when outside law enforcement encountered the Navya shuttle and was not familiar with its sensor setup and capabilities.

Incidents

Less than an hour into operations on November 8, 2017, a truck crashed into the Navya ARMA shuttle. No one was injured and no other serious safety incidents were recorded. After a review of the data, Navya indicated that the automated control software performed as designed, and no changes were needed in the algorithms.[9]

NTSB investigated the crash (HWY18FH001) "to better understand how self-driving vehicles interact with their environment and the other human-driven vehicles around them." They note that "while there have been other crashes of self-driving vehicles, this crash is the first of a self-driving vehicle operating in public service. Our decision to investigate this crash aligns

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[9] Other analysts raised the consideration that a more adaptive algorithm and louder horn may be needed in a mixed-traffic environment where dealing with driving culture and communicating with people on the road is necessary to stay safe. Bigelow, Pete. "Self-Driving Shuttle Returns to Service, but NTSB Wants to Examine Vegas Crash." *Car and Driver*, November 13, 2017. https://www.caranddriver.com/news/a15339189/self-driving-shuttle-returns-to-service-but-ntsb-wants-to-examine-vegas-crash/.

with our process of deciding to investigate those highway crashes that can advance our knowledge of safety issues."[10] This investigation was recently completed and the NTSB cited the truck driver's actions as the probable cause for the collision and the AV attendant's lack of easy access to a manual controller as a contributing factor for the collision. The NTSB made no recommendations as a result of their investigation but will continue to monitor the development of those vehicles to better understand their potential safety impacts and any unintended consequences.

Project Evaluation

The City and AAA both sought regular shared automated shuttle service that maximized ridership and visibility for the technology. The public partners sought to test the performance of the DSRC infrastructure and the ability of the LSAV to operate in conditions like those of public transit. AAA sought broad exposure of a successful AV operation in order to understand consumer acceptance of the technology. AAA measured this through the level of rider satisfaction in post-trip surveys.

Ridership

By the end of the pilot, over 32,000 people rode on the shuttle.

User Acceptance

The core objective of this project was to gauge the public's reaction to an AV operated as a public shared transportation on a public road. There were two surveys conducted in relation to this project. One survey was administered by AAA to survey riders on their experience while the second was an academic study by researchers at the University of Nevada–Las Vegas (UNLV).

Riders who completed the AAA survey indicated they enjoyed the experience. They recorded an average response of 4.9/5 stars. Additionally, 96 percent of the respondents stated they would recommend the service to their friends. Based on general feelings toward AVs before and after the ride, there was a 30 percent improvement on overall AV sentiment.

The UNLV research effort surveyed riders of the shuttle as well as the general population around Las Vegas, measuring their perceptions and attitudes regarding "autonomous and connected vehicles (ACVs)."[11] In general, respondents were positive about the potential of the technology with riders of the shuttle even more so. For example, 68 percent of the general population wanted to see automated transportation more widely available compared to 82 percent of shuttle riders. The researchers suggest that firsthand experience is important to alleviate negative and uncertain feelings about ACV technology and that trial periods are useful as an opportunity to build trust.

Automated Technology Performance

Keolis noted that the Navya shuttle worked as intended, with no incidents with the automated control software. The shuttle successfully navigated a mixed-traffic environment, within a lane marked with cones designated for its operation. The vehicle traveled at speeds of up to 10 mph along the fixed route, with an average speed of approximately 8 mph.

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[10] NTSB, "NTSB Launches Investigators to Self-Driving Vehicle Crash." Nov. 11, 2017, https://www.ntsb.gov/news/press-releases/Pages/PR20171110.aspx.

[11] The researchers recorded survey data from 236 respondents from the general population and 153 respondents who were shuttle riders. They used a stratified stated preference approach, with a 30-question survey of people in the general population and a 17-question survey of shuttle riders. "Perceptions and Attitudes Towards the Deployment of Autonomous and Connected Vehicles: Insights from Las Vegas, Nevada" (Submitted for TRB Annual Meeting 2020, July 31, 2019).

Transportation System Integration

The AAA Free Self-Driving Shuttle was designed as a use case that was not integrated into RTC's transit system (with either integrated fare or coordinated service and scheduling). The vehicle was integrated with local infrastructure such as DSRC RSUs. The City considered the pilot to be a useful validation of the connected vehicle DSRC units, which provided redundancy for the vehicle's positioning, and relayed information about traffic light status to the vehicle, including signal phase/timing data.

Rider Accessibility/Universal Design

The Navya AUTONOM shuttle is accessible for people using wheelchairs via a built-in ramp. The on-board attendant oversaw securing the wheelchair once it was on board the vehicle, which he or she could do manually. This vehicle did not have a human–machine interface to allow communication with passengers who had a visual, cognitive, or hearing-impaired passenger. The attendant was available to answer any questions that arose during travel.

Lessons Learned

AAA, Keolis, and the City of Las Vegas and RTC identified the following lessons learned:

- **Attendants or ambassadors helped explain the technology.** These employees, located at stops and on board, provided a critical path for disseminating information and answering questions at shuttle stops or on board the vehicle.
- **Curbside management is key.** For preprogrammed shuttles with fixed stop locations to operate smoothly, a strategy needs to be implemented to ensure that people are not double parking or standing illegally in these spots. Brand ambassadors often performed this function. AAA suggested that closer collaboration with local law enforcement would also facilitate keeping pick-up and drop-off areas available to the LSAV.
- **Heat can have a big impact on ridership and vehicles.** Because people do not want to wait on the sidewalk in the heat (or other adverse conditions), ridership may be decreased if there is not a covered shelter. Extreme heat conditions also strain electric vehicle batteries, which may impact the duration of daily operations and require more charging than expected.
- **Deployment of vehicles in mixed traffic with variable speeds may cause anxiety under 25 mph.** AAA noted that some passengers may be uncomfortable riding in a vehicle at 15 mph when surrounding traffic is operating at 30 mph.
- **Practitioners need to have a communications strategy and partnership plan with local businesses to make a new LSAV pilot a success.** Community and stakeholder engagement are key to acceptance given the novelty of the LSAVs. Prior familiarity with the vehicle and the goals of the project are especially key for all stakeholders during any crisis event.
- **Localities or practitioners need to seek incident reports from the vendor.** Stipulate this in the contractual agreement.
- **Training local law enforcement/first responders on how to respond to LSAV shuttle incidents is necessary.** To maintain safe operations during the pilot, it was important that project stakeholders had ongoing conversations with police and fire departments in Las Vegas.
- **Partnership between public entities is often necessary to get an LSAV shuttle pilot up and running.** Both the City and RTC had reasons to explore automated shuttle technology through a public pilot and had complementary skills, regarding local infrastructure and transit operations experience. Through this project, local stakeholders were more coordinated and prepared to plan for a Phase 2 shuttle to be funded through an FTA BUILD grant.
- **Vendors should share more data with project sponsors.** Navya shared technical disengagement reports and other logs with Keolis. However, neither the City, RTC, nor the project sponsor AAA received these reports on disengagements or other incidents. All three noted that this information should be shared subject to protections of Navya proprietary information.

APPENDIX E

LSAV Mini Case Studies

To complement the case studies of completed pilots found in Appendix D, the research team reviewed a wider set of 14 projects that are in various stages of planning and operation. These pilots represent a snapshot of what agencies and stakeholders are undertaking with LSAV shuttles; Table E.1 provides an overview of the projects reviewed. For each of these mini case studies, the research team summarized the stages of planning, procurement/implementation, operations, and evaluation. Interviewees provided insight into planned activities, operations, metrics, and key performance indicators.

The research team used both interviews and document reviews to capture the key elements of these pilots. These interviews were less extensive than those for the three main case studies and typically were focused on the project lead. When an interview was not possible, information was gathered from primary and secondary sources.

The mini case studies were developed as of October 2019 and statuses are current as of November 2020.

Table E.1. Mini case studies highlights.

#	Lead/ Location	Status	Use Case	Partners	Principal Objectives
E.1	City, Mountain View, CA	Planning	First/Last Mile	VTA Google LEA Elliott Apex Strategies	Connect transit employment & residential Provide competitive travel times Provide operational flexibility peak/off-peak
E.2	CCTA, San Ramon, CA	Testing Completed on Phase 1; Phase 2 underway at GoMentum, with deployment at Babcock in 2021.	Circulator First/Last Mile	EasyMile GoMentum Station AAA NorCal Local Motors First Transit	First/Last Mile Reduce GHG Economic development Minimize Road Widening
E.3	RTD, Denver, CO	Completed	First/Last Mile	LC Fulenwider EasyMile Panasonic City/County of Denver Transdev Next	Assess LSAV tech in public transit Link employment to transit

(continued on next page)

Table E.1. Mini case studies highlights.

#	Lead/ Location	Status	Use Case	Partners	Principal Objectives
E.4	JTA, Jacksonville, FL	Operational	Circulator	EasyMile Navya KPMG	Improve safety Enhance economic competitiveness Reduce GHG emissions Increase ridership
E.5	HART, Tampa, FL	Planning	Shuttle	Transdev EasyMile	Connect riders to transit hub and downtown businesses and attractions Increase transit ridership
E.6	City, Chamblee, GA	Planning	Circulator	Stantec	Connect to MARTA station and adjacent destinations Reduce parking requirements
E.7	Mcity, Ann Arbor, MI	Operational	Shuttle	University of Michigan Navya	Understand consumer acceptance Assess various ODDs
E.8	Bedrock, Detroit, MI	Operational	Shuttle	May Mobility	Improve/increase frequency for an employee shuttle to remote parking Demonstrate viability in mixed traffic Test innovative autonomous technology and brand Detroit as a mobility technology leader
E.9	City, Grand Rapids, MI	Operational	Circulator	May Mobility	Mobility for the elderly and people with disabilities Test LSAV interactions with other road users
E.10	Smart Columbus, Columbus, OH	Operational	Circulator	May Mobility	Connect downtown to museums and employment Provide shuttles to inexpensive remote parking Introduce Autonomous Service
E.11	RIDOT, Providence, RI	Operational	First/Last Mile, Shuttle	May Mobility	First/Last Mile Expand access to economic opportunities Test the feasibility of a public LSAV service
E.12	City, Frisco, TX	Completed	Circulator	Drive.ai Frisco Station DCTA	Attract tenants with mobility amenities Demonstrate circulator service value for future transit Demonstrate safety of LSAV operations Learn about LSAV technology Reduce car use for midday errands, eating out

Table E.1. (Continued).

