The Automated Mobility District Implementation Catalog:

Insights from Ten Early-Stage Deployments

Stanley Young[1] and J. Sam Lott[2]

1 National Renewable Energy Laboratory
2 Automated Mobility Services, LLC

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5400-76551
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Suggested Citation
Young, Stanley and J. Sam Lott. 2020. *The Automated Mobility District Implementation Catalog: Insights from Ten Early-Stage Deployments*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-76551. https://www.nrel.gov/docs/fy20osti/76551.pdf.

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Golden, CO 80401
303-275-3000 • www.nrel.gov

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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Disclaimer

The data and information provided herein is accurate to the best of the author's knowledge as of the end of 2019, relying primarily on publicly accessible data and news articles, as well as direct but informal communication with project stakeholders. The purpose of the data collection and sharing through this catalog is to convey lessons learned and promote networking among parties and researchers pursuing the deployment of automated shuttle systems. The objective of the research process is to foster the creation of automated mobility districts. Please bring any errors or omissions to the author's attention, and they will be remedied in future editions of the catalog.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the Vehicle Technologies Office through the Energy Efficient Mobility Systems (EEMS), Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative, and the Technology Integration Technologist-in-City (TIC) program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

Foreword

This catalog of information has been prepared by the National Renewable Energy Laboratory (NREL) for the benefit of researchers and stakeholders working in the space of "automated mobility districts (AMDs)," as defined herein, and their prototype deployments, often called "automated vehicle (AV) shuttles." The stakeholder community with whom NREL will progressively share this information and its updates includes researchers, practitioners and collaborators at the U.S. Department of Energy (DOE), U.S. Department of Transportation (DOT), academic research institutions, and the organizations deploying initial AMDs and AV shuttles.

This body of information and data has been arranged as comparative "site deployment" summaries, which were current as of the end of 2019, and serves as a tool to inform those researching or working with existing AV pilot demonstrations. This catalog is also intended to inform stakeholders considering implementations in the future by conveying a history of significant deployments and demonstrations and their related findings and lessons learned. Through this body of information, the intent is that new endeavors can benefit from the experience of others.

If opportunity and funding allow it, NREL plans to keep this catalog up to date and relevant as additional projects and demonstrations come online and reach sufficient maturity to produce appropriate lessons learned. Indeed, since the contents of this document were finalized, there have been two potentially major impacts on the young AV shuttle industry. In early 2020, the National Highway Traffic Safety Administration (NHTSA) put a hold on all EasyMile operations within the United States while a safety issue was assessed, and vehicle modifications were proposed and developed. Secondly, COVID-19 has caused essentially all AMD sites to cease operations due to the issues of passengers and operators riding in close proximity. COVID-19 and the essential social distancing for transmission suppression have implications for transit vehicle design and operations including vehicle capacity, internal features of the passenger cabins, means of sterilization while in service, etc. These and other major forces coming to bear on the AV shuttle industry since the document contents were finalized will be the subject of research as time goes on.

As a "living document" that will be continually improved and advanced, the submittal of additions and corrections to information in this catalog is welcomed and encouraged.

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List of Acronyms

AAA	American Automobile Association
ADA	Americans with Disabilities Act
ADS	automated driving system
AES	automated electric shuttle
AMD	automated mobility district
APM	automated people mover
AV	automated vehicle
CITA	Collaborative Institutional Training Initiative
DOE	Department of Energy
DOT	Department of Transportation
DSRC	dedicated short-range communications
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GRT	group rapid transit
HVAC	heating, ventilation, and air conditioning
IMU	inertial measurement unit
IRB	Institutional Review Board
JTA	Jacksonville Transportation Authority
LIDAR	light detection and ranging
NHTSA	National Highway Traffic Safety Administration
NREL	National Renewable Energy Laboratory
RFP	request for proposals
RTC	Regional Transportation Commission
RTD	Regional Transportation District
RTK	real-time kinematic
RTS	Regional Transit System
TNC	transportation networking company
U^2C	Ultimate Urban Circulator
V2I	vehicle-to-infrastructure
VVVF	variable-voltage/variable-frequency

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1 Introduction

Major disruptive technologies are set to redefine the way in which people view travel, particularly in dense urban areas. Already, ride-hailing services have redefined mobility expectations of a new generation of urban dwellers in some places around the country. Over the next few decades, the proliferation of automated vehicles[1] (AVs), will be enhanced by the next generation of shared mobility. This combination of AV operations with on-demand service will provide convenience of mobility similar to that being exhibited in today's transportation networking companies (TNCs). Shared, automated, public mobility resulting from the cross-hybridization of AVs with on-demand mobility service will bring economic and system efficiencies. Economic efficiencies may be realized by less vehicle ownership and more vehicle "usership." Many companies are already exploring avenues for shared automated mobility through fleet operations as the wave of the future.

Along these lines, a concept called "automated mobility districts (AMDs)" has emerged that describes a campus-sized implementation of automated and connected vehicle technology that is intended to realize the full benefits of an AV shared mobility service within a confined geographic campus or district. In an AMD, automated fleets of "shuttle" vehicles (battery-electric or gasoline engine) are expected to serve most of the mobility needs for people in the district, thereby dissuading the use of personal vehicles. This new "mode" is now being envisioned as one that supports and enhances traditional public transit modes by making access to transit more convenient and efficient for both new and existing transit patrons.

The database of AV technology deployment sites compiled in this catalog documents the growing experience that both private and public entities are accruing through operations within confined districts. These current demonstration pilots are showing the promise of low-speed AV shuttles operating on city streets in urban settings. In the near future, the prototype AMDs discussed herein will be enhanced by larger fleets of automated electric[2] shuttles and will be deployed on existing roadways to serve passengers "on-demand," combined with the targeted use of physically larger and higher-capacity AVs on fixed routes. This functionality will not only save capital costs, but will also provide users with a "customized" service which legacy transit systems operating strictly with buses on fixed routes fail to provide.

This catalog compilation started in early 2019, in part from the National Renewable Laboratory (NREL)'s review of a key reference document by Volpe National Transportation Systems Center (Cregger, Dawes, Fischer, Lowenthal, Machek, and Perlman 2018). This report helped NREL identify the "top ten" sites that were selected for inclusion in this initial catalog, with the descriptions and data sheets representing their status as of the end of 2019.

[1] "Autonomous vehicle" is also a popular term used in the media, although true "autonomy" will not be plausible until Level 5 driving system automation is reached at some point well in the future. For purposes of this report, the vehicle technologies being discussed will be referred to as "automated vehicles"—the term generally known and used within the automated driving technology and automotive industries.

[2] Some deployments may use other alternative fuels like compressed natural gas or fuel cells, and others may use conventional gasoline-powered vehicles, or gasoline/electric hybrid vehicles.

However, this catalog is considered to be a "living document" that will be expanded beyond the ten sites and be further refined as time passes. In its initial form, the ten sites selected for inclusion have had planning and deployment activities underway for several years. Other emerging sites will be added over time as information becomes available and these new deployments mature.

It is noted that implementation of automated electric shuttles in the United States has typically required approval to operate from the National Highway Traffic Safety Administration (NHTSA), primarily because most sites are deploying noncompliant vehicles according to today's standards (e.g., no steering wheel or rearview mirror). When required, the process of obtaining NHTSA approval of a waiver to operate noncompliant vehicles has been an important factor in almost all applicable demonstrations. This aspect of obtaining NHTSA approval is therefore a common and critically important step for most of the deployment sites described in this catalog, with an obvious exception for the deployment site located outside the United States. Therefore, a discussion of certain aspects of NHTSA approval is given below.

1.1 AMD Definition

The concept of an AMD has been in development at NREL for the purpose of researching the benefits to personal mobility and energy consumption when AV technology is applied in a managed fleet context within a limited or confined geographical area. As a U.S. Department of Energy (DOE) facility, NREL has a mission to determine how technology application can improve the quality of life for all Americans, while also reducing energy use.

The Mobility Systems Team within NREL has defined an AMD as follows:

> An Automated Mobility District is a geographically confined district or campus-sized implementation of connected and automated vehicle technology for the purpose of publicly accessible mobility by which all the potential benefits of a fully automated mobility service can be realized.

The concept of an AMD is depicted in Figure 1. The illustration in the figure conveys the concept's applicability to business districts, mixed-use developments, university campuses, and similar major activity centers.

The principal focus within the AMD research initiative is on shared-ride, fully automated (SAE International's classification of Level 4 or 5, i.e., driverless) electric vehicles operating in combinations of fixed-route, flex-route, and on-demand types of service. Although the focus on deployment sites included in this initial version of the catalog has been on low-speed electric vehicle "shuttle" technology[3] during the initial analysis process, AV technology utilizing hybrid or combustion engine propulsion systems are also of interest within the possible AMD concept

[3] Multiple demonstration pilot deployments of low-speed electric shuttles with Level 3–4 automation are being monitored by NREL, and the comparable characteristics are being cataloged to assess their key technology attributes, performance metrics, and operational parameters defining a prototype AMD deployment site.

deployment, particularly in the near to medium term as battery-electric propulsion systems are still evolving.

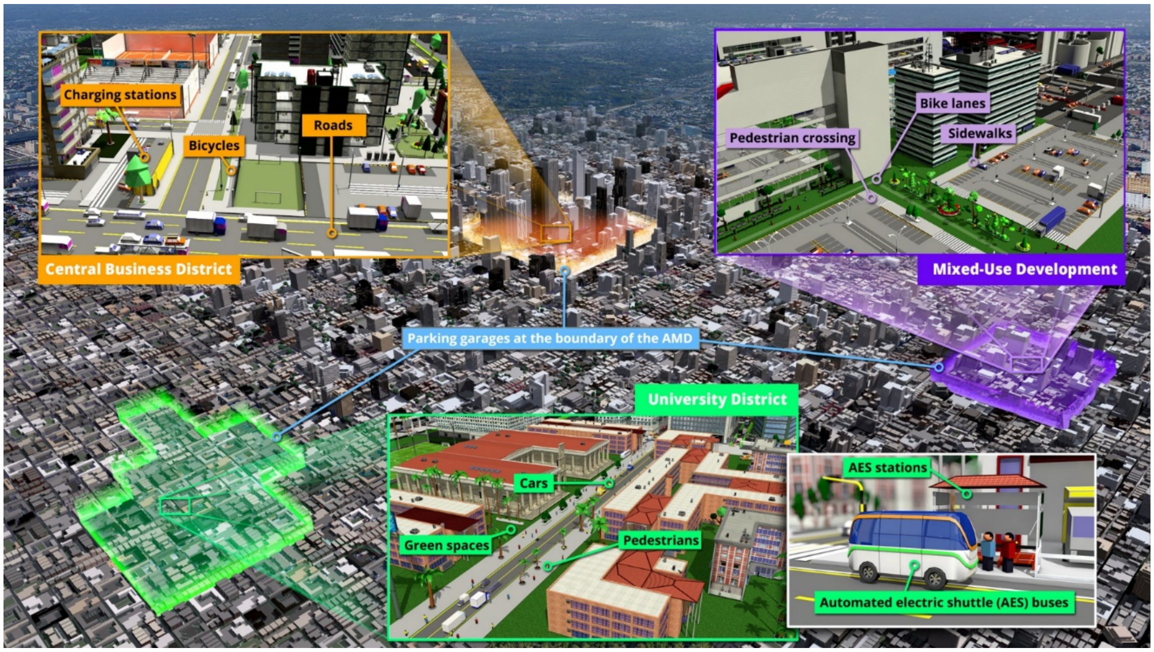


Figure 1. Graphical depiction of automated mobility districts

AMDs are believed to be most relevant in high trip-generation areas that are relatively compact in scale and have well-defined boundaries. AMDs also are characterized as having significant internal trip-demand patterns with both trip ends being internal to the district, in addition to having external-to-internal trip demand when the external trip connects with nearby intermodal travel facilities (like a bus or train station). Districts with such characteristics include dense urban districts and central business districts, major activity centers such as airports, and campus environments such as medical complexes or university campuses.

The key characteristic of AMDs is that internal circulation systems of the type described above can efficiently operate within the boundaries of the district, providing a high-quality alternative to personal vehicle circulation within the district. AMD fleet operations of AVs provide a viable alternative travel option to a personal, single-occupant vehicle when the trip distances or environmental conditions make a purely pedestrian trip unreasonable for internal district "circulation" trips.

The second aspect of an AMD is the provision of efficient shared-ride, AV connections to intermodal facilities in proximity to the AMD, and generally on the perimeter of the service area where high-capacity transit stations, parking facilities, and/or automobile pick-up/drop-off curb fronts can be cost effectively provided. This second aspect of AV shared-ride service will be referred to herein as "first-mile/last-mile" trips.

NREL is currently undertaking research endeavors to develop analytical tools for planning AMD implementation and providing operational insight. A second area of investigation addressed is the conceptual definition of the "management" framework necessary when multiple technology platforms and operating companies are all deployed within the same district or campus location. A "system-level" look at overall operational safety is envisioned as a means to mitigate risk on the part of the authority having jurisdiction over the AMD. Considerations of vehicle-to-infrastructure (V2I) communications are also being discussed as a topic of interest in the context of this AMD jurisdictional management and related safety concerns at complex roadway intersections.

1.2 Requirements and Conditions of NHTSA Approvals

From 2016 through 2019, deployments of AV transit "low-speed shuttle" vehicle platforms have been reviewed on a case-by-case basis by NHTSA for compliance with Federal Motor Vehicle Safety Standards (FMVSS)—which is their primary mission under the U.S. Department of Transportation (DOT). Existing FMVSS were developed when all vehicles had a human driver, and prior to the introduction of AV technologies, which are rapidly evolving. Since several of the deployed AV platforms do not have provisions like steering wheels or rear-view mirrors, it is necessary for NHTSA to provide a "waiver" from compliance with FMVSS before deployment. Further, with the safety concerns as AV technologies in general are tested in places where pedestrians, bicyclists, and other manually operated vehicles are present, NHTSA waiver applications must also describe the operating environment as well as any manually operated movements of the vehicle, even for transfer of the vehicle to its maintenance and charging locations. NHTSA's decisions to provide a waiver and to approve the demonstration pilot's initiation of vehicle operations are therefore based on a multifaceted set of criteria. This decision-making process by NHTSA and the features and characteristics of the vehicle technologies are in a continual state of review within DOT. Further, for vehicles manufactured outside of the United States, obtaining a NHTSA waiver and approval to operate is required before U.S. Customs and Border Protection will release the vehicle for delivery to the site.

The application of some low-speed AV technologies, when deployed in an operating environment protected from other roadway vehicles, has been recognized by NHTSA as satisfying their criteria for a "Box 7" category of research, testing, and demonstration application. With this special category, NHTSA's approval of each specific site deployment, as well as the period of time for which the waiver is valid for operations, has allowed early testing and demonstration projects to proceed throughout the United States. The most common operating environment that has received the Box 7 waiver has been the application of low-speed electric shuttles operating as a transit system constrained to a geofenced area on a fixed route, and typically in areas not exposed to "mixed-traffic" operations with other conventional roadway vehicles. A few, however, have involved mixed-traffic operations, but usually with very low speeds involved.[4]

The site deployments represented in this catalog that have required a NHTSA waiver have had differing experiences in obtaining the approval to operate, with a few having faced a hold placed by NHTSA on their operations based on a strict interpretation and enforcement of the waiver terms granted to the technology supplier or operator (depending on which entity actually applied

[4] The insights gained by Mcity in obtaining the NHTSA waiver approval for their driverless shuttle for operations on University of Michigan roadways in mixed traffic are documented in their Case Study report. See pages 13–14 of the report posted on the Mcity website (University of Michigan 2018).

for the waiver). There have been cases where NHTSA has issued a directive to cease operations for certain circumstances which, for example, involved a different classification of passengers being carried from that described in the Box 7 waiver application, or for vehicle operations occurring along travel paths not strictly defined in the waiver application.

Most of NHTSA's waivers for deployment sites surveyed in this initial catalog have stated that the system is for "testing and demonstration" only and not for normal transit operations in passenger service. NHTSA waivers often state that its approval provides "permission to temporarily import the driverless shuttle for testing and demonstration purposes." In one case where NHTSA determined there was a variance to the operations from the strict details of the operator's AV site waiver application, NHTSA subsequently issued a directive to cease the noncompliant operations. This directive noted that the passenger services in question were "not (for the acceptable use as defined in the waiver application Box 7). (The transit operator) failed to disclose or receive approval for this (special) use."

In December 2018, NHTSA revised the application and review process for vehicle waiver petitions submitted by manufacturers. This revision improves both the efficiency and transparency of the process to focus on the safety review.

With this careful scrutiny by NHTSA over every aspect of the Box 7 waiver details, the waiver process typically requires a 45–90-day waiting period. Further, anytime there is a change to an application's specific operational design domain (e.g., a route change), an updated waiver is required. As described by a representative from one of the AV research and test deployment sites, when their waiver expired they were required to impound or destroy the vehicles. However, since the site owner was planning to hold the vehicles for more internal uses after the test and demonstration project was completed, they applied for a corresponding waiver extension. Further, if any of the vehicles then operating at their site were to be given to another entity in a different site location, a new waiver transfer process would have to be initiated with NHTSA.

The Federal Transit Administration (FTA) has been advancing their policy guidelines for "automated buses," which are defined such that almost all rubber-tired AV transit vehicles would fit the definition. A recent policy document was posted by FTA in July 2019 titled "Frequently Asked Questions: Transit Bus Automation" (FTA 2019). This document provides a broad discussion of the different federal laws and regulations that must be considered when planning an AV transit application, including Americans with Disabilities Act, Title VI, and FMVSS requirements. Other FTA-specific requirements, such as FTA Buy America stipulations, are also addressed.

Within the document, there are several additional links to NHTSA policy papers describing the processes for manufacturers and for entities wanting to import noncompliant vehicles for purposes of research, investigations, demonstrations, and other special uses.

Even with these guidelines, one transit operating company representative noted that NHTSA policy regarding deployment of FMVSS noncompliant vehicles is much clearer for foreign-manufactured and imported AV transit vehicles than it is for noncompliant U.S.-manufactured AV transit vehicles.

1.3 Comparison of Deployment Sites Contained in this Catalog

Selected sets of data are presented below in comparative summary tables. These comparisons are top level in nature, but provide a quick overview of the range of applications and technology features that have been demonstrated over the past few years. As new and emerging site deployments are added to this comparative presentation in future editions of this catalog, a broader spectrum of technologies and applications will be presented and the most critical aspects will become even more apparent.

Table 1 introduces the ten sites and lists a few basic aspects of each site's operational status. Table 2 summarizes key parameters that give insight into the vehicle platforms and the AV technologies, as well as the site deployment characteristics.

Table 1. Comparison of AV Deployment Site Operational Durations and Scale of Operating Routes

AMD #	Site/Owner	Initial Phase	Period of Operations	Next Phase of Operations Planned
AMD #1	Columbus, Ohio Phase 1: Drive Ohio (under Ohio DOT) Phase 2: City of Columbus	Phase 1 1.4-mi Loop	Start: Dec. 2018 End: Sept. 2019	Phase 2 Deployment Linden Neighborhood
AMD #2	Arlington, Texas City of Arlington	Demonstration Pilot 0.75-mi Linear Route	Start: Aug. 2017 End: Aug. 2018	Phase 2 Entertainment District
AMD #3	Las Vegas, Nevada City of Las Vegas	Demonstration Pilot 0.6-mi Loop	Start: Nov. 2017 End: Oct. 2018	Phase 2 Medical District
AMD #4	Jacksonville, Florida Jacksonville Transportation Authority (JTA)	Multi-Vendor Test Phase 0.33-mi Test Track	Start: March 2018 – 1st Vendor End: Aug. 2019 – 2nd Vendor	3rd Vendor On Test Track
AMD #5	University District, Houston, Texas Houston METRO	Phase 1 Pilot 0.5-mi Texas Southern University Shuttle	Start: June 2019 End: Nov. 2019	Phase 2 University of Houston
AMD #6	University of Michigan, Ann Arbor Mcity/University of Michigan	Phase 1 1.1-mi Loop	Start: June 2018 End: Dec. 2019	No Phase 2 Extension Will Occur
AMD #7	Rivium Office Park City of Capelle aan den IJssel	Phase 1 and Phase 2 1.5-mi Linear Route	Start: 1999 End: 2019	Phase 3 Deployment Rivium Business District
AMD #8	Denver, Colorado Regional Transportation District	Demonstration Pilot 1.0-mi Loop	Start: Jan. 2019 End: July 2019	TBD
AMD #9	Gainesville, Florida Gainesville Regional Transit System (RTS)	Phase 1 0.5-mi Linear Route	Start: TBD End: TBD	Phase 2 & 3 Extensions University of Florida/Depot Park
AMD #10	Babcock Ranch, Florida Babcock Ranch Transportation Services	Phase 1 1.0-mi Linear Route	Start: Mar. 2018 End: TBD	On-Demand Services Development-Wide

Table 2. Key Site Technology Descriptive Information

AMD #	Site/Owner	Technology Supplier	Operator	Vehicle Model	Bidirectional/ Unidirectional	Vehicle Capacity (including standing)	Max. Operating Speed (mph)	Sensor Array	Passenger Communications
AMD #1	Columbus, Ohio Drive Ohio (under Ohio DOT)	May Mobility	May Mobility	Polaris GEM	Unidirectional	6	23	LIDAR, Radar, roadside sensing units	Onboard attendant
AMD #2	Arlington, Texas City of Arlington	EasyMile	First Transit	EZ10 Gen1	Bidirectional	12	12	8 LIDAR, 6 stereo cameras, Odometry, IMU	Onboard attendant
AMD #3	Las Vegas, Nevada City of Las Vegas	Navya	Keolis	Autonom Shuttle	Bidirectional	15	16	8 LIDAR, front/rear cameras, Odometry, IMU	Onboard attendant
AMD #4	Jacksonville, Florida	Phase 1: EasyMile	Phase 1: Transdev	Phase 1: EZ10 Gen2	Bidirectional	12	12	LIDAR, stereo cameras, Odometry, IMU	Onboard attendant
	JTA	Phase 2: Navya	Phase 2: First Transit	Phase 2: Autonom Shuttle	Bidirectional	15	16		
AMD #5	Texas Southern University, Houston, TX Houston METRO	EasyMile	First Transit	EZ10 Gen2	Bidirectional	12	8	LIDAR, stereo cameras, Odometry, IMU	Onboard attendant

AMD #	Site/Owner	Technology Supplier	Operator	Vehicle Model	Bidirectional/ Unidirectional	Vehicle Capacity (including standing)	Max. Operating Speed (mph)	Sensor Array	Passenger Communications
AMD #6	Ann Arbor, Michigan Mcity, University of Michigan	Navya	University Logistics, Transportation & Parking	Navya Autonom Shuttle	Bidirectional	15	16	8 LiDAR, front/rear stereo vision cameras, Odometry, IMU	Onboard attendant
AMD #7	Rivium Office Park, Capelle aan den IJssel City of Capelle aan den IJssel	2getthere	Connexxion, a division of Transdev	Group Rapid Transit (GRT)	Bidirectional	22	25	LiDAR, radar and high definition camera pairs, ultrasonic	Intercom
AMD #8	Denver, Colorado Regional Transportation District (RTD)	Transdev	Transdev/ EasyMile	EZ10 Gen1	Bidirectional	12	12	LIDAR, stereo cameras, Odometry, IMU	Onboard attendant
AMD #9	Gainesville, Florida Gainesville RTS	EasyMile	Transdev	EZ10 Gen2	Bidirectional	12	15	LIDAR, stereo cameras, Odometry, IMU	Onboard attendant
AMD #10	Babcock Ranch, Florida Babcock Ranch Transportation Services	EasyMile	Transdev	EZ10 Gen2	Bidirectional	12	12	LIDAR, stereo cameras, Odometry, IMU	Onboard attendant

2 Site #1: Columbus Scioto Mile District Circulator

2.1 Overview

This low-speed shuttle operated in downtown Columbus, Ohio throughout an area called the "Scioto Mile" near Civic Center Drive. Configured as 1.4-mile loop, the self-driving vehicle service—also known as the SMART Circuit—connected the National Veteran's Memorial and Museum with the Center of Science and Industry, the SMART Columbus Experience Center, and Bicentennial Park. This demonstration pilot deployment was a centerpiece of the SMART Columbus initiative and it operated between December 2018 and September 2019. This pilot project was primarily funded through the cost-share commitment of Ohio's DOT for the U.S. DOT grant awarded to Columbus in the Smart City competition, and was administered by Drive Ohio, the Ohio DOT initiative that is advancing smart mobility projects across the state.