#	Lead/ Location	Status	Use Case	Partners	Principal Objectives
E.13	Houston METRO, Houston, TX	Operational Next Phase Sept. 2021	Shuttle	EasyMile Texas Southern University	Test LSAV technology integration in public transit Introduce the LSAVs to community
E.14	UDOT, Salt Lake City, UT	Completed	First/Last Mile, Circulator	UTA EasyMile WSP	Improve access to rapid transit rail Understand how the Utah Transit Agency can integrate this technology with larger network Demonstrate the feasibility of serving each use case

E.1 Mountain View AGT Studies for Shared AV Transit

City of Mountain View, Valley Transit Authority (VTA), Google Mountain View, CA

Project Profile

The project will provide fixed-route LSAV shuttles or medium-capacity transit vehicles on a dedicated lane that connects the North Bayshore office district (a.k.a. Googleplex) with downtown Mountain View and first/last mile service to rail stations. This project anticipates a regular or permanent deployment of LSAVs on dedicated roadways, which may include fixed guideways that will mitigate congestion by increasing travel choices. Planning assumptions contemplate headways of approximately 30 seconds with a 20-passenger vehicle.

The project goals include

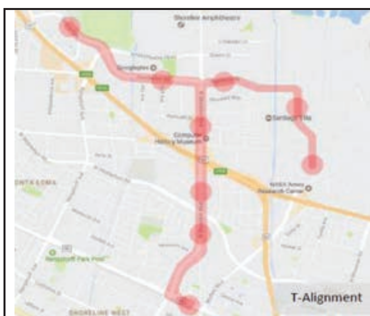
- Connect major transit stations with nearby employment/residential.
- Limit impacts on existing built environments.
- Provide highly competitive travel times compared to auto and traditional transit service.
- Provide operational flexibility to change operating modes peak/off-peak.

The City of Mountain View (City) and VTA envision a low-speed service using electric vehicles capable of recharging at stations, a capacity of 20–25 passengers/vehicle, and operating in platoons on short headways with planned 25–35 mph operational speeds.

VTA is participating in Calstart Next Gen Shuttle to produce a transit-ready, accessible vehicle.

Possible routes include North Bayshore to Downtown Mountain View Caltrain/VTA station and Moffet Field VTA station.

Google Map 2019



Mini Case Study Highlights	
Status	Planning
Use Case(s)	First/Last Mile
Duration	Open-ended
Project Lead	City of Mountain View
Project Partners	VTA, Google, LEA Elliott, Kimley-Horn, Nelson\Nygaard, Apex Strategies
Vendor	TBD
Operator	TBD
Funding Source	Local, Private

Planning

In 2017, the City, VTA, and Google began planning with a review of automated mobility systems that could provide a "medium-capacity," fast, and reliable transit service to link office workers in the growing office area with existing Caltrain and VTA stations. Feasibility studies assume automated technology to connect with North Bayshore; expected ridership is 9,000 riders per day with 300 riders every 10 minutes of estimated peak-hour transfers from Caltrain and local ridership.

As part of feasibility studies, in 2017 the City held community meetings, and additional City Council study sessions were focused on technology options, corridor characteristics, and evaluation criteria. In 2019, the City also held stakeholder meetings with Mountain View Transportation Management Association, VTA, and Google. A project website was set up to provide information and updates on the studies.

Safety planning includes emergency evacuation of elevated guideways and inclusion of a dedicated guideway and lanes to limit potential hazards and increase safety. Development of protocols will occur at a later stage.

Procurement and Preparation

Procurement: The City Council approved the next phase of detailed studies and the plans are to issue an RFP in mid- to late 2019.

Federal and State Approvals: The State of California now permits on-road operation of AVs subject to appropriate approvals and reporting requirements. Both federal requirements and vehicle types are expected to change before the launch of service.

Infrastructure: The team does envision constructing physical infrastructure improvements along the selected route to include dedicated lanes, street redesign, and potential elevated guideway.

Operation and Safety Planning

Development of an SOP will occur at a later stage.

Evaluation and Data Collection

The project team is currently designing evaluation criteria for technology options to include system design, configuration, and alignment based on

- Capacity, with objectives for capacity-holding peak demand of 330 passengers (capacity must also include on-board bicycles).
- Connections to other transport modes.
- Travel time, with an objective of approximately 7–15 minutes end to end.
- Accessibility, with objectives including ADA compliance and ride comfort.
- Expandability and adaptability, including potential new route extensions.
- Environmental management factors to include impact on protected wetlands near North Bayshore area.

E.2 CCTA GoMentum Station/Bishop Ranch Shuttles

Contra Costa Transportation Authority
San Ramon, CA

Project Profile

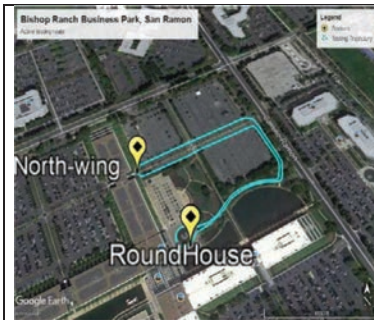
Beginning in 2016, the Contra Costa Transportation Authority (CCTA) launched a series of LSAV shuttle pilots, the first operated in the Bishop Ranch Business Park. The purpose was to test in order to evaluate LSAV technology and validate its safety. The eventual vision is using these shuttles in a first/last mile use case, especially for BART stations with limited parking. The program has not yet delivered rides to the public, and the EZMile shuttles testing at Bishop Ranch is completed. Local Motors and others are still undergoing testing at GoMentum Station. Deployment at Bishop Ranch is scheduled for 2021.

The project goals include

- Address the key first/last mile connections at BART with parking lots full by 6:00 a.m.
- Increase transit ridership.
- Reduce single-occupancy vehicle trips.
- Reduce greenhouse gas emissions.
- Increase economic development.
- Provide alternatives to freeway widening.

From 2016 to 2019, the EasyMile EZ10 Gen-1 vehicles were tested by CCTA and its consultant at GoMentum Station and on a route within Bishop Ranch Office Park. When the vehicle leases ended in July 2019, CCTA and AAA NorCal (serving as manager of GoMentum Station and project manager) took delivery of three Local Motors Olli LSAVs to continue the project. CCTA intends to expand the routes to serve BART rapid transit stations in the Bay Area.

Google Map 2019



Mini Case Study Highlights	
Status	Testing
Use Case(s)	Circulator, First/Last Mile
Duration	Open-ended
Project Lead	CCTA
Project Partners	EasyMile, GoMentum Station, Advanced Mobility Group AAA NorCal
Vendor	EasyMile Local Motors
Operator	CCTA, EasyMile First Transit Local Motors
Funding Source	State, Regional, Private

Planning

CCTA and GoMentum Station planning included

- Identifying the federal, state, city, and local approvals and permits required to operate LSAVs on public roads.
- Holding two public hearings under the auspices of the City of San Ramon. The hearings introduced CCTA's transportation goals for the LSAV testing/pilot, provided information on expanding transit accessibility (especially for underserved communities), and described the potential for increasing economic development. At that time, the California Department of Motor Vehicles regulations required a plan for interaction with local law enforcement. According to CCTA, these hearings were also done to comply with guidance from the California Public Utilities Commission (CPUC), which has the authority to issue permits for AV carriers that provide transportation services to the public.
- In 2016 and 2017, CCTA and EasyMile operated in a closed circuit at GoMentum Station, an automated vehicle proving ground, and on a closed course at Bishop Ranch.
- As part of the hazard assessment, EasyMile and CCTA identified concerns with unprotected left turns. To mitigate this risk, the required procedure for the EasyMile safety driver was to take manual control of the LSAV when not on a predetermined route and/or in the case of any unsafe behavior (of the vehicle) or external situation.
- CCTA, EasyMile, and the San Ramon Police Department developed an Emergency Plan and Accident Report Plan for pilot activities, as required by the CPUC. The outline of the emergency response is included as a resource.

The project team is assessing and planning for future pilot phases to open LSAV shuttle services to public ridership and longer routes to connect with BART and other rapid transit in the Bay Area. Specifically, the project team is pursuing approval to cross a major suburban arterial road (Camino Ramon). CCTA proposed a modified signal time to allow for safe crossing of the LSAV through the intersection.

Procurement and Implementation

Procurement: The original EasyMile EZ10 vehicles were procured through an informal consultative process. At the time of the original lease in 2016, it was very early in the development of LSAV shuttle technology, and EasyMile was one of the few vendors providing vehicles.

Funding: The public and private funding includes direct and in-kind resources from local/regional and state agencies, a private landowner/developer, an engineering firm, and EasyMile, the vehicle vendor. These included

- Sunset Development (owner of Bishop Ranch Business Park): in-kind storage and charging, funding for EasyMile vehicle lease.
- Stantec (engineering firm): in-kind engineering services.
- EasyMile (vehicle vendor): provided "additional dollars" and in-kind resources to support the project.
- BART (regional transit agency): $250,000 contribution, through Measure J sales tax.
- Bay Area Air Quality Management District: $1 million grant contribution.
- State of California: $3.5 million discretionary line item in budget.

Federal and State Approvals: The vendor's LSAVs are imported and did not meet the FMVSS regulations. CCTA was the first agency to apply for FMVSS waivers for LSAVs in July 2016; the waiver expired in July 2019 after the time limit of three years.

At the state level, the California Department of Motor Vehicles, the California Environmental Protection Agency, and the California Air Resources Board approvals were sought. Before the pilot carried members of the public, the operator needed to seek approval from the CPUC (as discussed).

CCTA will require a temporary FMVSS exemption for the Local Motors Olli vehicles to operate on public roads. The agency is working with its federal lobbyist and expects regulatory approval within 3 months to 1 year. They are testing these vehicles at GoMentum Station in the interim.

Infrastructure: CCTA installed temporary signage to alert pedestrians and drivers of the presence of AVs at the Bishop Ranch office park.

CCTA is installing transit signal prioritization technology at key intersections as well as RSUs and DSRC. The latter will provide V2I communication.

Operations

LSAV shuttles are being tested and evaluated under controlled conditions in parking lots and circulator roads in the office park, as well as at a dedicated testing facility at GoMentum Station. First Transit was the primary operator of the two EZ-10 vehicles at Bishop Ranch.