Columbus was the first public deployment of the May Mobility technology, and the second May Mobility deployment overall. It was a complete operational system built around the Polaris GEM battery-electric vehicle platform, which was already certified by NHTSA to operate on public roads. The vehicle has a five-passenger capacity, with one additional "driver/attendant" also onboard.

Figure 2. Route map (left) and vehicle technology (right)

Source: DriveOhio 2019

2.2 Period of Project Deployment

The service was operational between December 2018 and September 2019, after which the option to extend the operating period was not exercised and the focus of SMART Columbus shifted to implementation of the Linden deployment.

The nature of the SMART Circuit service was as a connector between what are primarily "tourist" attractions around the Scioto Mile area. As such, the ridership was found to be quite low during the cold winter months, even though the service ran from 6 a.m. to 10 p.m. every day. As of the end of the deployment, the total ridership was 16,026 passengers.

By the nature of the service area, it was found that ridership increased significantly during times of the year when school is out and the weather is warmer, primarily during the summer months.

2.3 Description of the Operational System

The May Mobility automated electric shuttle technology as it was deployed in Columbus is offered as a complete operating system, with installation, operations, and maintenance all provided through a direct contract with May Mobility, Inc. The automated driving system (ADS) component of the vehicle controls is considered to be a “self-driving” system, with a safety operator (called “fleet attendants” by May Mobility) always in the vehicle to monitor the vehicle operations and to take control when necessary. A dedicated operations control center was located in Columbus, with May Mobility staff managing all aspects of operations and maintenance from this location.

The system deployment included the installation of roadside sensing units, which are designed to monitor road conditions such as the status of traffic signals using video camera technology and transmit this information to the vehicles using cellular communications.

The vehicle platform applied by May Mobility for the Columbus project is a customized version of the Polaris GEM battery electric vehicle, described as a low-speed electric vehicle.

May Mobility has chosen the Polaris GEM e6 vehicle platform, in part because of its approval by NHTSA for operation on public roads, complying with FMVSS 500 regulations. The six-seat vehicle is accessible by passengers through manually opened doors, two doors on each side with a wider door to access the back passenger compartment configured with two sets of facing seats (“campfire” seating for four passengers). During the course of the year’s operation, this modified vehicle design was deployed by May Mobility (shown in Figure 2), which allows a wheelchair to be accommodated within the reconfigured seating and door arrangement. SMART Columbus offered Americans with Disabilities Act (ADA)-compliant service in the service area using this modified configuration prototype vehicle, but operating under manual control only.

The vehicles traveled 1.4 miles each round trip, with three of the six vehicles in service during peak periods on headways of 10 minutes (contractual requirement) or less. Four stops were served during each round trip.

2.4 Operational Analysis – Status and Complexity

The relative simplicity of the operating environment and the straightforward loop route with four stops was not studied using modeling or simulation tools. The operational dwell times and the timing of service stops have been refined through observations and adjustments.

With the total fleet being twice the necessary operating fleet during peak ridership periods, and with round-trip times typically being less than 15 minutes (including dwell times), the ability of the system to provide the necessary 10-minute maximum headways was not of concern.

2.5 Challenges Faced and Lessons Learned

The challenges and issues faced by this project, as a “first of its kind” in many ways, primarily involved the legal contract, governmental authorizations to operate, and multiparty cooperation and communications. A general problem area that needed a strong cooperative effort was data collection by May Mobility and related to confidentiality concerns—generally requiring that a common understanding be reached by all parties on what data were needed and for what purposes.

Roadside infrastructure installed by May Mobility was of a special design and did not strictly conform to the expected dedicated short-range communications (DSRC) equipment installation needs. This required a special arrangement for power supply installation that was not typically provided by the municipality.

Other issues related to where the stops could be located while complying with the Manual on Uniform Traffic Control Devices and city traffic regulations for signage, striping, and suitable pedestrian access provisions.

2.6 Other Reference Documents

The "lessons learned" document is available from the SMART Columbus website (SMART Columbus 2019).

3 Site #2: Arlington Entertainment District Milo Circulator

3.1 Overview Description

This was one of the first automated electric shuttle (AES) demonstration pilots in the United States. It deployed two EasyMile vehicles along a route operated in conjunction with sports events occurring in either the Cowboys' football stadium or the Rangers' baseball stadium in Arlington, Texas. The longest of the three operating routes (depending on the event being served) was 4,000 feet (0.75 miles) from end-to-end, or 1.5 miles round trip. All routes carried passengers to and from parking and the sports stadiums via a 10-foot-wide pedestrian walkway without entering mixed traffic.

This demonstration pilot has provided the City of Arlington a means of learning firsthand the benefits and challenges to deploying AV technology. The functional purpose of Milo was a first/last mile circulation connection within the Entertainment District. The "mile 0" designation became known as "Milo"

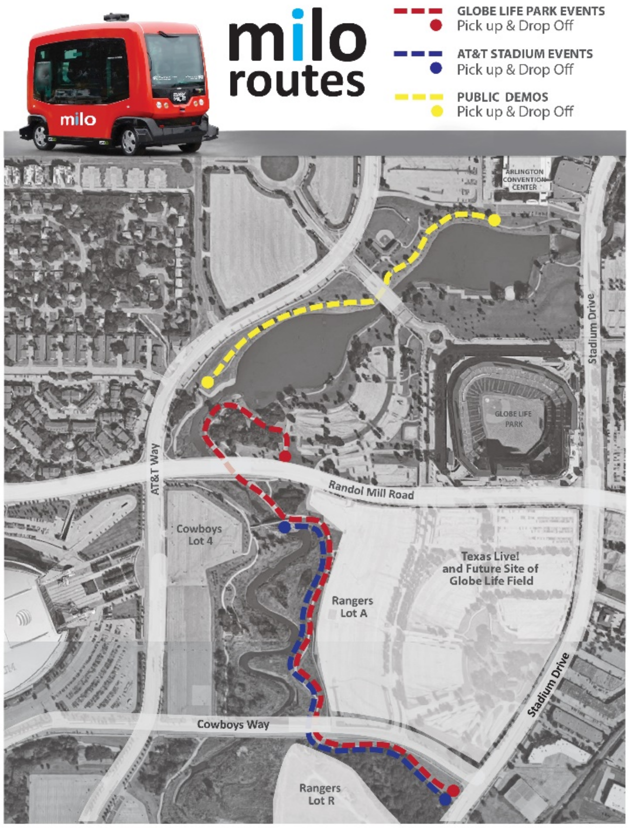


Figure 3. Milo route map

Source: City of Arlington

Milo was implemented with the first-generation EasyMile EZ10 low-speed shuttle, a vehicle designed to provide seating for six passengers and six standees, but with operating speeds limited to 15 mph for this deployment. First Transit was contracted as the day-to-day operator for stadium events, and city staff operated the vehicles for public demos and special tours. During that time, Milo serviced 78 stadium events, 17 public demos, 18 group demonstrations, and 3 special events.

Figure 4. EasyMile EZ10 vehicle technology

3.2 Period of Project Deployment

Arlington operated the vehicles for a total period of 12 months, ending in August 2018. During this period, some delays occurred for brief periods of time as technical issues with this first-generation vehicle were resolved by the EasyMile engineering team.

3.3 Description of the Operational System

Three operating routes were used, depending on the events and venues being served, including a route to serve AT&T Stadium (NFL football) and Globe Life Park (MLB baseball) from a remote parking lot. Each linear route had two dedicated stops at the beginning and end, and the route round-trip distances varied between 0.75 and 1.5 miles in length. Not all routes were operated simultaneously due to only having two vehicles in the fleet.

The EasyMile EZ10 vehicles were designed and manufactured in France. The first-generation EZ10 vehicle included a wheelchair ramp that was deployable by either the attendant or a passenger with the push of a button. The vehicle ADS utilized light detection and ranging (LIDAR), wheel odometry, and inertial measurement units (IMUs), as well as network real-time kinematic (RTK) technology (the European version of GPS) for vehicle "localization." Stereo cameras are also included in the EZ10 sensor array, but were not operational in Arlington. 4G telecommunications links connected the vehicles to the operations center in France for continuous monitoring.

The ADS component of the vehicle controls is a "self-driving" system, with a safety operator always in the vehicle to monitor operation and to take control when necessary.

3.4 Operational Analysis – Status and Complexity

The fairly simple linear route configurations and the use of only two vehicles did not require any advance operational analysis. Further, due to its operation along a pedestrian pathway the shuttle did not encounter other vehicles throughout any of the operating routes. The vehicle deployment operational complexity was not difficult, in that the shuttles were deployed only during the beginning and ending of the sporting events. For example, a game beginning at 7 p.m. and ending at 10 p.m. had Milo shuttle service between 6 p.m. and 8 p.m. and between 9 p.m. and 11 p.m., with vehicles having their batteries charged between the service times.

3.5 Challenges Faced and Lessons Learned

One of the first challenges faced was securing correct insurance for the project. Most insurance was carried by the vehicle supplier/owner (EasyMile) and the system operator (First Transit).

A second challenge was the effect of underpasses and the impacts of overhead foliage on the vehicle's localization (knowing its precise location). Some modifications to the site were required to provide proper clearances for the vehicle and to establish fixed objects to assist with the vehicle's localization.

With regard to safety, Arlington believes that the technology provided a suitably robust protection from the safety systems onboard.

In passenger surveys, Arlington found that there was strong acceptance of the AV technology by those who used this service. Ninety percent of those surveyed strongly agreed that it was an enjoyable experience, and 87% would ride again. Regarding safety, 93% felt safe riding and 84% supported the continued deployment of AV technologies.

In a final closeout report on the project (City of Arlington 2018), the City of Arlington states that they believe there is great potential of the technology: "AV technology is improving rapidly and the City of Arlington is excited to be part of the testing, process improvement, and path toward wider adoption."

Finally, the initiative of the City of Arlington to test AV applications continued following the Milo pilot project with the contracting of Drive.ai to operate a demand responsive service in the Entertainment District. The Drive.ai deployment of self-driving Nissan NV200 was operational for several months, up until the time Drive.ai announced it was closing its doors as a company. The lesson learned is that during these early years with small start-up companies, an operations contract does obviate business failures.

4 Site #3: Las Vegas Fremont East Entertainment District Self-Driving Shuttle

4.1 Overview

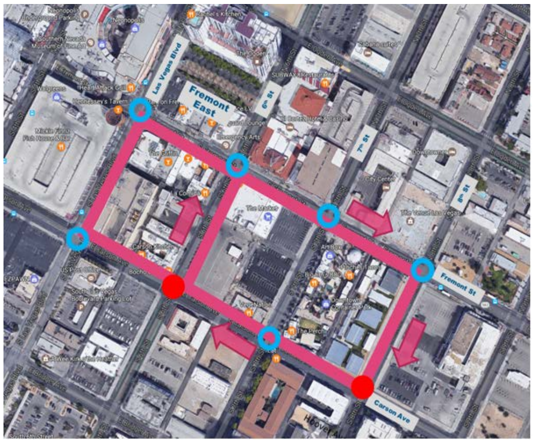
The Keolis/American Automobile Association (AAA) “self-driving shuttle” operated in the Innovation District located within downtown Las Vegas, Nevada in an area known as the Fremont East Entertainment District that sees over 20 million visitors per year. The main pick-up/drop-off location was located near a shopping complex known as Container Park. The pilot was a joint endeavor between AAA, the City of Las Vegas, the Regional Transportation Commission (RTC) of Southern Nevada, and Keolis North America. Automated Navya Autonom vehicles were operated on city streets through mixed traffic, as well as through signalized intersections serving a high level of pedestrian activity along the 0.6-mile loop route that encircled three square blocks.

Keolis, which owned a 40% share of the Navya vehicle technology at the time, served as the primary operator and maintainer during the pilot project in partnership with the city. AAA provided “host” attendants at the three station stops where anyone could board to ride the vehicle during service hours.

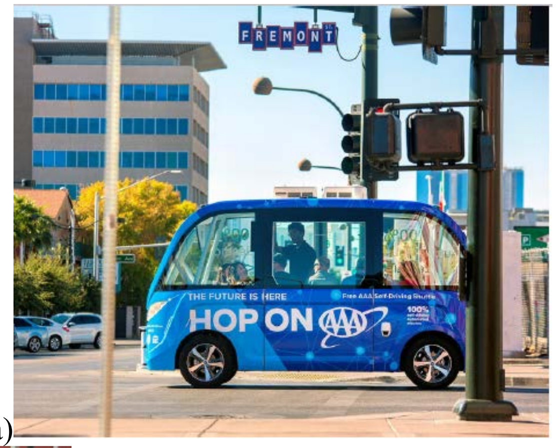
AAA’s objective in helping fund the demonstration project was to demonstrate self-driving shuttle technology to the entire country. AAA surveyed riders on their experience in order to understand why a large percentage of consumers remain wary of driverless technology, and whether a personal experience would change their perception.

4.2 Period of Project Deployment

The initiation of the demonstration project occurred in November 2017. Billed by AAA as “the nation's first self-driving shuttle pilot project geared specifically for the public” in their November 8, 2017 press release, the project continued to operate through October 2018 in accordance with the original plan (PRNewswire 2017). There were no known delays to the project, other than a minor traffic accident caused by another driver.



(a)



(b)

(c)

Figure 5. (a) Route map; (b) route along Fremont Street; (c) vehicle technology

Source: City of Las Vegas and American Automobile Association

4.3 Description of the Operational System

This deployment was a second-generation design that did not include a built-in wheelchair ramp, although this feature was at that time in design for the next-generation Navya vehicle. The service operated Tuesday through Sunday between 11 a.m. and 7 p.m. along the route shown in Figure 5a. The map shows blue circles where there are traffic signal-controlled intersections, and red dots at all four-way stop signs. During periods of heavy congestion, the alternative route shown on the map (upper left) was used to bypass the heavy congestion along Las Vegas Boulevard.

The Navya vehicles have a sensor array comprising eight LIDAR, front/rear cameras, wheel odometry, and IMUs onboard the vehicle, with localization provided by “differential” GPS that includes fixed beacon locations in proximity to the operating site. As a provision to assist the vehicle through conditions beyond its ability to navigate, a safety operator was always in the vehicle to monitor the vehicle operations and take control when necessary.

In addition to the onboard sensors, V2I communications using DSRC technology were used to tell the vehicle the traffic signal status at six of the eight intersections. In addition, the vehicle passed through all-way stop signs at other intersections along the 0.6-mile route, with the vehicle sensor array ensuring safe progression through the intersections. A 4G communications link provided continuous transmissions of vehicle operational status and hardware/software diagnostics to the Navya engineering and operations center in France.

4.4 Operational Analysis – Status and Complexity

The level of traffic activity was of a low to moderate level within this small “district.” The route comprised a relatively short length with all right-hand turns, and therefore the operating conditions were relatively simple. With this operational simplicity and no requirements for headways or passenger carrying capacity, nor any concerns about managing “fleet” operations, there was no need for analytical modeling studies to be performed for this deployment.

4.5 Challenges Faced and Lessons Learned

The deployment in Las Vegas provided good insight to the city and RTC about management of AV technology in transit service. For example, it was found that coordination between operations staff and police/fire departments is an important aspect of both initial preparations and ongoing operations management. Also, it was learned that the continual management of curb space at dedicated stops is a constant challenge, since other vehicles (such as delivery vehicles) would frequently stop in these designated shuttle boarding locations. Mobile operations support staff within the service area typically had to intervene and clear the space to allow the shuttles to properly pull to the curb so passengers could safely board and alight the vehicle.

The overall public perception was good, with the experience scoring 4.9 out of 5.0 for the 20,000 passenger trips during the first six months of operations. This positive response, and the continued endorsement of the evolving AV technology, resulted in a commitment of public officials to move to a larger and more purposeful transit deployment in the next phase.

In December 2018, the RTC, in partnership with the City of Las Vegas, received a $5.3M grant from DOT to fund the next phase of self-driving shuttles. A small fleet of automated shuttles will be deployed in the Las Vegas Medical District, which is close to the original demonstration pilot site. Operations of the “GoMed” service are currently planned to begin in 2021 when four self-driving vehicles begin to operate along a four-mile route between the Las Vegas Medical District and the Bonneville Transit Center downtown.

5 Site #4: Jacksonville Ultimate Urban Circulator (U^2C) Initial Test Track Pilot

5.1 Overview

Several years ago, the Jacksonville Transportation Authority (JTA) in Jacksonville, Florida began planning to replace the aging automated people mover (APM) system that operates along an aerial guideway structure through the Jacksonville central business district. The conclusion was that AV technology would soon allow an upgrade to an AES system with greater alignment and operational flexibility. Known as the Automated Skyway Express, the initial "Phase 1A" segment of the APM fixed-guideway system originally began operations in 1989 with a rubber-tired vehicle technology operating in an open-channel viaduct—similar to a roadway viaduct.

This elevated transitway alignment was extended through the heart of the central business district in the 1990s for a small monorail system, retaining the viaduct configuration. Currently, the aerial transitway system comprises 2.5 miles of dual-lane structure, with eight stations and a crossing of the St. Johns River on the Acosta Bridge. This structure provides an elevated "roadway" along which AV technology will eventually be deployed.

The initial series of AV demonstrations began in March 2018 along a 1/3-mile test track located at at-grade level. This test track is within the sports complex surrounding the stadium for the Jacksonville Jaguars football team, near Metropolitan Park in downtown Jacksonville. The dedicated and protected lane on which the shuttles operate connects a station at A. Philip Randolph Boulevard to a station at Daily's Place in front of the TIAA Bank Field football stadium. Different AES vendors have been invited to provide a demonstration pilot operation for six months along the single-lane test track, with passenger service limited to times during special events. Passengers are simply transported between two end-of-line stations. Other testing is also being conducted by JTA.

Figure 6. EasyMile vehicle on test track

Source: Jacksonville Transportation Authority

The first six-month period of test track operations deployed a single EasyMile vehicle during 2018, with Transdev performing operations and maintenance responsibilities. A second test track demonstration phase has deployed a Navya vehicle, with First Transit performing operations and maintenance services. A third technology will be tested during a six-month demonstration with the request for proposals (RFP) from AV technology suppliers on October 9, 2019. Notice to proceed on the third phase of testing was still pending as of the date of this publication at the end of 2019.

The future components are in developmental stages, but the planned progression of U^2C system deployment phases are as follows:

- Autonomous Avenue – Converting a short section of elevated transitway as a second phase of testing
- Bay Street Innovation Corridor – Developing an at-grade system in dedicated lanes connecting downtown Jacksonville to the sports complex, serving 6–10 station stops along a two-mile length
- Agile Plan – Deploying short (less than half-mile) AV service at approximately 20 locations
- Converting the remaining elevated transitway structure to accommodate AV operations along its length
- U^2C Buildout – Extending the system to a 10-mile length by connecting the 2.5-mile elevated transitway system to new at-grade extensions by building connecting ramps down to ground-level transitways.

5.2 Period of Project Deployment

The planning is underway for the phases that will come after the initial test-track period. This scheduling and program planning is a work in progress and has not been finalized.

Figure 7. U²C system will include aerial segments (green) and at-grade segments (blue) with transitions to grade

Source: JAX Transit Innovation Corporation and Source: Jacksonville Transportation Authority

5.3 Description of the Operational System

The initial test phase of the multiphase project is deploying several different low-speed shuttle vehicle technologies as JTA broadly assesses this class of technology. The ultimate deployment along the elevated transitway, after removal of the monorail system, would be possible without major structural modifications for the EasyMile or Navya vehicle sizes. Other AV technologies may also be tested.

JTA's plan is to first deploy a selected vehicle technology along one segment of the aerial transitway, and then proceed to retrofit the entire 2.5-mile transitway. Connections to grade will extend the transitways to an ultimate length of 10 miles, as illustrated in Figure 7.

5.4 Operational Analysis – Status and Complexity

The initial operations along the test track have a shuttle configuration with a single vehicle operating in a protected and dedicated lane. However, the future deployments being investigated for locations that will involve more complicated operations and mixed-traffic environments are currently planned for analysis through modeling studies during future phases of the project.

5.5 Challenges Faced and Lessons Learned

JTA had to obtain a NHTSA waiver for vehicle noncompliance with FMVSS in order to begin the test-track phase of the operations.

One of the most significant findings from the initial test-track operations is the detrimental effect of rain on the AES operations, at times requiring vehicle operations to cease until weather conditions improved.

6 Site #5: Houston University District AV Transit Circulator

6.1 Overview

The University District AV Transit Circulator is being deployed in two initial phases in Houston, Texas. The first is a half-mile-long shuttle with one vehicle operating along the Tiger Walk pedestrian facility in the middle of the Texas Southern University campus. Phase 2 is being planned to extend the route half a mile off campus on city streets to reach a nearby light-rail transit station on the edge of the University of Houston campus.

Phase 1 is only a demonstration pilot; however, it is operating during specific times of the day and provides a convenient alternative to walking for students traveling along the spine corridor of the campus. The effort also provides Houston METRO (the contracting authority) a pilot project for automated shuttle applications in urban districts. Through this initial Phase 1 deployment, METRO is gaining a better understanding of the necessary infrastructure installations, operational challenges, and public acceptance issues that will be faced in the Phase 2 deployment on public roads.

The Phase 1 deployment was contracted by METRO to First Transit following a competitive RFP process. The initiation of passenger service occurred at the beginning of June 2019, with a single EasyMile EZ10 second-generation vehicle being operated and maintained by First Transit. This vehicle operates in a lane designated by painted markers along the center of Tiger Walk, with pedestrian or bicycle crossing of the lane possible at any point (i.e., the shuttle is not operating in a physically protected lane).

Figure 8. Route map and vehicle technology at Texas Southern University

Source: Houston METRO

6.2 Period of Project Deployment

The RFP process began in June 2018, with the original expectation that the vehicle would be operating for a six-month lease period, during which passenger service would be provided throughout the Spring 2019 semester. A combination of delays due to contract negotiations, as well as delays to the delivery of the new EZ10 vehicle coming from the factory in France, resulted in the initiation of passenger service at the end of May 2019. The operating period of the Phase 1 demonstration has now been extended from the original conclusion date of November 2019 to March 2020, in part due to these delays.

6.3 Description of the Operational System

The First Transit proposal originally suggested several alternative vehicles that would allow deployment of an automated vehicle with ADS controls providing a "self-driving" system. First Transit's proposal provided for maintaining a safety operator in the vehicle to continuously monitor the operations and to take control when necessary.

As part of the final negotiated contact agreement, METRO agreed to the deployment of one bidirectional EasyMile EZ10 vehicle with six seats and provisions for another six standing passengers. The second-generation EZ10 vehicle design has an improved access feature of a semiautomated wheelchair ramp, which extends from underneath the passenger compartment floor upon the activation of a push button by the onboard attendant or potentially by a passenger.