CCTA and EasyMile conducted field training with the police and the city/traffic engineer in accordance with the "Emergency Plan and Accident Plan."

The project team conducts monthly meetings with the Bay Area's metropolitan planning organization to keep stakeholders informed.

With the knowledge it has gained with the EZ10 vehicles, CCTA expects to be able to move more quickly in testing the Local Motors Olli vehicles for the same functions.

The plan is for commercialization and wider deployment after the testing phase has been completed.

Evaluation and Data Collection

The project team is evaluating how the vehicle can be verified for safe operation, based on meeting a list of functional challenges in real-world conditions to ensure the LSAV vendor provides agreed-upon deliverables. The project team partnered with the LSAV vendor to develop evaluation criteria, test scenarios, and safety goals.

The functional challenges include a list of 155 maneuvers for the vehicle to perform safely, including making basic turns, approaching and leaving a station, responding to obstacles, handling intersections like T-junctions and roundabouts, and responding to traffic signals. A full list of test elements is provided in the Practitioner Guide of this report.

Building from its work at Bishop Ranch, CCTA and its partners were awarded an Automated Driving System Demonstration Grant from U.S. DOT in September 2019. The funding will support the testing work at the GoMentum Station along with the deploying of vehicles and technology in three projects: First/last mile shuttles in Walnut Creek, hospital-linked accessible transportation in Martinez, and connected vehicle infrastructure along I-680 in San Ramon.

E.3 Denver RTD 61AV Shuttle

Denver Regional Transportation District (RTD)
Denver, CO

Project Profile

The 61AV Shuttle was an operational 6-month pilot designed to evaluate the capabilities of an LSAV shuttle within one public transit integration use case and demonstrate how RTD could safely implement an AV project on public roadways in the State of Colorado.

The project goals included

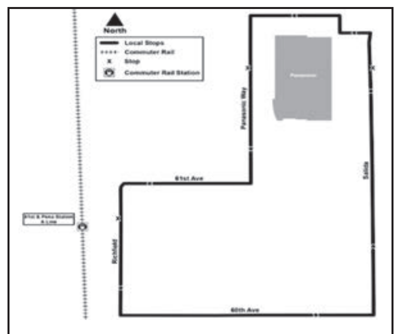
- Safely introduce automated vehicle technology on a public roadway in the Denver metro area.
- Assess the reliability and availability of an AV shuttle vehicle and its suitability for a public transit application.
- Provide additional first/last mile service to/from an RTD bus/rail station, business and residential areas.
- Align the interests of multiple stakeholders in order to advance the LSAV project.

The LSAV selected for the program was an EasyMile EZ10 Gen-1 with a capacity of 10 to 12 passengers and a built-in automatic access ramp.

The LSAV shuttle started January 29, 2019, traveling on a 1-mi one-way loop route connecting the 61st and Pena Station on the RTD East Rail Line to the Panasonic building, an emerging apartment complex, and the Pena park-n-ride owned by Denver International Airport. The route is on public roads with the LSAV traveling at approximately 10 mph to 12 mph. The LSAV shuttle was a free service for public use and intended trip purposes included employment access and access to transit. This was one of the first deployments nationally of an LSAV operating on a public roadway and integrated with a transit agency's service offering.

The 61AV Shuttle pilot project was completed on August 2, 2019.

Denver RTD website 2019



Mini Case Study Highlights	
Status	Complete (August 2019)
Use Case(s)	First/Last Mile
Duration	6 Months
Project Lead	RTD
Project Partners	EasyMile, Transdev, Panasonic, LC Fulenwider, City and County of Denver
Vendor	EasyMile
Operator	Transdev
Funding Source	Transit, Private

90 Low-Speed Automated Vehicles (LSAVs) in Public Transportation

Planning

The demonstration project was a partnership between RTD, EasyMile (the automated vehicle provider), TransDev (the operator and provider of the on-board Customer Service Ambassador), Panasonic, and LC Fulenwider (co-developers of Pena Station Next), and the City/County of Denver (including Public Works and Denver International Airport).

Stakeholders, including members from EasyMile, RTD, City of Denver, and local developer LC Fulenwider, reviewed and assessed alternative routes. EasyMile also conducted a Site Assessment Report as part of its standard project planning process to assess hazards and recommend risk mitigation measures to include infrastructure modifications. As a result of these assessments, Denver RTD selected the route for this project to avoid higher-speed arterial roads. Both RTD and the Colorado Autonomous Vehicle Task Force met with the Denver Police Department and Denver Fire Department before the launch. These briefings provided information on the vehicle, including battery location and emergency-response protocols.

Although this project has concluded, RTD has submitted a grant application to U.S. DOT and is planning to partner with the City and County of Denver as well as EasyMile on another project to provide a first/last mile connection between the University of Denver and the adjacent light-rail station.

Procurement and Implementation

Procurement: RTD contracted directly with EasyMile as the vendor for this pilot project. At the time of the pilot, EasyMile was establishing its North American headquarters in Denver (at the location of the pilot), and the company offered to contribute in kind through reduced lease costs.

Funding: RTD leveraged existing relationships and contracts with a private developer/property owner, a transit service provider, and an LSAV vendor to develop, fund, and provide services for the pilot. The private developer provided cash and in-kind support. The contracted transit service provider reduced operation and maintenance costs related to the project. The vendor provided reduced lease costs. RTD contributed cash and staff time.

Federal and State Approvals: The EasyMile EZ10 vehicle was imported from France; RTD and the vendor obtained the required NHTSA approval.

Under legislation passed in 2017, Colorado State's Autonomous Vehicle Task Force developed the regulatory framework and approved RTD and the vendor's application to operate on public streets.[1] The City of Denver also participated in site/route review, assessment, and selection through its Public Works group.

Infrastructure: To mitigate safety risks identified in the traffic engineering analysis, RTD chose a route that excluded an arterial with high traffic volumes and 45 mph speed limits. The project team worked with the Colorado Department of Transportation to determine and post appropriate signage that was compliant with the Manual on Uniform Traffic Control Devices for a slow-moving vehicle. RTD/City of Denver posted signage noting the presence of AV operations and that identified LSAV shuttle stop locations.

[1] The Colorado Autonomous Vehicle Task Force, comprising representatives from the Colorado Department of Transportation, Colorado State Patrol, and Colorado Department of Revenue/Division of Motor Vehicles, is charged with reviewing applications to operate autonomous vehicles on public roadways. Colo. Rev. Stat. § 42-4-242.

The developer added ADA-compliant bus stops with concrete pads for enhanced access.

There was no need for connected vehicle technology for vehicle-to-infrastructure connectivity.

Operations

The vendor and RTD prepared an SOP that included a daily operations schedule, operations protocols, role descriptions, and detailed operational checklists.

The LSAV operation was limited to one charge cycle for one vehicle ranging between 10 and 12 hours and enough reserve for contingencies. The charge cycle was dependent on the temperature and level of air conditioning utilized.

Operations were based at the vendor's North American headquarters located along the route.

A contract with Transdev provided an on-board safety attendant known as a Customer Service Ambassador, who took manual control of the vehicle when necessary to deviate from the AV's predetermined route for obstructions such as construction vehicles.

RTD and EasyMile publicized the service through traditional and social media. RTD created a specific 61AV page with scheduled information and frequently asked questions. 61AV information was included in RTD's trip planner and could be accessed through RTD's real-time vehicle location tracker for rider-monitoring.

RTD and the Colorado Cross-Disability Coalition completed a successful test of the automated ramp for people with disabilities.

Evaluation, Data Collection, and Lessons Learned

Metrics included uptime, number of emergency stops, errors, and battery charge at the start/end of the service day.

On a daily and weekly basis, the vendor and operator provided RTD data on ridership, percentage of LSAV uptime, and vehicle errors. (An example of one of these reports is provided in the Practitioner Guide.)

The project team did not conduct customer surveys because the sample size would be statistically insignificant.

During the period of operation, current service availability ranged from 45 percent to 99+ percent, with weather and road construction being the primary factors in limiting LSAV shuttle service availability.

After the pilot concluded, the project team developed a list of lessons learned. They noted that stakeholder alignment was a key element. The project team explained that to launch each stage of the project takes significant time, including regulatory requirements, contractual, project preplanning (route and schedule), and marketing/communication, as well as the implementation itself. It was important that marketing and communications activities were proactive between project team members, stakeholders, and the public. The project team also noted that the budget needed to include all project elements at the outset, as there may be small components that are overlooked.

The project team noted that the EZ10 Gen-1 vehicle may not yet be reliable enough; potential improvements discussed included enhanced sensors (which are available in the Gen-3 vehicle), improved battery life, and the addition of a heater.

The RTD 61AV Autonomous Shuttle Demonstration Project Final Report (August 2019) can be accessed in the Practitioner Guide Resources, Section 5.6.

E.4 JTA Ultimate Urban Circulator

Jacksonville Transit Authority (JTA)
Jacksonville, FL

JACKSONVILLE TRANSPORTATION AUTHORITY

Mini Case Study Highlights	
Status	Operational (Ph. 1) Planning (Ph. 2 and 3)
Use Case(s)	Circulator
Duration	Phase 1: 18 months Phase 2: 24 months Phase 3: APM deployment, open-ended
Project Lead	JTA
Project Partners	EasyMile, Navya, KPMG
Vendor	EasyMile, Navya, TBD
Operator	JTA
Funding Source	Federal, State, Transit

Project Profile

The Ultimate Urban Circulator (U2C) is a multiphase project to test and pilot LSAVs as a replacement of Jacksonville's existing automated people mover (APM) system (the Jacksonville Skyway). Phase 1 is operational and the focus of this study; notes are also included for ongoing or planned activities in the later phases.

The project goals include

- Improve safety.
- Maintain a state of good repair for transit infrastructure.
- Enhance Jacksonville's economic competitiveness.
- Protect the environment and reduce emissions.
- Improve quality of life through innovative technologies and new partnerships.
- Increase ridership (expect growth to 2,500 passengers daily).

EasyMile and Navya fielded one LSAV shuttle each for Phase 1 activities. The EasyMile EZ10 and Navya AUTONOM shuttles both have a capacity of 12 to 15 passengers/shuttle.