The bidirectional vehicle has doors on only one side. Alternative route alignments tested during vehicle commissioning included turning the vehicle around with a 180° turn at each end of the shuttle route, as well as operating the vehicle with its bidirectional capabilities, allowing a simple shuttle operation in which reversing the head end is performed by the automated control system. The placement of the final station stop positions was ultimately the determining factor in the decision to operate the vehicle as a bidirectional simple shuttle. When operated as a "loop" with a single continuous direction of travel, the side of the vehicle with the door location was on opposite sides of the Tiger Walk (i.e., during westbound movement the door was on the south side versus eastbound movement with the door on the north side) for the two intermediate stations. This was confusing to passengers and affected the decision for bidirectional operation of the vehicle.

The half-mile-long shuttle route provides a headway of about 12 minutes for the single vehicle in operation. Midday charging of the vehicle's batteries occurs during the time between the two periods of scheduled operation: 8 a.m. to 2 p.m. and 5 p.m. to 8 p.m. First Transit personnel are continuously present on the vehicle, and the vehicle's operational status is monitored at EasyMile's engineering offices in France.

6.4 Operational Analysis – Status and Complexity

The shuttle operations are quite simple, and there was no need to perform analytical modeling of the Phase 1 operations. Round-trip times were adequately calculated "by hand," since there was neither a specified schedule of operations nor a minimum ridership capacity requirement. With the Phase 2 operations entailing a "first-mile/last-mile" service feature through an extension to reach a high-capacity light-rail transit system, analytical studies and simulation modeling could be beneficial in the subsequent phase of work.

6.5 Challenges Faced and Lessons Learned

The primary issues facing the Houston University District AV Transit Circulator deployments will come in the next phase from governmental approvals to operate in mixed traffic and cross over a light-rail line. Although the State of Texas has passed legislation that allows AV operation on public roads, the specific approval to allow the Phase 2 deployment will be needed by NHTSA, the City of Houston and the University of Houston (where the connecting light-rail station for Phase 2 is located). These entities will actively participate in planning for the eventual Phase 2 deployment.

NHTSA's approval to operate, which is technically a waiver of the vehicle's compliance with FMVSS regulations, was obtained for Phase 1 with the vehicle operating on a private pedestrian facility. Obtaining the necessary NHTSA waiver approval for Phase 2 deployment on public roads and in mixed traffic will be a significantly greater challenge.

7 Site #6: Ann Arbor University of Michigan Mcity Driverless Shuttle

7.1 Overview

Mcity, located at the University of Michigan in Ann Arbor, is one of the premier university research centers in the field of automotive research, and in recent years has become a leader in testing connected and automated vehicle technology. With a number of private firms collaborating as “affiliate” members of Mcity’s research programs, there was a natural research and development environment that attracted the French firm Navya to become an affiliated member in 2016. Throughout 2017, this collaborative initiative research program at the Mcity Test Facility put Navya vehicles through a variety of operational and environmental tests by Mcity and Navya researchers.

Figure 9. Navya Autonom vehicle technology

Source: University of Michigan, M-City

Beginning in June 2018, the driverless shuttle deployment took the step as a research project focused on challenges and opportunities of operating driverless shuttles in a mixed-traffic environment. This research continued on to collecting data and assessing the driverless shuttles’ interactions with riders, pedestrians, bicyclists and other vehicles until December 2019. Throughout the time passenger service was provided, two Navya vehicles transported University of Michigan students, faculty, and employees at the North Campus Research Complex.

Over the last few years, the research program has produced reports that are helpful to the entire industry, such as the Mcity Driverless Shuttle case study report that further documents the objectives, research, and findings from a full year of testing followed by a second year of passenger operations (University of Michigan 2018).

7.2 Period of Project Deployment

The Mcity Test Facility provided a protected research environment for the initial year of testing. The testing within the facility occurred along streets and intersections that mimic an urban setting within which controlled conditions could be imposed on the operating vehicle to assess its response to roadway environments, intersections, and critical scenarios prior to actual deployment on the passenger service route. These test conditions were based on what a vehicle might encounter when operating along the planned future route, comprising a series of "challenges" such as pedestrians at crosswalks, cyclists traveling along the roadway, and vehicles at intersections.

Near the end of 2017, a contract between the University of Michigan and Navya was established under which two new vehicles were to be delivered and prepared for initiation of passenger service in June 2018. The vehicle operations were handled by the Logistics Transportation and Parking division of the university, with the maintenance to be performed by Mcity staff throughout the operational period ending in December 2019.

7.3 Description of the Operational System

Campus trips between the two stations at the parking area in the south and the North Campus Research Complex buildings were served every five minutes by a shuttle as the two Navya vehicles moved continuously along the loop route (Figure 10), with a one-mile round-trip distance. Vehicles operated along the route in mixed traffic on University of Michigan campus roadways while passing through seven stop signs (indicated by the red dots in Figure 10) and two shuttle stops—one at each end of the North Campus Research Complex.

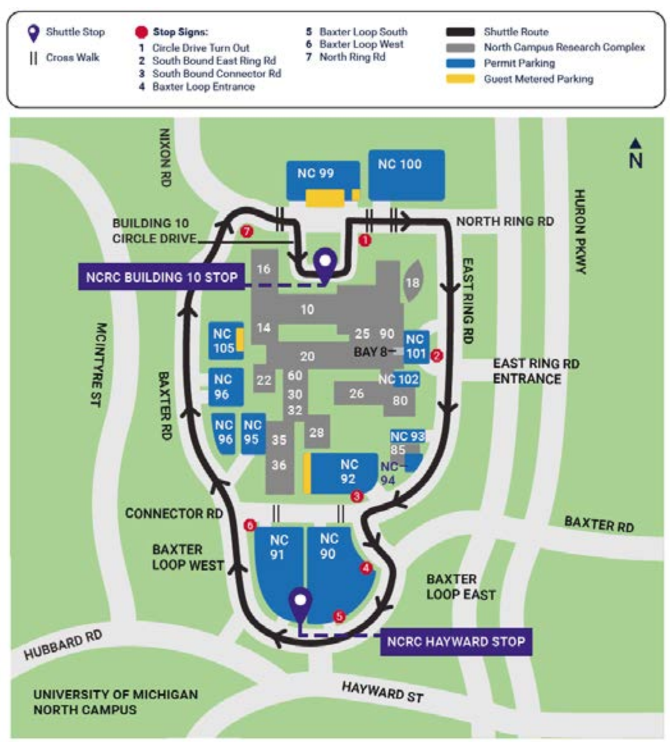


Figure 10. Map of shuttle service on University of Michigan's campus

Source: University of Michigan, M-City

The shuttle service operated Monday through Friday between 9 a.m. and 3 p.m.—a cycle time that sufficient for even extreme weather conditions, which can accelerate the battery charge depletion. Charging of the vehicle's batteries was performed in a location along the route.

The Navya Autonom vehicles were configured with a sensor array comprising LIDAR, front and rear stereo vision cameras, odometry, and IMUs for the ADS controls. Localization equipment included the normal global navigation satellite system enhanced with RTKs utilizing a single beacon that adequately served Mcity's multiple research endeavors.

A special assembly of cameras and sensors was installed specifically for research data collection apart from the sensor array that the vehicle used in the ADS controls. These sensors provided a data stream of audio, video, and sensor information by which Mcity researchers assessed the vehicle's interactions with other drivers, pedestrians, and obstructions encountered along the vehicle's path. This specially designed and implemented data acquisition system accomplished collection, synchronization, and transmission of data to Mcity's cloud systems for later processing by researchers authorized to access these data.

7.4 Operational Analysis – Status and Complexity

There was no operational analysis performed through simulation modeling prior to the start of passenger service. Rather, the extensive test program of a Navya vehicle onsite at Mcity during 2017 provided sufficient information to assess the performance and operational factors of the passenger route before service began in mid-2018.

7.5 Challenges Faced and Lessons Learned

Mcity utilized an extensive research program in which both NHTSA and Michigan DOT provided direct input to the planning and preparations for passenger service. The Mcity Driverless Shuttle case study report provides excellent documentation of all that was done to prepare for the second phase of operations, following the extensive testing that occurred (University of Michigan 2018). In particular, the report describes the Operational Design Domain for the specific deployment site and operating route, with dynamically changing weather, roadway and traffic conditions, and construction impacts.

8 Site #7: Rivium 3.0 AV Transit Circulator System, Rotterdam/Capelle aan den IJssel

8.1 Overview

In a suburb of Rotterdam, Netherlands, the small city of Capelle aan den IJssel is home to the fully automated electric shuttle system that serves the Rivium Office Park—a commercial development that is across a major motorway from an important Rotterdam Metro rail station. The current expansion phase of the Rivium system will create a prototype AMD with an internal transit circulator system.

In 1999, the small company 2getthere was contracted to deploy a fully automated system of three vehicles which operated along a 3/4-mile-long dedicated transitway between the subway station and the edge of the Rivium Office Park. The technology deployed was the same as was soon operating at the Amsterdam Schiphol Airport remote parking lot, dubbed the "ParkShuttle." During a second expansion phase opening in 2006, the original driverless vehicles were replaced by six second-generation vehicles and the route was extended another quarter mile throughout the length of the Rivium Office Park, serving a total of five stations.

Rivium 3.0 is the expansion currently underway to reach a total length of 2.5 km (1.7 miles). The additional route length will allow six larger and higher-speed third-generation vehicles to travel beyond the current transitway to operate in mixed traffic on city streets within the Rivium business district. This ultimate transit line will serve nine passenger stations and traverse eight roadway intersections between the Kralingse Zoom subway station in Rotterdam on the north end to a new Waterbus ferry terminal (opening in 2020) on the south end at the Nieuwe Maas River.

Since the original Rivium 1.0 system began operations, the system has been operated by Connexxion (a subsidiary of Transdev) and maintained by 2getthere. A new contract extension through 2033 has been issued to Connexxion by the Rotterdam regional transportation authority. Further, a significant change to the system supplier's business structure has occurred, which strengthens this source of supply. 2getthere now has a 60% majority ownership by ZF—a major automotive parts and technology supplier with factories in the United States and around the world.

Figure 11. 2getthere vehicle technology: (top left) Rivium 1.0 ParkShuttle vehicle, 1999–2005; (top right) Rivium 2.0 GRT vehicle, 2006–2019; (bottom) Rivium 3.0 GRT vehicle, 2020–2039

Source: 2getthere

8.2 Period of Project Deployment

The original project that began operation in 1999 was 2getthere's first deployment of the low-speed vehicle technology specifically for passenger service. This followed the successful deployment of AVs carrying shipping containers at the Port of Rotterdam. The prototype passenger vehicle design was also deployed at Amsterdam Schiphol Airport as the Parking Hopper system in a remote parking lot. In 2006, 2getthere introduced the second-generation vehicle at the same time that the transitway was lengthened to extend through the business park (see Figure 11, top right). The GRT vehicles travel along a dedicated lane that has grade crossing arms at five roadway intersections that protect motorists and pedestrians from traveling across the active transitway when a shuttle vehicle is approaching. The third-generation GRT vehicle design from 2getthere is now in the process of being deployed as part of the Rivium 3.0 expansion. This current project, when completed, will provide transit service through the heart of the mixed-use Rivium urban district starting in 2020.

8.3 Description of the Operational System

The new Rivium 3.0 vehicles have a capacity of 22 passengers (8 seated and 14 standing passengers) and are configured as minibus-sized vehicles that operate as an unmanned, fully automated system in mixed traffic. This same vehicle technology is currently being implemented in several places around the world, including Brussels Airport (11 vehicles operating in mixed traffic by 2021).

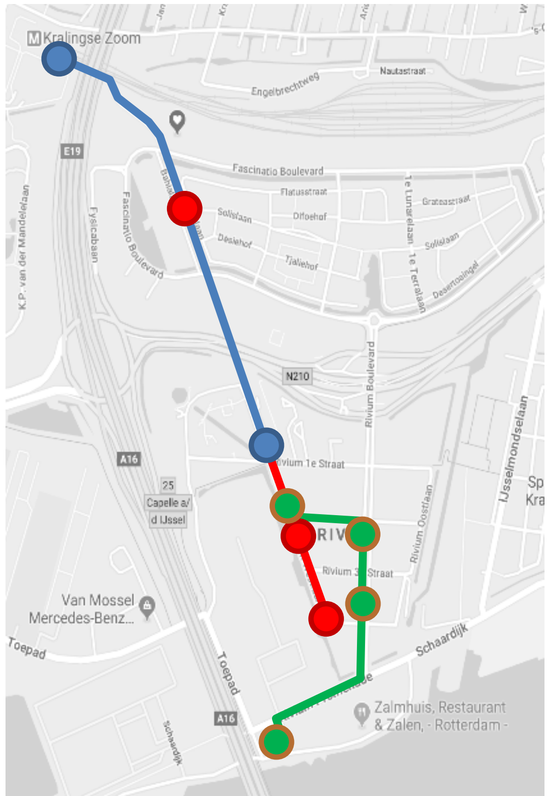


Figure 12. Route map, Rivium office and residential district; Rivium 1.0 starter line, 1999–2005 (blue); Rivium 2.0 first expansion, 2006–2019 (red); Rivium 3.0 full buildout, 2020–2039 (green)

Source: 2getthere

During the 20 years that the Rivium system has been in operation, the vehicles have carried over eight million passengers. Throughout that time, the vehicles have operated in Level 4 automated driving along the dedicated transitway without a safety operator or attendant. For the current Rivium 3.0 deployment of the new vehicles, the anticipated system ridership will increase 20%, to 3,000 passengers per day.

8.4 Challenges Faced and Lessons Learned

Over the past twenty years of operations at the Rivium Office Park, as well as other deployments around the world, 2getthere has identified several important elements of an operational design domain for a given site deployment that can present particular challenges for safe operations: (1) vehicle operating speed, (2) access to the operating lane by other vehicles and pedestrians, (3) human driver and/or pedestrian behavior/misbehavior, and (4) roadway intersections. These elements may require system-level design provisions in order to mitigate the risks.

9 Site #8: Denver Peña Station – RTD 61AV

9.1 Overview

The Denver RTD launched the first AV shuttle deployment in the State of Colorado in January 2019. This transit deployment provided first-mile/last-mile service within a master planned commercial development site. The EasyMile vehicle operated during the demonstration pilot project along a one-mile loop route identified as the RTD 61AV Route. This route connected RTD's Peña Station on the A Line rail system with offices located nearby within the Peña Station commercial complex currently under development near Denver International Airport. This complex will develop over time into a diverse mixed-use district, but during the time of the pilot the only building served was the Panasonic Building, where EasyMile has their North American headquarters and a Park-n-Ride lot serving RTD's 61st and Peña commuter rail station for the University of Colorado A-Line train to Denver International Airport. A new apartment complex was under construction during the demonstration period and opened for residents shortly before the end of the demonstration period.

9.2 Period of Project Deployment

The 61AV shuttle pilot was operated over a seven-month period, concluding operations on August 2, 2019. The pilot project provided a "proof of concept" demonstration and allowed RTD to make an initial assessment of the technical capabilities of the new AV technology in a public transit application.

9.3 Description of the Operational System

One EasyMile vehicle was in service on weekdays from 10 a.m. to 6 p.m., with seating for six passengers and a capacity of 12 when standing passengers are included. The vehicle was a first-generation design with an automatically deployable wheelchair ramp (when a button is pushed by the operator or a customer). The round-trip running time of the one-mile loop was approximately 12 minutes and the vehicle departed from the A Line Peña Station approximately every 15 minutes. A safety operator/customer service attendant was onboard at all times that the vehicle was operating.

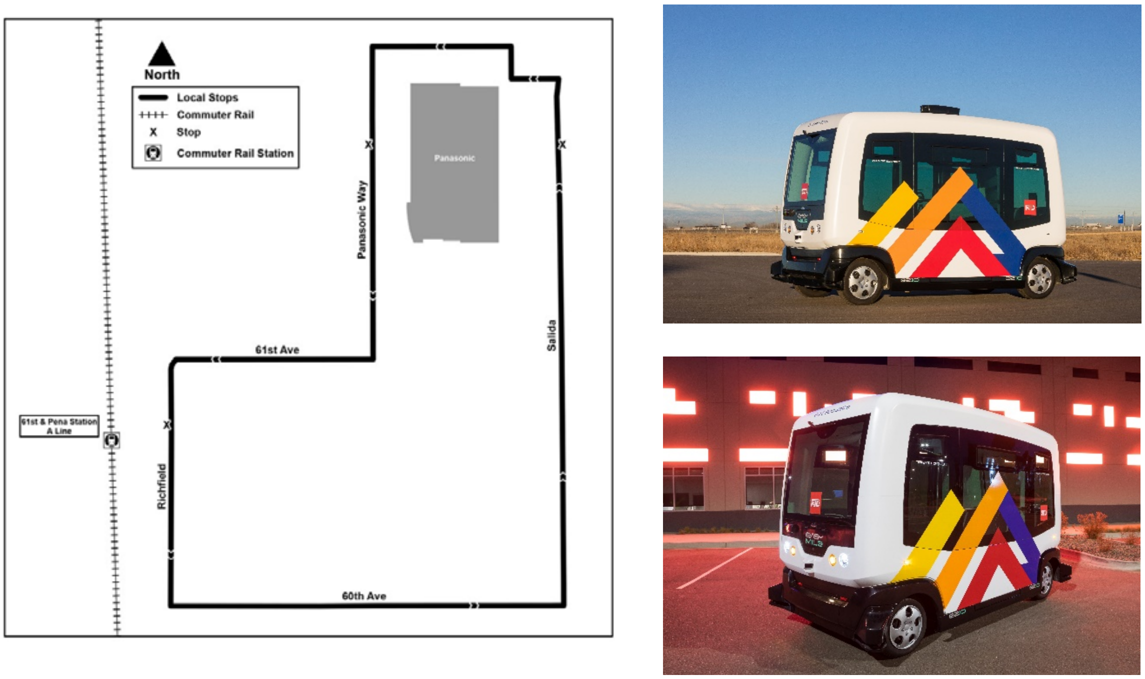


Figure 13. (left) Route map of one-mile loop for 61AV; (right) 61AV vehicle technology

Sources: Denver RTD

Figure 14. View looking north along Richfield Street, with Peña Station on the left and the Panasonic Building on the right

As can be seen in Figure 14, the level of traffic activity at this pilot project site was minimal and the operations on a "city street" should be understood in the context of this operating environment.

9.4 Operational Analysis – Status and Complexity

The simple loop route configuration, low level of traffic activity, and the limited ridership demands minimized the complexity of this pilot deployment, and therefore operational analysis in advance of the vehicle deployment was not warranted.

9.5 Challenges Faced and Lessons Learned

The official objectives of the pilot were listed in an article coauthored by the RTD project manager and the EasyMile North American Director of Business Initiatives (Abel and Isaac 2019):

- Introduce AV technology safely on a public roadway in the Denver metro area
- Provide additional connectivity between station and businesses and residential areas
- Explore first-mile/last-mile solutions for future growth throughout the district
- Test AV technology in a transit setting.

The article also described the "takeaways" of the project planning and implementation with the large group of stakeholders, which included RTD, Transdev (the operator of the service), and EasyMile as the contracted parties (Abel and Isaac 2019). Other stakeholders that were active in the coordination and extensive planning process included the Colorado Autonomous Mobility Task Force, the City and County of Denver, Denver International Airport, and the developers of the Peña Station NEXT commercial site.

Regulatory requirements and associated delays for obtaining approval to operate were noted as important items to address. Public marketing and publicity initiatives were undertaken for the purpose of explaining the pilot, and to ensure public perceptions are based on the facts of the deployment.

RTD's objectives that were accomplished included obtaining data on reliability and availability of the pilot vehicle throughout the project.

10 Site #9: Gainesville AV Shuttle Phased Deployment Project

10.1 Overview

The Gainesville AV deployment will serve as a public transit supplement on a new route connecting passengers from the University of Florida to downtown Gainesville, Florida. Initially, two EasyMile EZ10 Gen2 vehicles will be operated by Transdev, with additional vehicles added to the fleet during progressive phases of deployment. The AV Shuttle Pilot Project is planned for four progressive deployment stages with increasing degrees of operational complexity.

The initial one-block shuttle deployment was a demonstration and test pilot in downtown Gainesville. Subsequently, the full Phase 1 route will extend operations along a half-mile length of SW 2nd Ave. to reach Innovation Square. Subsequent phases that are not yet operational will deploy more vehicles along extensions to both ends of the Phase 1 route and will test V2I communications technology and demand-response operations.

Figure 15. Phase 1 EasyMile vehicle technology with roof air-conditioning unit

Source: City of Gainesville, Gainesville Regional Transit System

Each EZ10 vehicle seats six people and allows six standees, boarding and alighting through one biparting door. A semi-automated ramp that can be deployed by the onboard attendant to allow a wheelchair to be manually rolled into the vehicle. Under normal operations, each vehicle will completely drive itself along the pre-mapped route under the control of its automated driving system.

The City of Gainesville's RTS has contracted with Transdev to gradually expand and operate up to four EasyMile vehicles, with the University of Florida supporting the integration and testing of V2I communications systems in the later phases of the project. Florida DOT is a major project sponsor, having funded the three-year multiphase project.

10.2 Period of Project Deployment

The first phase of full deployment into mixed-traffic operations is planned to provide regular passenger service Monday through Friday for 10 hours per day, with headways between 10 and 20 minutes.

Phases 2 and 3 will extend the line a half mile east to reach the University of Florida, and then one mile south to a station at Depot Park. The ultimate two-mile alignment will test demand-response operational service in a fourth phase, if public acceptance supports this operating mode.

10.3 Description of the Operational System

The ADS component of the vehicle controls is the conventional EasyMile "self-driving" system. A safety operator/attendant will always remain onboard to assist passengers, monitor the operations of the vehicle, and assume control of the vehicle steering and propulsion when necessary to circumvent conditions that may arise along the operating route that are outside the ADS operational design domain parameters.

The EZ10 Gen2 vehicles will utilize EasyMile's conventional ADS control and a sensory suite comprising LIDAR and stereo cameras for object detection and localization, enhanced by wheel odometers and inertial IMUs. Each vehicle will be continuously monitored and diagnostic data will be transmitted in real time to the engineering support operations center at the EasyMile U.S. headquarters.

The addition of V2I communications equipment to connect the vehicle to the traffic signal system infrastructure is planned during Phase 2 of the project, with the University of Florida to be involved in the testing and integration of these systems. DSRC and potentially 4G/5G telecommunication links are expected to be tested during these V2I communications research studies.

10.4 Operational Analysis – Status and Complexity

Modeling and analysis of the operational system is planned during future phases of the project, with the complexity of Phase 2 and 3 analyzed to assess the uncertain performance of the vehicles along the route when operating in mixed-traffic flows.

Phase 4 operations with demand-response service will greatly benefit from simulations of the limited four-vehicle fleet operations.

10.5 Challenges Faced and Lessons Learned

The project has experienced unanticipated delay due to problems obtaining a waiver from FMVSS regulations by NHTSA. The original vehicle arrived in Gainesville during May 2018 and began the initial mapping operations at the downtown test location. However, NHTSA has not yet allowed any vehicle operations to proceed into either Phase 1 or Phase 2 as of the writing of this report. These operations had been programmed to provide passenger service between downtown and the University of Florida campus by January 2019. Over 11 months of project delay occurred during 2019.

Three challenges that have been anticipated by the Gainesville RTS are programmed for research and development during the course of the project's increasingly more complex operational phases. The first is the challenge of charging the vehicle batteries at an RTS facility almost half a mile from the end of the line. The other challenges that will be addressed concern data sharing and workforce retraining.

11 Site #10: Babcock Ranch – Punta Gorda, Florida

11.1 Overview

As one of the most unique residential developments, Babcock Ranch is an 18,000-acre site that sits among cattle land and natural Florida habitat. Kitson & Partners bought the 91,000-acre ranch from the Babcock family, then resold 73,000 acres to state and local governments for land conservation and wildlife preserves. As of early 2019, over 150 homes had been built and occupied on the 2,000 lots that have been sold to builders. The present population of about 400 residents is planned to eventually grow to as many as 50,000 residents in the master planned town.