The Phase 1 route is a short test track located behind TIAA Bank Field and consists of a 0.3-mi dedicated road segment. JTA is planning for a 3.2-mi route along Bay Street (Phase 2) and a 2.5-mi dedicated elevated guideway on the existing Skyway with undetermined mixed-traffic extensions (Phase 3). Testing conducted in Phase 1 will inform the final determination of later phase routes consisting of public roadways with a dedicated lane and multiple operational domain designs.

Planning

JTA completed a policy study as part of the North Florida Transportation Planning Organization's "Smart Region Master Plan" to evaluate the potential of automated vehicles in the region.

Separately, there is an ongoing JTA planning for modernization of the Jacksonville Skyway titled "Transit Concept and Alternatives Review" that is being conducted in cooperation with the Florida Department of Transportation (FDOT).

The ridership projections for the U2C transit route concepts were developed using the FTA's Simplified Trips-on-Project Software travel demand model.

The North Florida Transportation Planning Organization adopted the outcomes of this work in June 2018 resulting in the Bay Street Innovation Corridor being adopted as a locally preferred alternative.

The JTA secured funding through a U.S. DOT BUILD grant for their Phase 2 Bay Street Innovation Corridor, and this funding is the foundation for its program of pilots.

KPMG conducted a risk assessment of the entire U2C program in November 2017 and a copy is included in the Practitioner Guide. JTA plans to mitigate the identified risk factors by developing detailed project risk registers at key stages of project development and will include planning for concepts, permit, PR procurement/procurement activities, constructions, and operations/maintenance.

JTA coordinated with local law enforcement to develop a safety operation outline, which includes the most common scenarios during vehicle testing (Phase 1), and shared the outline with the vendors' vehicle safety operators. A copy of this outline is provided in Section 5.5 of the Practitioner Guide.

Procurement and Implementation

Procurement: Procurement is through a formal process by JTA, utilizing a "Request for Information" and RFPs for vendors to participate.

Funding: The project team combined local JTA funds with a U.S. DOT BUILD grant (for Phase 2) and supplemental FDOT funding.

Federal and State Approvals: Vendors and JTA applied for FMVSS exemptions for Phase 1 testing of the dedicated LSAVs. The State of Florida specifically allows automated vehicle operation (316.85 of the State Uniform Traffic Control) and no additional permits are required.

Infrastructure: JTA is the primary project sponsor and is pursuing approvals from the City of Jacksonville on civil infrastructure on the corridor.

Signage for testing of LSAVs was installed for Phase 1 operations.

Operations

A formal SOP has not been developed for Phase 1 but is under development for Phase 2 and 3 by leveraging lessons learned from the ongoing LSAV testing.

JTA has conducted online surveys for riders and provided presentations to stakeholder groups, including elected officials, policymakers, community leaders, and citizens. Multiple public forums were held to provide more opportunity for public input.

The Jacksonville Chamber of Commerce developed a supporting press release and one of the third-party operating vendors published a press release regarding Phase 1.

Evaluation and Data Collection

JTA currently monitors the performance of the three vendors based on automated control performance (e.g., average speed, consistency, disengagements). This is accomplished through frequent testing events/demonstrations where the public is invited to participate.

JTA has designed the phased project to test out LSAV technologies with the public to determine their willingness to ride in LSAVs before committing to a large change of fixed infrastructure on the Skyway.

JTA is planning for an "integrated data exchange" to collect, manage, and analyze information from sensors and automated vehicles. During this planning process, development of the exact process, access, and sharing protocols will occur to provide a streamlined way to collect and share real-time data between operators, the transit agency, and City of Jacksonville government along the Bay Street Innovation Corridor.

E.5 HART Marion Street Transitway AV Shuttle

Hillsborough Area Regional Transit Authority (HART)
Tampa, FL

Project Profile

In 2015, the Hillsborough Area Regional Transit Authority began planning the Marion Street Transit AV Shuttle, a fixed-route service from HART's central transit hub to the commercial

HART
Hillsborough Area Regional Transit Authority
www.goHART.org

Mini Case Study Highlights	
Status	Planning
Use Case(s)	Shuttle
Duration	12 Months
Project Lead	HART
Project Partners	TBD
Vendor	TBD
Operator	TBD
Funding Source	State

core of downtown Tampa. Starting October 2020, Beep, the autonomous program manager and operator, began operation of a Navya shuttle to operate on a dedicated transitway on a public right-of-way in mixed traffic with conventional vehicle buses. Operation is approved for 12 months, with an option for a 1-year extension.

The project goals include

- Improve the connection between HART's central transit hub and downtown businesses and attractions.
- Demonstrate and test LSAV technology feasibility.
- Increase transit ridership by improving the accessibility of the transit network to key downtown destinations.

The LSAV vendor will provide an LSAV shuttle capacity of six or more passengers per shuttle. The shuttle vehicle ramp will provide mobility impaired individuals with full access.

The planned route is shared with conventional vehicle buses and will have headways of 10 minutes or less along the Marion Street route. The project will create eight predetermined stops at bus shelters to include the Marion Transit Center, Cass Station, City Hall Station, Fort Brooke Station, Washington Station, Kennedy Station, Federal Station, and Floridian Station. The LSAV shuttle is expected to travel at 15 mph.

Planning

In 2015, HART introduced the concept of an AV shuttle in Downtown Tampa in its U.S. DOT Smart Cities Challenge grant application. In 2015, the Florida Department of Transportation (FDOT) awarded HART funding for the project.

In 2016–2017, HART prepared for a 1-year pilot to connect people from their central transit hub to the commercial core of downtown Tampa.

HART contracted with technical consultants to determine the feasibility of operating an LSAV shuttle on their busy downtown transitway and required physical/digital infrastructure improvements to include cameras and RSUs.

In February 2018, HART introduced the concept of automated shuttles on the Marion Street Transitway through public demonstrations with May Mobility.

Procurement and Implementation

Procurement: HART issued an RFP to solicit a vendor to provide a turnkey solution, that is to say for a shuttle and operations on the Marion Street Transitway.

Before launch of the service, HART is requiring vendors to submit a detailed Quality Assurance/Quality Control plan detailing vehicle manufacturing, operations, and maintenance. Further, HART is requiring the vendor to provide a Preliminary Hazard Assessment and a Test Plan for the LSAV shuttles to clearly demonstrate safe operations.

HART also requires a detailed incident protocol from the vendor before launch and operations.

Funding: FDOT is funding this project.

Federal and State Approvals: In August 2019, the vendors sought necessary federal approvals. Since 2012, the State of Florida has allowed automated vehicles to operate on public roads and no additional permits or approvals are required. In June 2019, the State of Florida passed a new law which authorized the operation of automated vehicles without a safety driver, if the AVs meet stipulated insurance and safety requirements.

Operations

The LSAV shuttle will operate on a regular schedule between 6:00 a.m. to 7:00 p.m. Monday through Friday.

The SOP has not yet been developed, but all operations will comply with requirements in the RFP.

Evaluation and Data Collection

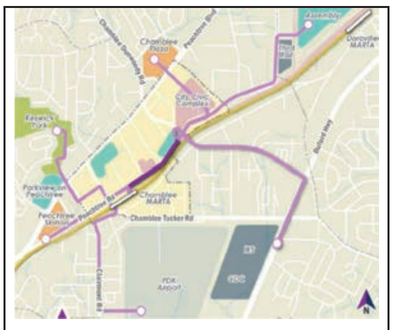
The vendor will provide HART with agreed-upon operational data over the course of the project. Reported data will include ridership, quality of service, the performance of the automated system, and incident reporting.

HART intends to track LSAV ridership, operational hours, quality of service (downtime), number of vehicle incidents, emissions, and AMS energy/carbon intensity.

E.6 City of Chamblee Self-Driving Shuttle

City of Chamblee
Chamblee, GA

Project Profile



Mini Case Study Highlights	
Status	Planning
Use Case(s)	Circulator, First/Last Mile
Duration	12 Months
Project Lead	City of Chamblee
Project Partners	Stantec
Vendor	TBD
Operator	TBD
Funding Source	Federal (Pending), Local

The City of Chamblee is planning a 12-month pilot to deploy an LSAV shuttle to connect its growing downtown to MARTA and adjacent destinations while reducing the parking demand in downtown Chamblee.

The project goals include

- Determine feasibility of deploying LSAV shuttles on local streets.
- Understand how to utilize LSAV shuttles to reduce parking needs.

The intended LSAV shuttle fleet size is 1 to 2 vehicles with a capacity of between 6 and 15 passengers per shuttle.

The routes under consideration would support two LSAV shuttles operating simultaneously with headways between 7.5 and 15 minutes based on expected demand. They will likely include core segments along Peachtree Road in downtown Chamblee, with potential extensions to Peachtree Station shopping center, the Assembly, Chamblee Plaza, Keswick Park, IRS/Center for Disease Control, and Dekalb-Peachtree Airport.

Planning

The City of Chamblee contracted a transportation planning consultant to complete the 2018 Chamblee/Self-Driving Shuttle Feasibility Study (Feasibility Study) and Concept Plan. This Feasibility Study and Concept Plan cover potential routes, operational parameters, and cost estimates. A market assessment was included as part of this process to determine ridership populations, but not a demand analysis; instead, a combination of data sources was used, including MARTA ridership data and ESRI Business Analysis Online.

The Chamblee Mobility Plan is currently under review and outcomes from these planning activities are being discussed by the City of Chamblee government for potential implementation. The City of Chamblee submitted a funding application for the recent U.S. DOT ADS Notice of Funding Opportunity and was not awarded a grant.

An informal risk assessment was conducted as part of the Feasibility Study and Concept Plan focusing on speeds and intersection complexity along potential routes. Planned mitigation involves a safety driver for each LSAV and improved infrastructure.

Stakeholder workshops were conducted to engage community groups and organizations to include MARTA, the Atlanta Regional Commission, the mayor/city council, local businesses, developers, residents, and city staff. An online survey about AVs was conducted with more than 100 Chamblee residents participating.

Planned signage included in the Chamblee Mobility Plan will increase marketing and outreach along the proposed main corridor route and at MARTA station.

Procurement and Implementation

Procurement: This pilot will use a formal procurement process to select the vendors.

Funding: The funding mix and amounts are not yet established but may include City of Chamblee general funds and potential MPO funding. They also applied for a U.S. DOT ADS Demonstration grant, but in the September 2019 announcement, they were not one of the selected applications.

Federal and State Approvals: If required, vendors and the City of Chamblee will apply for FMVSS waivers for shuttles after procurement and the vendors are selected. The State of Georgia has specifically allowed AV operation in its motor vehicle code and does not require permits. The City of Chamblee controls most streets being considered for implementation. MARTA controls the station site potentially needed for LSAV turnaround and will require approvals before pilot launch.

Infrastructure: Physical improvements may be required to include improved signage, lane markings, and signal timings to manage crossings.

Operations

Initial operational parameters were developed in the Feasibility Report with operations envisioned for a 14-hour service day, 6 days a week.

The selected LSAV vendor will work with the City of Chamblee to develop formal operational plans, training, and safety protocols.

Evaluation and Data Collection

The project team is evaluating potential LSAV pilot routes considering the following:

- Number of residents along the route
- Number of jobs along the route
- Route length (number of trips per hour with two vehicles)
- ODD compatibility with LSAV
- Increase in transit service coverage (derived from comparative metrics based on other similar projects)

The data collection plan is to be determined but will likely include data collected by the vendor and provided to the City of Chamblee for appropriate analysis and reporting.

The City of Chamblee will measure consumer satisfaction through ridership and rider satisfaction surveys. It will also use consumer willingness/interest measured during planning through online surveys and workshops.

E.7 Mcity Driverless Shuttle

University of Michigan
Ann Arbor, MI

Project Profile

The Mcity Driverless Shuttle is an operational 24-month pilot to deploy LSAVs to provide a live transportation service on the University of Michigan (UM) research campus. Mcity is a UM-led public–private partnership to accelerate advanced mobility vehicles and technologies. This applied research project aims to better understand human acceptance, trust, and behavior when riding in a driverless shuttle or interacting with one on the road.

The project goals include

- Study how passengers react to the driverless shuttle to gauge consumer acceptance of the technology.
- Observe technology's performance in the real world, based on specific types of interactions in a variety of weather conditions.
- Understand how trust in shuttle technology changes over time, and how an interaction with the shuttle (either riding or as a pedestrian) changes feelings about AVs.
- Track ridership to provide insights on parking usage and campus destination.

The vendor fielded a fleet of two AUTONOM LSAV shuttles with capacity of up to 11 passengers per shuttle.

The LSAV shuttles travel at 10 to 15 mph along circulator roads at UM North Campus Research Complex. A planned extension to Lurie Engineering Center along a mixed-traffic street was canceled because of construction.

Route Map
(University of Michigan website)

Mini Case Study Highlights	
Status	Operational
Use Case(s)	Shuttle
Duration	24 Months (ending December 2019)
Project Lead	Mcity
Project Partners	University of Michigan, Navya
Vendor	Navya
Operator	Mcity
Funding Source	University, Private

Planning

An Mcity research team selected the specific route based on the manufacturer's specifications for ODD and then premapped the route.

The Mcity research team tested the Navya shuttles in a variety of weather and lighting conditions within the Mcity Test Facility to ensure safe operation. The research team put together a series of challenges like those on the selected route. The challenges included a cyclist moving in the same direction, a car crossing from the right, a car crossing at a roundabout, a pedestrian approaching, and a car driving in the opposite direction in proximity.

The Mcity research team did not conduct external public engagement but facilitated meetings with internal university stakeholders. These included campus stakeholders, the Ann Arbor police department, and the University of Michigan police department to ensure the appropriate functional planning was accomplished and emergency procedures were accounted for.

Procurement and Implementation

Procurement/Funding: The pilot is funded through internal University of Michigan research funding and received required internal approvals. The LSAV fleet was purchased with financial support from Mcity corporate members. Therefore, formal procurement processes that could be compared to public agency processes were not required.

Federal and State Approvals: The University Office of General Counsel received an FMVSS waiver from NHTSA. The State of Michigan specifically allows operation of automated vehicles on public streets (Public Acts 332-335 of 2016). The University of Michigan owns all the land used for pilot operations; therefore, no additional permits were required for operation.

Infrastructure: Signage was installed at stops and along the route to inform drivers of the presence of driverless shuttles.

ADA Compliance: In November 2019, the University of Michigan and the Department of Justice reached an agreement related to the ADA requirements for compliance of autonomous vehicles purchased by the University and operated on a fixed route. The agreement included, among other requirements, that all future vehicles must comply with Title II accessibility requirements for disabled individuals and until that is provided for all autonomous vehicles, equivalent services must be provided to those individuals, including those using wheelchairs.

Operations

Detailed operational protocols and procedures were developed that covered actions to include shuttle start up, regular operation, and incident response. Operational procedures also detailed employee sign-in steps, vehicle cleaning, shuttle start up, running the data-acquisition system, checking route safety, ridership rules, and other parameters. Daily and weekly tasks were delegated to the conductors as part of their start-up and shutdown procedures.

Safety checklists are used to include incident/collision response and provide immediate access to step-by-step emergency procedures and vital information such as proof of insurance, government exemption letters, route maps, and shift schedules.

A three-step training process was set up for LSAV operators using the Mcity Test Facility closed course to allow safety operators to become familiar with the vehicle.

Mcity developed a website accessible by the public to provide information, schedule, and key safety-related messages.

The University of Michigan handled all marketing for the pilot and local media to include MLive, the *Michigan Daily*, and other state/regional/local outlets that have reported on pilot activities.

Evaluation and Data Collection

The Mcity research team uploads camera and sensor data into the Mcity Cloud, at which time the processing engines count passengers, anonymize/blur faces, characterize weather conditions, and classify interactions. These data are then provided to researchers and Mcity partner companies via a web browser interface with filtering and analysis tools.

Mcity worked with JD Power, an automotive market research firm, to design a user survey for riders of the shuttle. The aim is to understand the attitudes of riders and nonriders toward driverless shuttles, including longitudinal tracking to better understand how perceptions change over time.

UM and Mcity are also part of the Michigan Mobility Collaborative that received an award in September 2019 of a U.S. DOT Automated Driving System Demonstration Grant to fund AV safety testing and deployment in the region. In addition to UM and Mcity, the members of the Michigan Mobility Collaborative include the City of Detroit, the Michigan Department of Transportation, the Michigan Economic Development Corporation, the American Center for Mobility, Wayne State University, Ford Smart Mobility, LLC, and Deloitte LLP.

E.8 Bedrock Detroit Parking LSAV Shuttle

Bedrock Detroit
Detroit, MI

Project Profile

Mini Case Study Highlights	
Status	Operational
Use Case(s)	Shuttle
Duration	Open-ended
Project Lead	Bedrock Detroit
Project Partners	May Mobility
Vendor	May Mobility
Operator	May Mobility
Funding Source	Private

In June 2018, the Detroit-based commercial real estate firm Bedrock launched an LSAV shuttle service on a public right-of-way in mixed traffic to provide its employees connections from the Bedrock offices to remote parking in downtown Detroit. The 1-year contract for service has been renewed.

The project goals include

- Improve frequency for shuttle service on a regularly scheduled route connecting employees to offsite/remote parking.
- Assess feasibility of extending the roll-out of LSAV shuttle service to other routes currently operated by conventional vehicle diesel-powered shuttles.
- Position Detroit as a mobility technology leader.

May Mobility fielded a fleet of five LSAV shuttles based on the Polaris GEM-6 with a capacity of five passengers per shuttle (one seat is taken by the safety driver).

Planning

Bedrock Detroit, the project sponsor, explored opportunities to use innovative mobility technologies to address employee shuttles to parking locations. Bedrock Detroit decided to field and evaluate an LSAV shuttle in downtown Detroit.

Bedrock Detroit selected a local LSAV vendor and oversaw testing in October 2018 to determine the vendor's LSAV shuttle's ability to operate in mixed traffic in downtown Detroit.

Bedrock Detroit and the vendor conducted safety planning and identified risks on the route and determined mitigation through a regular fixed-route shuttle service on a premapped route, an in-vehicle safety driver, and real-time vehicle monitoring from a central control center.

The project team led planning with Detroit Police for incident- and emergency-related activities.

Procurement and Implementation

Procurement/Funding: Bedrock Detroit funded the project through internal approval and procurement processes. No additional external or formal procurement processes were used.

Federal and State Approvals: The State of Michigan specifically allows operation of AVs on public streets (Public Acts 332–335 of 2016). No additional permits were required for operation on Detroit public streets. No further federal government approvals were required.

Infrastructure: Cameras were installed at key intersections along the route to provide sensing redundancy for the vehicles. No other physical or digital improvements or changes were needed and no DSRC RSUs were installed.

Operations

The LSAV shuttles travel on public roadways between Bedrock Detroit's One Campus Martius office building and the Bricktown Garage, with peak-hour service before and after the normal working day hours.

The LSAV shuttles operate in automated mode on premapped or programmed fixed routes. When not on this service route, the safety driver takes manual control of the vehicle.

LSAV shuttles operate with an in-vehicle safety driver and are monitored in real time from the vendor's local central control center.

The vendor's control center also serves as the location for LSAV storage, charging, and maintenance.

The vendor published an SOP, which includes a daily schedule for regular operations during the 15-hour service day. The SOP also includes operational protocols, safety procedures, operational checklists, role descriptions, shift changes activities, and procedures for servicing and charging LSAVs.

The published SOP also outlines how spare LSAV shuttles are used and swapped in to ensure continuous operations. LSAV shuttles are charged at the vendor's local base of operations ½ mi south of the service route.

The vendor provided safety attendants with training that included familiarization with AV technology, as well as safety operations best practices.

Bedrock Detroit provided all marketing for the LSAV shuttle service, project and service information on its website, and posted signage at the two LSAV shuttle stops.

Evaluation and Data Collection

The vendor collects data at its operations base in downtown Detroit and its engineers analyze the data and refine automated systems accordingly.

The vendor provides Bedrock Detroit with reports on ridership, operational performance, and rider satisfaction. The vendor does not provide information about disengagements and automated technology performance.

The vendor surveys customers on a regular basis to derive their Net Promoter Score (NPS), an industry-standard measure of whether riders would recommend the service to others. (Customer satisfaction for the service consistently registered a +60 NPS score.)