Babcock Ranch is a community built with energy conservation and renewable energy sources as its hallmark. All buildings are designed to high energy-efficiency standards, and the solar-power-generated electric supply for the development has created the first solar-powered AV shuttle system.

Figure 16. Babcock Ranch Operational Route map

Source: EasyMile

Operations of the first EasyMile EZ10 Shuttle vehicle began in March 2018 through a new entity called Babcock Ranch Transportation Services. This operating company is a joint venture between Kitson & Partners and Transdev, an international company with many transit operations and maintenance contracts around the world.

Beginning as a relatively limited service with the shuttle operating along a fixed route with fixed station stops, the service is gradually being extended as the scale of the development site grows. A limited form of on-demand service from a few selected points of origin is now possible with the EZ10 vehicles, and smaller vehicles are planned to be integrated in the future (Theoret 2018). Currently, service continues with up to two EasyMile vehicles in operation at any one time.

11.2 Period of Project Deployment

The official news outlet for the development described in a February 2018 article that the "self-driving shuttle" system is the first phase of their long-term mobility plan (Theoret 2018). Babcock Ranch Transportation Services is expected to be the entity that will continue to provide the operations and maintenance of future transit services as well.

11.3 Description of the Operational System

Currently, fixed-route shuttle service is available to visitors and residents from 11 a.m. to 4 p.m. daily, with a vehicle departure every 15 minutes. Operation of the EZ10 Gen2 shuttle vehicles occurs with a safety attendant from Babcock Ranch Transportation Services onboard at all times. The vehicles travel along seven miles of mapped routing through the mixed-traffic operating environment where pedestrians, bicycles, and motorized vehicles interact with the AV shuttle. Operating speeds up to 12 mph can be provided along the private roadway network that connects the residential areas with the town center. Vehicles are now operating on the many possible routes currently mapped between the 17 station stops.

As stated on the Babcock Ranch website, the "ultimate goal of [Babcock Ranch Transportation Services] is to create a mobility system consisting of integrated, shared, tailored and electric vehicles that is so compelling that Babcock Ranch residents … eventually feel they do not need to own a vehicle at all" (Babcock Ranch 2020).

11.4 Challenges Faced and Lessons Learned

NHTSA has enforced a strict interpretation of the waiver granted to Transdev to operate the EasyMile EZ10 Gen2 vehicles. Since these vehicles are "noncompliant" with FMVSS, NHTSA's strictly worded authorization to operate the vehicles has limited some of the types of operations that were planned for the Babcock Ranch deployment.

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Appendix: Datasheets of AMD Pilots, Demonstrations, and Deployments

The original research by NREL of the growing number of demonstration and pilot projects deploying AV shuttle technology used an approach which compiled the data within tabular datasheets. This approach to organization of the data in a template form has facilitated comparisons and cross-referencing between the different deployment sites and the different AV technologies.

Narrative summaries of each of the Top Ten sites found in the body of this report were prepared primarily from the information contained in the datasheets. To assist other researchers with their own comparisons between the various projects documented herein, the Appendices that follow provide a version of the original datasheets which have been formatted to fit into this document.

It is NREL's intent to continue assembling data on additional deployment sites that are underway or in planning as of the date this document was completed. New datasheets compiled for the proliferation of emerging deployment sites have already begun to be prepared using the same template of data and information to document of each site's programmatic, operational and technical details, as well as any other unique features.

A.1 AMD #1: SMART Circuit - Columbus Downtown Scioto Mile Loop

Project Site Data

AV/AMD Site No.	AMD #1
Location	Columbus, Ohio
Dates in Service	December 2018–September 2019, Demo Deployment, Phase 1

Ownership Data

Owner/Contracting Authority:	Drive Ohio (under Ohio DOT)
Programmatic Lead:	SMART Columbus
Technical Lead:	Michael Baker Intl. (Consultant)

AMD Project Description

Operating as a low-speed self-driving shuttle, the vehicles circulated around the "Scioto Mile" traversing a 1.4-mile loop route. This is an area in downtown Columbus near Civic Center Drive. The route connects the Veterans Memorial with COSI, SMART Columbus Experience Center, and Bicentennial Park.

Cooperating Agencies	DriveOhio, Smart Columbus, City of Columbus, and Ohio State University
Type of Deployment	
Initial Deployment Phase:	Demonstration Pilot – 10 months
Subsequent Phases:	Four other lines are being considered, with the second line's implementation underway between St. Stephens and Linden TC with EasyMile as the contractor.
Status of Project Implementation	
Funding Committed?	Yes. Part of SMART Columbus USDOT grant awarded in 2016
Procurement/Contract?	RFP July 2018, Contract September 2018
Operational Status?	Service began December 2018, completed September 2019

Time Frame for Project

Date of Funding:	2016
Date of Procurement:	July 2018
Date of Award:	September 2018
Date of Service Initiation:	December 2018, Initial Demonstration Period
Date of Service Completion:	September 2019, Options to extend contract not exercised
Date of Line Extension:	RFP 2019, Linden Implementation with EasyMile

Contracted Parties

Technology Vendor:	May Mobility
Service Operator:	May Mobility
Maintainer:	May Mobility

Operational System

System Type (1) (2):	Moderate-Speed Shuttle
Hours of Operation:	6 a.m. to 10 p.m. daily
Max. Operating Speed (mph):	23
Propulsion (EV, Hybrid, Conv.):	Electric Vehicle
System Config. (Linear/Loop):	Loop
Number of Dedicated Stops:	4
Round-Trip Distance (Miles):	1.4
Total Vehicle Fleet Size (Veh.):	6
Peak Period Vehicles in Service (Veh.):	3
Dedicated Control Center (2):	Yes
Operational Analysis Modeling (2):	No

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	May Mobility/Magna Intl.
Vehicle Model:	Polaris GEM
Bidirectional/Unidirectional:	Unidirectional
Number of Seats:	6; Safety Operator occupies one seat
Number of Doors:	4
Maximum Passenger Capacity:	6
ADA Features:	No; New design by May Mobility for wheelchair access in process
Onboard Passenger Communication:	Onboard attendant
Vehicle Tare Weight (lbs.):	1,696
Vehicle Dimensions (ft.):	Length 13.92, Width 4.63, Height 6.08
Vehicle Heating, Ventilation, and Air Conditioning (HVAC):	Yes, Onboard diesel heating unit
Electric Propulsion:	Yes, variable-voltage/variable-frequency (VVVF) Controller with AC Induction motor

Max. Sustained Operations (mph):	35; Propulsion max. sustained speed capability
Typical Service Time:	Not Available
Typical Recharge Time:	Not Available
Sensor Array Types:	LIDAR, Radar, roadside sensing units

Communications/V2I

Technology(ies):	Roadside Sensing Units, 4G telecom
Localization Method(s):	GPS

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	Ohio Executive Order
Federal Regulations/Approvals:	NHTSA FMVSS 500 compliant, approval of mixed traffic options
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	3 ClipperCreek charging stations in a nearby parking garage
Vehicle Performance:	Not Available
System Operations:	Not Available
Passenger Service Levels:	10 min. headways (per contract), sufficient capacity for ridership

Passenger Data Collection

Institutional Review Board (IRB)/ Collaborative Institutional Training Initiative (CITA) Certification:	No. Certification by Institutional Review Board not applicable
Boarding/Fare Requirements:	No cost to ride; boarding data collected by station stop
Onboard Surveys:	Yes. Survey questionnaire results are available
Other Data Collection Methods:	See data available on the SMART Columbus Operating System (see discussion below in Other Notes and Information)

Lessons Learned

Selected points from AV Shuttle Deployment Lessons Learned (SMART Columbus 2019): Communications between all parties is essential, especially (1) with multiple funding partners concerning objectives, data expectations/formats, and designated point-of-contact to the

Contractor; (2) with system/technology vendors concerning off-vehicle equipment installation needs, with power supply of essential importance; (3) with authorities responsible for permits, licensing and approvals required for legal vehicle on-street operation; and (4) with municipalities concerning the stopping locations and associated lane configuration/marking.

Other Notes and Information

The May Mobility contract provided a complete operations and maintenance service for the leased vehicles, and the operations are continuously monitored at the Columbus operations control center. The operations are also monitored at the engineering headquarters in Ann Arbor, Michigan.

Although the system operations have not been modeled in detail with an analytical simulation, the operational dwell times and service stops have been analyzed.

SMART Columbus Operating System data, records, and briefing materials available at the following two websites:

https://smart.columbus.gov/projects/smart-columbus-operating-system
https://smartcolumbusos.com

A.2 AMD #2: Arlington Entertainment District Milo Circulator

Project Site Data

AV/AMD Site No.	AMD #2
Location	Arlington, Texas
Dates in Service	August 2017–August 2018, Demo Deployment, Phase 1

Ownership Data

Owner/Contracting Authority:	City of Arlington
Programmatic Lead:	City of Arlington, Planning Department
Technical Lead:	First Transit (Contractor)

Other Sources/References North Central Texas Council of Governments

AMD Project Description

Project deployed two EasyMile vehicles along a route operated in conjunction with sports events occurring in either the Cowboys' football stadium or the Rangers' baseball stadium. The 4,000-ft. (0.75 mi.) route carries passengers to/from parking and the sports stadiums via a 10-foot wide pedestrian walkway.

Cooperating Agencies Convention and Visitors Bureau, Central Texas Council of Governments

Type of Deployment

Initial Deployment Phase:	Demonstration Pilot – 12 months
Subsequent Phases:	A second operating phase occurred with AV shuttles operating in mixed traffic on-street in the Entertainment District. Drive.ai, using conventional gasoline-fueled minivans, provided on-demand AV services from October 2018 through May 2019, when the company ceased all operations.

Status of Project Implementation

Funding Committed?	Yes
Procurement/Contract?	Yes
Operational Status?	Pilot Completed

Time Frame for Project

Date of Funding:	March 2017
Date of Procurement:	April 2017, Sole Source Procurement
Date of Award:	April 2017

Date of Service Initiation:	August 2017, Initial Demonstration Period
Date of Service Completion:	August 2018. Initial Demonstration Period
Date of Line Extension:	N/A, 2019 Demonstration by Drive.AI now completed

Contracted Parties

Technology Vendor:	EasyMile
Service Operator:	City of Arlington
Maintainer:	First Transit

Operational System

System Type (1) (2):	Low-Speed Shuttle
Hours of Operation:	Scheduled per game times; 2 hours at start and 2 hours at end
Max. Operating Speed (mph):	12
Propulsion (EV, Hybrid, Conv.):	Electric Vehicle
System Configuration (Linear/Loop):	Linear
Number of Dedicated Stops:	2 Stops, Each of 3 routes
Round-Trip Distance (Miles):	0.75, 1.5 Depending on the route
Total Vehicle Fleet Size (Veh.):	2
Peak Period Vehicles in Service (Veh.):	2
Dedicated Control Center (2):	Not local; See "Other Notes and Information"
Operational Analysis Modeling (2):	None

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	EasyMile
Vehicle Model:	EZ10 first-generation
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	6
Number of Doors:	1
Maximum Passenger Capacity:	12
ADA Features:	Manually deployable wheelchair ramp, no onboard wheelchair securement
Onboard Passenger Communications:	Onboard attendant

Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length 12.89, Width 6.52, Height 9.02
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with 2 asynchronous motors
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability
Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	8 hours typical
Sensor Array Types:	8 LIDAR, 6 stereo cameras, Odometry, IMU

Communications/V2I

Technology(ies):	4G telecom
Localization Method(s):	GNSS (network RTK) with LIDAR detectable markers in some locations

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Texas legislation permits AV operations
Federal Regulations/Approvals:	NHTSA approval not required, since no operations in mixed traffic
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	Data not collected by the City, only Contractor records
Vehicle Performance:	Data reported by vehicle operators and EasyMile vehicle systems
System Operations:	Schedule monitored by city staff
Passenger Service Level:	10 to 15 min. headways (per route) with sufficient capacity

Passenger Data Collection

IRB/CITA Certification:	None
Boarding/Fare Requirements:	The shuttles were free for anyone's use during service times
Onboard Surveys:	Conducted by onboard attendants
Other Data Collection Methods:	Onboard attendants counted passengers

Lessons Learned
Securing the correct types of insurance was one of the biggest challenges for the project. Vehicles are insured with General Liability & Auto Liability policies carried by EasyMile.