E.9 Grand Rapids Autonomous Vehicle Initiative

City of Grand Rapids
Grand Rapids, MI

Project Profile

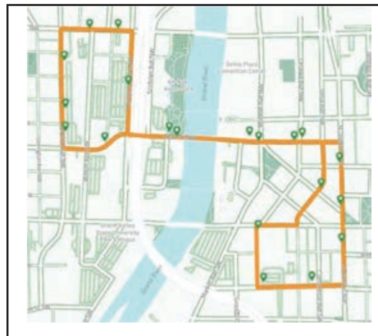
The Grand Rapids Autonomous Vehicle Initiative (AVGR) is a pilot that began in July 2019, was suspended for COVID-19, and relaunched in August 2020. It offers LSAV shuttle services to the general public in downtown Grand Rapids. The circulator provides service every 20 minutes along the DASH West route of the City of Grand Rapids (City) public transportation system. New sites will be launched in Q1 2021.

The project goals include

- Determine feasibility and gain insight into how automated vehicles impact existing urban structures.
- Address how automated vehicles improve or impact mobility for the elderly and people with disabilities.

- Gather data and study LSAV operations safety in real-world scenarios to include interactions with vehicle traffic, bicycle riders, and pedestrians on city streets.
- Engage the local community through open sessions for local stakeholders to provide community visioning, goal setting, plan making, and recommendations for public investments specific to automated vehicles.

Route Map (©Mapbox © Open Street Map)



Mini Case Study Highlights	
Status	Operational
Use Case(s)	Circulator
Duration	12 Months
Project Lead	City of Grand Rapids
Project Partners	City of Grand Rapids, Consumers Energy, Faurecia, Gentex, May Mobility, PlanetM/MEDC, Rockford Construction, Start Garden/Seamless, Steelcase
Vendor	May Mobility
Operator	May Mobility
Funding Source	Local, Private

Planning

Community leaders and local businesses came together under the banner of the AVGR.

This consortium, led by the City of Grand Rapids, determined that an LSAV shuttle was feasible. This was confirmed through discussions and outreach with the City's preferred vendor, May Mobility.

In the second half of 2018, the City of Grand Rapids, the Rapid (the local transit agency) and their partners developed the concept for a downtown circulator to run along the DASH West route.

Procurement and Implementation

Procurement: The public–private consortium was formed through a series of discussions throughout 2018; these included participation of the selected LSAV vendor. The vehicles were selected through this informal consultative process.

Funding: The consortium, consisting of nine companies, the City of Grand Rapids, and the State of Michigan (through the Michigan Economic Development Corporation), provided funding for this pilot. Members of the consortium provided in-kind contributions, cash, and logistics support such as LSAV shuttle storage and charging facilities.

Federal and State Approvals: The State of Michigan specifically allows LSAV testing and operations on public roads without further permits. The City of Grand Rapids was part of the project management team and no additional permits were necessary for operating on city streets.

No further federal government approvals were required.

Operations

The fixed-route LSAV circulator runs along a 3.2-mi looped route in downtown Grand Rapids with 22 stops. This route follows an existing downtown circulator (the DASH West) and provides regular service that runs every 20 minutes from 7:00 a.m. to 7:00 p.m. Tuesday through Friday, and 10:00 a.m. to 7:00 p.m. Saturday. In 2020, based on rider requests and trends, the service schedule will shift to operate Monday through Friday. The LSAV shuttle operates in mixed traffic along this route and navigates 30 traffic lights and 12 turns (including three left turns).

The LSAV shuttle service is provided to the public free of charge.

The vendor prepared an SOP before launch. The SOP includes a daily schedule for regular operations during 12-hour service days 5 days a week. The SOP also includes detailed safety procedures, operational checklists, protocols, role descriptions, shift changes, and procedures for servicing and charging LSAVs. The SOP also outlined how spare LSAVs would be used and swapped in as required to ensure continuous operations.

The vendor developed comprehensive training for safety attendants, with theory and practical sections to ensure they understood the technology and could provide a high level of service safely.

The signage includes existing DASH bus signage along with a May Mobility sign. Information panels with a route map, customer service information, and hours of operation were installed in December 2019. The City of Grand Rapids manages all marketing and promotion, leveraging its website and social media to describe the shuttle service, and answers frequently asked questions.

The initially launched vehicles are not accessible to wheelchairs. However, the May Mobility team will begin offering a wheelchair-accessible vehicle (WAV) in parallel with other vehicles beginning in December 2019. The WAV service will be accessed by calling a customer service number posted on information panels at stops and online.

Evaluation and Data Collection

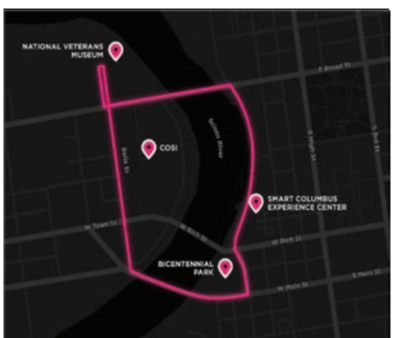
The metrics to evaluate project goal achievement include ridership and customer satisfaction. Community workshops held during the year-long pilot will gauge feedback from citizens.

All data are collected by the vendor at its operations center in Grand Rapids and provided to vendor headquarters for automated system refinement. The vendor surveys its customers on a regular basis to derive their Net Promoter Score. Information about disengagements and automated performance is kept confidential by the vendor. Key ridership and customer satisfaction data are provided to the AVGR consortium.

E.10 Smart Columbus Smart Circuit

Smart Columbus Consortium (Smart Columbus)
Columbus, OH

Route Map (Columbus Partnership)



Mini Case Study Highlights	
Status	Completed
Use Case(s)	Circulator
Duration	10 months
Project Lead	Smart Columbus
Project Partners	May Mobility
Vendor	May Mobility
Operator	May Mobility
Funding Source	State, Local, Private

Project Profile

The Smart Circuit was a downtown circulator pilot project sponsored by Smart Columbus and DriveOhio that launched in December 2018 and completed in September 2019. The shuttle deployment was the first of two automated vehicle projects in a portfolio of more than 30 projects for Smart Columbus. The shuttle was designed for a downtown circulator use case to give central Ohio residents and visitors a firsthand experience with the mobility technologies of the future and a chance to learn more about automated vehicles' capabilities and suitability to address real mobility challenges in communities.

The project goals included

- Conduct pilot, evaluate results, and subsequently scale/sustain/sunset effort.
- Engage stakeholders and partners appropriately at every step of the process.
- Successfully and safely deploy an automated vehicle technology to better connect residents and visitors in the Scioto Mile area.
- Educate residents and visitors to build public trust and support for automated vehicle technology.

The second phase will focus on expanding mobility in an underserved community in northeast Columbus.

May Mobility fielded a fleet of three LSAV shuttles based on a Polaris GEM-6 with a capacity of six passengers/shuttle.

The LSAV shuttles traveled along a circular 1.4-mi route as part of the "Smart Circuit" along the Scioto Mile in Downtown Columbus. The route had four stops including the Smart Columbus Experience Center, Bicentennial Park (along the river), the COSI museum, and the National Veterans Museum.

Planning

Smart Columbus competed for the U.S. DOT Smart City Challenge Grant and beat out 77 applicant cities to receive $50 million in funding. Columbus's plan called for the use of AVs to solve first/last mile challenges in order to improve quality of life for residents.

The project team conducted outreach meetings as part of the Smart Columbus overall project plan.

Smart Columbus assessed the feasibility of LSAV shuttles in downtown as part of the U.S. DOT Smart City grant submission process. The vendor conducted further assessment and testing in late 2018 to determine the suitability of a specific route, how the vehicle would turn, where it would stop, and if any additional infrastructure would be needed for reliable operation.

The pilot project team led incident- and emergency-response planning discussions with Columbus Police before launch.

Procurement and Implementation

Procurement: A formal RFP for turnkey LSAV shuttle operations was issued by the Ohio Department of Transportation/DriveOhio on behalf of the Columbus Partnership. It was a 1-year contract to mobilize, deploy, and provide 10 months of service with two 1-year options. May Mobility was selected.

Funding: The funding for this pilot was provided by private investors who contributed to the Columbus Partnership and DriveOhio.

Federal and State Approvals

The State of Ohio specifically allows LSAV testing and operations on public roads without further permits. The City of Columbus was part of the project management team and no additional permits were necessary for operating on city streets.

No further federal government approvals were required.

Operations

The fixed-route LSAV shuttle service operates on roads that were remapped, providing a more controlled operation. When not on this service route, the safety driver takes manual control of the vehicle. As a further control to mitigate risk, vehicle status and performance are tracked from the vendor's local operations center in Columbus.

- The vendor prepared an SOP before launch. The SOP included a daily schedule for regular operations during the 16-hour service days, 7 days a week. The SOP also included detailed safety procedures, operational checklists, protocols, role descriptions, shift changes, and procedures for servicing and charging LSAVs. The SOP detailed how spare LSAV shuttles are integrated into the active fleet to ensure continuous operations.
- The vendor provided safety attendants training that included familiarization with AV technology, as well as safety operations best practices.

Signage was installed at each stop along the route, and information was provided at the Smart Columbus Experience Center downtown. Smart Columbus created a website describing the LSAV shuttle service; it managed user engagement and marketing activities.

The operations of the Smart Circuit ended on September 27, 2019.

Evaluation and Data Collection

The project metrics included ridership, the percentage of time the vehicle is operating in automated mode, and customer satisfaction.

The vendor collected data at its operations center in Downtown Columbus and its engineers analyzed the data and refined automated systems accordingly. The vendor surveyed customers on a regular basis to derive their Net Promoter Score.

Key ridership and customer satisfaction data were provided to Smart Columbus. Information about disengagements and automated performance was kept confidential by the vendor.

During the operating period, which ran from December 2018 to September 2019, more than 15,000 people rode the shuttles. Using lessons learned, Smart Columbus launched a second phase that concluded in late 2020.

Separately, the Ohio Department of Transportation, under DriveOhio, was awarded an Automated Driving System Demonstration Grant by U.S. DOT in September 2019. That project, "Deploying Automated Technology Anywhere in Ohio," is focused on highway truck platooning to the northwest of Columbus as well as rural ride-hailing and paratransit applications in Southeast Ohio. The project has a data-sharing partnership with Smart Columbus and the Smart Circulator.

E.11 RIDOT "Little Roady" AV Shuttle Pilot Project

Rhode Island Department of Transportation (RIDOT) Providence, RI

Little Roady route map (RIDOT website)

Mini Case Study Highlights	
Status	Operational
Use Case(s)	First/Last Mile, Shuttle
Duration	12 Months
Project Lead	RIDOT
Project Partners	May Mobility
Vendor	May Mobility
Operator	May Mobility
Funding Source	State

Project Profile

Launched in May 2019, the "Little Roady" LSAV Shuttle provides first/last mile connection to transit and intercity rail and serves business parks and other employment centers. The almost 6-mi route connects Olneyville with downtown Providence on public right-of-way and operates in mixed traffic. The shuttle concluded in March 2020; the final report is due December 2020.

The project goals include

- Provide better first/last mile connections with existing transportation modes.
- Expand access to economic opportunities in Olneyville along the river corridor.
- Demonstrate the feasibility of a connected automated vehicle (CAV) service open to the public.

The LSAV vendor fielded six LSAVs with capacity for six passengers/LSAV shuttle that operate at speeds of 20 to 22 mph.

Planning

Established in 2018 by RIDOT, the Rhode Island Transportation Innovation Partnership conducted preliminary studies and vendor testing (late 2018 through early 2019) in the Quonset Business Park south of Providence. Following this study and testing, RIDOT began a pilot project in the Woonasquatucket River corridor between Downtown Providence and Olneyville to demonstrate the feasibility of a public LSAV service in a dense urban area in all weather conditions. The initial pilot is planned for 1 year with an option to extend for an additional 2 years.

The pilot project team led incident- and emergency-response planning discussions with Providence Police before launch.

Procurement and Implementation

Procurement/Funding: RIDOT used funding from the Volkswagen EPA settlement and FHWA research funds for this pilot project and procured the LSAV shuttle services through a formal RFP in mid-2018.

Federal and State Approvals: The vendor's LSAV shuttles are FMVSS compliant and do not require further approval.

The State of Rhode Island has no specific AV statute and this pilot project is being coordinated by the state government by RIDOT. The project team is in active discussions with the City of Providence and no additional permits are necessary for operating on city streets.

Infrastructure: Signage was installed at each of the nine stops along with posted information at Providence Station.

Public Engagement: RIDOT conducted public outreach meetings before launch to explain the nature of the service.

Operations

The vendor prepared an SOP before launch. The SOP provides for a daily schedule for the six LSAV shuttles in regular operations during 12-hour service days (6:30 a.m.–6:30 p.m.), 7 days a week. The SOP also includes detailed safety procedures, operational checklists, protocols, role descriptions, shift changes, and procedures for servicing and charging LSAVs.

The vendor provided training to safety attendants that includes familiarization with AV technology as well as safety operations best practices.

The fixed-route LSAV shuttle service operates on roads that were premapped, providing a more controlled operation. When not on this service route, the safety driver takes manual control of the vehicle. As a further protection, vehicle status and performance are tracked from the vendor's local operations center in Providence.

RIDOT maintains oversight on the Little Roady project and is handling public marketing and media queries on the project.

Evaluation and Data Collection

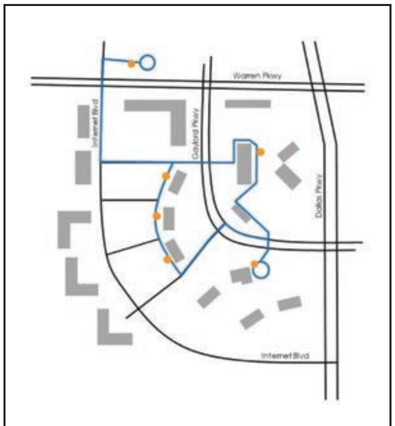
The metrics to evaluate project goal achievement include ridership, operational reliability, and customer satisfaction.

The vendor collects data at its operations center in Providence and its engineers analyze the data and refine automated systems accordingly. The vendor surveys customers on a regular basis to derive their Net Promoter Score.

Ridership and customer satisfaction data are provided to RIDOT. The vendor does not provide RIDOT information about disengagements or the amount of time the vehicle operates in automated mode.

E.12 Frisco Drive.ai Self-Driving Shuttle

City of Frisco, Frisco Station, Denton County Transportation Authority, Drive.ai
Frisco, TX



Mini Case Study Highlights	
Status	Completed
Use Case(s)	Circulator
Duration	8 Months
Project Lead	City of Frisco TMA
Project Partners	Drive.ai, Frisco Station, Denton County Transportation Authority
Vendor	Drive.ai
Operator	Drive.ai
Funding Source	Private

Project Profile

In July 2018 and March 2019, the City of Frisco sponsored a weekday (on-demand) LSAV shuttle service in an office and retail/entertainment district along a 1-mi route with programmed stops at speeds of under 35 mph.

The project goals included

- Attract tenants to the district by providing a differentiated service to provide effective mobility as densities increase.
- Demonstrate the need for a circulator service and lay the groundwork for future transit service (Frisco currently has no regular transit service).
- Demonstrate safe operations to the public.
- Understand the requirements of automated vehicle technology, including infrastructure needs.
- Determine whether car usage would be lower if LSAV service provided an effective midday circulator for errands and lunch options.

Drive.ai operated a fleet of modified Nissan NV-200 vans, which accommodated three riders in a bench seat and provided 6,000 rides over an 8-month period.

Planning

Under the auspices of the Frisco Transportation Management Association, a partnership was formed between the City of Frisco (City), the Denton County Transportation Authority (DCTA), Frisco Station Partners, the HALL Group, and the Star to improve connectivity between several mixed-use developments in Frisco's North Platinum Corridor. In addition to solutions such as improving walkability, ridesharing, and connected vehicles (with traffic signal data sharing), FTMA sought to introduce driverless vehicle service between the Star, HALL Park, and Frisco Station developments.

Initial planning focused on identifying and reviewing vehicle providers. The City identified two key factors in its selection: Drive.ai offered the pilot without charge to the City and an alternate vehicle was a neighborhood electric vehicle deemed unsuitable to travel on a section of the route with a posted speed of 45 mph. DCTA executed a memorandum of understanding with Drive.ai, which included insurance requirements to carry public passengers and logistical considerations (such as charging and storage).

The final route was shaped around vehicle specifications provided by Drive.ai. The team assessed hazards by reviewing all crash data for this area, parking, and bicycle usage. The project team held a tabletop exercise that included the LSAV vendor, emergency services, and visits to fire stations. Drive.ai prepared information on standard operations and incident response, which was shared with emergency responders and public safety officials. In addition to public briefings with City Council, the project team hosted two outreach sessions with Drive.ai briefing on the project demonstrating the vehicle.

Procurement and Implementation

Procurement: The vendor was selected through an informal consultative process that included a variety of automated vehicle providers.

Funding: Drive.ai funded the project for the initial 6-month pilot and 2-month extension.

Federal and State Approvals: No further federal or state approvals were required.

Infrastructure: The project team wanted to include a pilot of DSRC technology to provide redundancy to the LSAV sensors. Drive.ai's position was that it did not require V2I connectivity and preferred to rely on detailed 3D mapping of the route.

DCTA provided new signage on private and public property to inform road users and to direct passengers to pick up spots.

Operations

The fixed route of the shuttle was operated from 11:00 a.m. to 7:00 p.m. Monday through Friday with adjusted winter times of 10:00 a.m. to 5:00 p.m.

The vendor required the project team to have a system to notify them about anything happening in the route area that could affect the right-of-way of the LSAV shuttle (e.g., construction or other work order). Based on that information they adjusted operations accordingly.

The presence of delivery trucks in the fire lane was found to affect automated operations.

Evaluation

A total of 6,000 trips were made on the shuttle during the 8-month pilot. The average number of passengers per ride was 1.8. Information received from riders included requests for an expansion to more locations.

The Texas Transportation Institute assessed consumer acceptance and satisfaction through an online survey. The results indicated

- Demographics, attitudes, and behaviors influence acceptance and trust of AVs.
- If an AV has advanced driver-assistance systems, acceptance is raised.
- Interacting with AVs, such as through seeing, entering, and taking a ride in an AV, raises acceptance further.
- Acceptance and trust differ significantly across types of automated vehicles.
- Level 5 (Full Driving Automation) vehicles as on-demand shuttles or ride hailing are preferred.[1]

Drive.ai terminated its operations in Frisco in March 2019. The City was a key member of the Texas A&M Transportation Institute grant application for safety performance assessment of on-demand AV service under U.S. DOT's Automated Driving System grant. Its application was not awarded funding.

E.13 Houston METRO University District Circulator Pilot

Houston METRO, Texas Southern University
Houston, TX

Project Profile

Houston METRO (the Houston region's transportation and public transit provider) launched a 6-month LSAV pilot program in June 2019 on the Texas Southern University's (TSU) Tiger Walk, an off-street mixed-use pathway. The route is approximately 1 mi long and focused on

[1] Zmud, Johanna, "What the Public Really Thinks About Automated Vehicles: Evidence from Survey Research," Automated Vehicle Symposium. Orlando, Florida. 2019, https://s36.a2zinc.net/clients/auvsi/avs2019/Public/SessionDetails.aspx?FromPage=Sessions.aspx&SessionID=3404&SessionDateID=45.

Texas Southern University Campus

Mini Case Study Highlights	
Status	Operational
Use Case(s)	Shuttle
Duration	6 Months
Project Lead	Houston METRO
Project Partners	Houston METRO, Texas Southern University, Houston-Galveston Area Council, City of Houston
Vendor	EasyMile
Operator	First Transit
Funding Source	Private, Transit

the transportation of TSU students, faculty, staff, and visitors along the path. This is part of a set of projects including the AV grocery delivery Nuro in lieu of paratransit trips and 160 Memorial Express and completed creation of an AV Bus specification for a full-size AV bus using the APTA bus standard, for launch in Sept. 2021. This phase will connect the TSU campus to a nearby light-rail station.

The project goals include

- Understand how to integrate LSAV technology into public transit as an attractive option for Houston METRO patrons.
- Determine insights into human behavior, which can help train METRO staff to work better with these vehicles.
- Invite the public to imagine a transportation future which includes LSAV systems.

Houston METRO decided to mitigate risk by engaging procurement and legal professionals early, inviting vendors to review their technologies/deployments, and connecting with agency colleagues across the country who had experienced LSAV deployments.

Planning

Beginning in 2017, Houston METRO, the City of Houston, Houston-Galveston Area Council (H-GAC), Harris County, and the Houston Office of the Texas Department of Transportation established a working group looking at AV deployment as a regional transportation solution. However, after further review, it was decided that AVs on a university campus would be more feasible than a more complex deployment (e.g., open freeway) in the short term and would provide an opportunity to evaluate the new technology in a semi-controlled environment.

Stakeholders collectively decided on TSU as a promising first pilot location. The TSU appeal included its well-regarded transportation research institute and a major pedestrian mall in the center of campus. In considering the campus, the team identified the potential for a First/Last Mile use case, with an eventual connection to the nearby light-rail station.

First Transit was selected after a competitive procurement process by offering a turnkey approach featuring an EasyMile Gen-2 LSAV. Before the commencement of operations, EasyMile and Houston METRO conducted a workshop on safety design and safety assurance, a workshop on automated vehicle fleet operations and maintenance, and an automated vehicle transit system conceptual design review.

Procurement and Implementation

Procurement: Houston METRO was working as part of the Texas Innovation Alliance with the H-GAC (the local MPO) on a joint group procurement for AV services for local government entities. While Houston METRO originally intended to use that group procurement, the timing did not align with the project timeline. Houston METRO then issued a formal RFP for AV services, the Autonomous Vehicle Demonstration Pilot. The procurement process closed in July 2018.

First Transit was then selected and offered two vehicles for Houston METRO to select, either EasyMile or Navya. METRO selected EasyMile, and First Transit provided an EZ10 Gen-2 vehicle for Houston METRO's use, according to the agreed-upon contract terms.

Funding: The budget for this initial Phase 1 pilot was $250,000 and was provided by Houston METRO.

Federal and State Approvals: This EZ10 vehicle was not FMVSS compliant and required a waiver. First Transit was responsible for obtaining the FMVSS waiver for the vehicle.

Operations

The fixed-route LSAV shuttle service goes back and forth along an approximately 1-mi route on the campus of TSU, along the Tiger Walk pedestrian mall. There are four stops, which are indicated with METRO-branded signage: at a technology classroom building, the student center, the recreation center, and the university library.

Operations during the initial Phase 1 pilot are for 9 hours per day Monday through Friday, from 8:00 a.m. to 2:00 p.m. and 5:00 p.m. to 8:00 p.m. The service is open to university students, staff, and visitors; all passengers are required to sign a consent form before riding. A process was established for repeat riders, so they only must complete the forms once.

First Transit and Houston METRO prepared an SOP based on their prior experience with AVs, which includes operational checklists and protocols. A safety attendant is on board each shuttle to monitor operations and answer questions.

Evaluation and Data Collection

Data is collected by First Transit and by TSU's Center for Transportation Training and Research. The TSU team is being funded by a research grant from H-GAC and is focused on getting feedback from users on their comfort and willingness to use the service and recommend it to others.

The metrics that Houston METRO requested from First Transit are ridership information, the number of users at each station that get on/off the shuttle, the number of customers that need assistance, and the number of disengagements. The other metric being assessed, in partnership with the Idaho National Laboratory, is energy consumption and the battery range of the vehicle while in service.

To date, the vehicle has been well received by users and the data collection is going well. Houston METRO believes that the experience on this project will be informative for the region and nationally.

E.14 Utah Self-Driving Shuttle

Utah Department of Transportation (UDOT); Utah Transit Authority (UTA)
Salt Lake City, UT

Project Profile

UDOT and UTA are conducting a pilot program for LSAVs, originally planned for a year, which launched in April 2019 and concluded in September 2020, following COVID-19. This program consisted of a series of three 5-week pilots designed to evaluate the capabilities of an LSAV shuttle to connect to fixed-route transit in a variety of operating environments and locations. The Final Report is due out by the end of 2020, along with an evaluation of consumer acceptance.

The project goals include

- Improve access to UTA's FrontRunner commuter rail and TRAX light-rail networks.
- Understand better how UTA can integrate LSAV technology with its larger network.
- Demonstrate the feasibility of serving each specified use case.
- Have a broad discussion with the public about autonomy, specifically focused on trust and safety.

avshuttleutah.com

Mini Case Study Highlights	
Status	Operational
Use Case(s)	First/Last Mile, Circulator
Duration	12 Months
Project Lead	UDOT
Project Partners	UTA, EasyMile, WSP
Vendor	EasyMile
Operator	UTA Lead, EasyMile Assist
Funding Source	State

The LSAV shuttle selected for the program is an EasyMile EZ10, with a capacity of 12 passengers per shuttle. The LSAV shuttle will travel routes in multiple locations to include Farmington Station Park, circulator roads at the Canyons Resort, an office park in Salt Lake City, the Utah State Capitol, the University of Utah, the Mountain America Expo Center, a hospital site in the Salt Lake City metro area, and one location in St. George in southern Utah.

Planning

The project team (UDOT and UTA) created an internal project plan to identify the scope of the program, operational hours, the anticipated operational design domain for the vehicles given the use cases, and the logistics required to include charging and maintenance. UTA contracted with WSP to create the SOP and safety management plan.

EasyMile conducted risk assessments for each location to identify hazards and recommended mitigation measures for a given route. The elements considered include the width and characteristics of the pathway, close walls and unclear edges, the speed of traffic, interaction with other road users, and vegetation that may block signals.

UTA hosted a tabletop exercise for local stakeholders and emergency personnel to walk through various scenarios.

UTA and the vendor prepared a safety plan and protocols, based on their prior experience. These covered the steps to switch from manual to automated mode, emergency stop procedures, oversight, and incident response. A communications plan was also prepared, which included the crisis communications plan to guide communications in the event of a serious incident.

Procurement and Implementation

Procurement: UDOT product-testing procurement processes allowed for consultation with vendors and open selection of products. Two vendors offered proposals and UDOT executed a contract for LSAV shuttle leasing and operations with EasyMile.

Funding: UDOT funded the project through state transportation funds, as part of the connected and automated vehicle program.

Federal and State Approvals: The vendor LSAV was imported and does not comply with the FMVSS. The vendor and UDOT will obtain any necessary FMVSS waivers for each deployment.

The State of Utah allows automated vehicles to operate on public roads; therefore, no permits from the state were required. Property owners' consent is required to operate an LSAV shuttle on private roadways in Utah and consent was received. The first of the deployments is on a private roadway, including a mixed-use development and a ski resort, therefore requiring consent.

Infrastructure: No physical permanent infrastructure improvements are required, and temporary cones/signage is installed at each deployment site for information and localization. The LSAV shuttle is using LiDAR localization and is not requiring DSRC RSU installation for its deployments. A DSRC on-board unit is available on the vehicle and will be used on at least one site to communicate with a traffic signal.

Operations

UDOT published an SOP prepared by the firm WSP. The SOP contains a description of organizations involved, roles, training, potential venues, applicable regulations and permits, passenger rules, and operator safety checklists.

The State of Utah hosts a website (http://www.avshuttleutah.com) with information about deployments, marks the route with branded signage at stops, and conducts marketing efforts about the individual pilot sites. The marketing efforts were a joint effort from UDOT's and UTA's public involvement team and Horrocks, a public engagement consulting firm. The project leaders at UDOT and UTA have been providing "site ambassadors" at each of the route stops to interact with potential riders and answer questions.

In 2019, the Autonomous Shuttle Pilot was operated in Park City in May, Station Park in Farmington in June and July, the 1950 West Business Park in Salt Lake City in July, and the University of Utah in Salt Lake City in August and September. The pilot was operated for events at the Mountain America Expo Center in Sandy from October 2019 to January 2020 and was scheduled for additional venues. These phases were interrupted by the pandemic, and the project was concluded in the fall of 2020.

On July 16, 2019, a 76-year-old rider suffered minor injuries after the LSAV came to an emergency stop. The vehicle was removed from service while an internal investigation was conducted by safety personnel at Utah Transit Authority. They found no vehicle error. As a safety precaution, the following actions were taken: the top speed was lowered from 12 mph to 9 mph, safety attendants increased outreach to riders and warned of potential emergency stops, and adhesive material was added to the seats to reduce the potential to slide from the seat. There was no NTSB investigation.

Evaluation

Key metrics will be ridership, qualitative information about the requirements of operating a low-speed automated shuttle, and public feedback. At the Station Park deployment, the shuttle carried a total of 2,613 passengers over the 4-week period (about 125 per day). The peak day was 205 passengers, which is close to full capacity, and the lowest ridership day had 71 riders. Ambassadors collected 318 surveys on a tablet about their experience.

UDOT will collect ridership and vehicle trip data from the vendor. UDOT will work with a team of cognitive psychologists from the University of Utah who will gauge the public's level of trust in the technology and will assess how trust changes over time.

The project team is currently designing evaluation criteria for technology options to include system design, configuration, and alignment based on

- Capacity, with objectives for capacity-holding peak demand of 330 passengers (capacity must also include on-board bicycles).
- Connections to other transport modes.
- Travel time, with an objective of approximately 7 to 15 minutes end to end.
- Accessibility, with objectives including ADA compliance and ride comfort.
- Expandability and adaptability, including potential new route extensions.
- Environmental management factors include impact on protected wetlands near the North Bayshore area.

APPENDIX F

Canadian Projects

Province	City	Status
Alberta	Beaumont (Western Canada)	Operational
Alberta	Calgary	Complete
Alberta	Edmonton	Complete
Alberta	Edmonton	Complete
Alberta	Edmonton	Complete
Alberta	Edmonton	Complete
Alberta	Okotoks	Planning
Alberta	Wetaskiwin Reynolds	Complete
British Columbia	British Columbia	Planning
Ontario	Ontario	Complete
Ontario	Ontario	Planning
Ontario	Ontario	Planning
Ontario	Ontario	Complete
Ontario	Ottawa	Complete
Ontario	Ottawa	Operational
Ontario	Stratford	Operational
Ontario	Toronto	Planning
Quebec	Candiac	Operational
Quebec	Cities in Greater Montreal Area	Planning
Quebec	Montreal	Complete
Quebec	Montreal	Complete
Quebec	Montreal	Complete
Quebec	Montreal	Complete
Quebec	Montreal	Operational
Quebec	Province of Quebec	Planning

Figure F.1. Canadian LSAV projects.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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