Operations are insured with Auto Liability, General Liability, and Workers' Compensation policies carried by First Transit.

The deployment environment is the most critical element to a successful program. Localization considerations: few, if any, underpasses; minimize sharp turns; regular stationary vertical elements; low level of tree cover.

Other Notes and Information
Passenger Surveys – Final survey results: n=292; strongly agree response was 90% enjoyed riding, 87% would ride again, 93% felt safe riding, and 84% support AV technology. We had over 1,600 riders over the survey period. We had a total of 113 events during the one-year pilot (78 stadium events, 17 public demos, 18 group demonstrations, and 3 special events).

Operating Route Configurations – Three operating routes were used, depending on the events and venues being served, including a route to serve AT&T Stadium (NFL football) and Globe Life Park (MLB baseball). Each linear route had two dedicated stops at the beginning and the end, and the route round-trip distances varied between 0.75 and 1.5 miles in length. Not all routes were operated simultaneously due to only having two vehicles in the fleet.

Operations Control Center – The only permanent operations control center that was continuously monitoring the Milo vehicles was at the EasyMile headquarters in France. Operational data and system diagnostics data were streamed in real time to this facility, including data, video, and audio, as well as some sensor data.

The Phase 2 began in early 2019 with mixed-traffic operations within the Entertainment District. Drive.ai contracted with the City of Arlington to provide self-driving vans in demand responsive service on fixed routes. ADS technology was developed by Drive.ai, installed in FMVSS-compliant Nissan vans. Operation continued for several months before the company ceased operations.

The Final Closeout Report is accessible via a "click here" link in this webpage:
https://www.arlingtontx.gov/visitors/transportation/autonomous_vehicles

A.3 AMD #3: Las Vegas Fremont East Entertainment District Self-Driving Shuttle

Project Site Data	
AV/AMD Site No.	AMD #3
Location	Las Vegas, Nevada
Dates in Service	November 2017–October 2018, Demo Deployment

Ownership Data	
Owner/Contracting Authority:	City of Las Vegas
Programmatic Lead:	City of Las Vegas
Technical Lead:	Keolis (Contractor)

Other Sources/References	RTC of Southern Nevada

AMD Project Description
A three-block loop was operated in the Innovation District within the city's downtown in an area frequented by visitors. AV transit vehicles operated in mixed traffic and pedestrian activity at signalized intersections. V2I communications for signal status at 6 of 8 intersections, and all-way stop signs at others.

Cooperating Agencies	RTC of Southern Nevada and the City of Las Vegas

Type of Deployment	
Initial Deployment Phase:	Demonstration Pilot has been concluded
Subsequent Phases:	Medical District AV shuttle project has received BUILD Grant funding from FTA and grant agreements are in process. Design/procurement will occur first, with operations beginning in 2021.

Status of Project Implementation	
Funding Committed?	Yes. Funding by City of Las Vegas
Procurement/Contract?	Contract with Keolis to operate in October 2017
Operational Status?	Service startup November 2017

Time Frame for Project	
Date of Funding:	2017
Date of Procurement:	2017
Date of Award:	2017
Date of Service Initiation:	November 2017, Initial Demonstration Period
Date of Service Completion:	October 2018, Initial Demonstration Period
Date of Line Extension:	2021, Timeframe shuttle operations are to begin

Contracted Parties

Technology Vendor:	Navya
Service Operator:	Keolis
Maintainer:	Keolis

Operational System

System Type (1) (2):	Low-Speed Shuttle
Hours of Operation:	11 a.m. to 7 p.m., Tuesday–Sunday
Max. Operating Speed (mph):	16
Propulsion (EV, Hybrid, Conv.):	EV
System Configuration (Linear/Loop):	Loop
Number of Dedicated Stops:	3
Round-Trip Distance (Miles):	0.6
Total Vehicle Fleet Size (Veh.):	2
Peak Period Vehicles in Service (Veh.):	1
Dedicated Control Center (2):	Yes (2)
Operational Analysis Modeling (2):	Yes (2)

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	Navya
Vehicle Model:	Navya Arma
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	11
Number of Doors:	1
Maximum Passenger Capacity:	15
ADA Features:	No deployable ramp (subsequent model has added auto ramp)
Onboard Passenger Communication:	Onboard attendant
Vehicle Tare Weight (lbs.):	5,292
Vehicle Dimensions (ft.):	Length 15.58, Width 6.92, Height 8.69
Vehicle HVAC:	Yes, Dual air-conditioning units
Electric Propulsion:	Yes, VVVF Controller with hub motors
Max. Sustained Operations (mph):	28, Propulsion max. sustained speed capability

Typical Service Time:	9 hours typical (without HVAC)
Typical Recharge Time:	4 hours typical (with higher wattage charger)
Sensor Array Types:	8 LIDAR, front/rear cameras, Odometry, IMU

Communications/V2I

Technology(ies):	DSRC (all signalized intersections); 4G telecom
Localization Method(s):	GNSS (RTK with differential beacons)

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Nevada legislation permits AV operations, with registration from Nevada Department of Motor Vehicles required for all vehicles
Federal Regulations/Approvals:	NHTSA approval of operations in mixed traffic
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	Yes
Vehicle Performance:	Proprietary
System Operations:	Proprietary
Passenger Service Level:	AAA Passenger Surveys

Passenger Data Collection

IRB/CITA Certification:	No
Boarding/Fare Requirements:	Free for anyone's use, with boarding monitored at stations
Onboard Surveys:	Yes, by AAA
Other Data Collection Methods:	N/A

Lessons Learned

Public perceptions change over time, possibly because some passengers were regular, repeat customers. The overall comments scored the experiences as 4.9 out of 5.0 after the first 20,000 passenger trips during the first 6 months of service.

Operators (called "ambassadors" in Las Vegas) will be necessary to retain onboard for some time, in particular to provide assistance to passengers. The deployment of ramps for wheelchair access, for example, will be the operator's responsibility.

It is important to track downtime of fully automated operations, as well as circumstances for handback to the operator or cessation of service. In addition, the tracking of normal transit performance metrics is important.

Coordination between operations staff and police/fire is an important aspect of initial preparations and ongoing operations management.

Curb management at dedicated stops is a constant challenge, since other vehicles are frequently making stops in these designated shuttle stops. Support operations staff in a conventional automobile typically intervenes to clear the space.

Other Notes and Information

During the summer months of 2018 the very high temperatures (105°F–110°F) were a challenge with respect to passenger comfort and battery charge degradation. New batteries were retrofitted, and this improved air conditioner performance.

During the day, the operating plan was subject to the fact that battery charge cycles required that while one vehicle was in service, the second vehicle was out of service having its batteries charged.

The “canyoning” effect of the urban environment can be a challenge, especially with GNSS and mobile communications links vital to operations, which are not always consistently available under these conditions.

(2) The only operations control room was in France for engineering support purposes.

(2) Operational modeling was performed, but only for safety assessments, and decision-making metrics for the shuttle controls.

The new Medical District AV shuttle deployment will enter the design and procurement phase in early 2020, with operations beginning in 2021. The new shuttle technology will be determined through the procurement process.

A.4 AMD #4: JTA Ultimate Urban Circulator (U^2C) System

Project Site Data

AV/AMD Site No.	AMD #4
Location	Jacksonville, Florida
Dates in Service	Feb. 2018–August 2020, Initial AV Transit Demos

Ownership Data

Owner/Contracting. Authority:	Jacksonville Transportation Authority
Programmatic Lead:	Jacksonville Transportation Authority
Technical Lead:	Jacksonville Transportation Authority

Other Sources/References Reynolds Smith & Hills (Consultant)

AMD Project Description

JTA began planning for replacement of the aging APM technology that operates along an aerial guideway structure through the Jacksonville central business district. The initial series of AV Transit demonstrations began in March 2018 on a test track near Metropolitan Park. The plan is to ultimately adapt the Automated Skyway Express guideway for AV technology use as the Ultimate Urban Circulator (U^2C).

Cooperating Agencies: City of Jacksonville, Florida DOT, North Florida Transportation Planning Organization, JEA, FTA, U.S. DOT

Type of Deployment

Initial Deployment Phase: Series of Demonstration Pilots by Various Vendors – 6 month each
Subsequent Phases: (1) Conversion of existing elevated track to accommodate AES, (2) revenue service deployment in 2 mi of dedicated lanes along Bay Street, (3) converted aerial guideway with connections to at-grade

Status of Project Implementation

Funding Committed?	Yes. JTA funding pilots; \$12.5M BUILD Grant for Bay St. Corridor
Procurement/Contract?	Pilot demonstrations by invitation to vendors
Operational Status?	Demonstration Pilots completed by EasyMile & Navya; NTP currently pending for 3rd AV Supplier Pilot

Time Frame for Project

Date of Funding:	Fall 2016, Demonstration Pilot – at grade
Date of Procurement:	June 2017, Invitations to AV technology providers
Date of Award:	December 2017, Contract Award

Date of Service Initiation:	February 2018, EasyMile/Transdev 1st Demonstration
Date of Service Completion:	August 2019, Navya/First Transit Demonstration Period
Date of Line Extension:	November 2019, Next Contractor TBD – 3rd Demonstration Period

Contracted Parties	**Test Track #1**	**Test Track #2**
Technology Vendor:	EasyMile	Navya
Service Operator:	Transdev	First Transit
Maintainer:	Transdev	First Transit

Operational System	**Test Track #1**	**Test Track #2**
System Type (1) (2):	Low Speed Shuttle, dedicated lane, pax during select events	
Hours of Operation:	Scheduled as periodic public demonstrations, no fixed schedule	
Max. Operating Speed (mph):	12	12
Propulsion (EV, Hybrid, Conv.):	EV	EV
System Configuration (Linear/Loop):	Linear	Linear
Number of Dedicated Stops:	2	2
Round-Trip Distance (Miles):	0.5	0.5
Total Vehicle Fleet Size (Veh.):	1	1
Peak Period Vehicles in Service (Veh.):	Selected Events	
Dedicated Control Center (2):	Vendor provided	
Operational Analysis Modeling (2):	To be performed during future phases	

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology	**Test Track #1**	**Test Track #2**
Vehicle Technology/Supplier:	EasyMile	Navya
Vehicle Model:	EZ10 Gen2	
Bidirectional/Unidirectional:	Bidirectional	
Number of Seats:	6	
Number of Doors:	1	
Maximum Passenger Capacity:	12	
ADA Features:	Auto-deployable wheelchair ramp with push button, No wheelchair securement	
Onboard Passenger Communication:	Onboard attendant	

NOTE: For the vehicle technology information on Navya, refer to the data shown for Las Vegas AMD #3

Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length: 13.19, Width: 6.56, Height: 9.42
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with two Asynchronous motors
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability
Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	6 hours typical with high-voltage charging station
Sensor Array Types:	LIDAR, stereo cameras, Odometry, IMU

Communications/V2I

Technology(ies):	TBD – DSRC; 4G telecom
Localization Method(s):	GPS with video-detectable markers in some locations

Legal/Regulatory Issues

Local Permitting:	Test Track through agreement with the City of Jacksonville
State Law/Regulations:	State of Florida legislation permits AV operations
Federal Regulations/Approvals:	NHTSA waiver required
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	TBD, Contractor records
Vehicle Performance:	TBD, Contractor records
System Operations:	TBD, Contractor records
Passenger Service Levels:	Limited to special events

Passenger Data Collection

IRB/CITA Certification:	Information Not Available
Boarding/Fare Requirements:	The shuttles were free
Onboard Surveys:	Yes, before and after
Other Data Collection Methods:	Information Not Available

Lessons Learned

Testing is ongoing – One key finding is that operations are affected by rain. Next (third) test demonstration will have JTA employees trained as operators to assist the contractor's staff in daily operational tests.

Other Notes and Information

September 2019 RFP Scope of Services – Supplier Requirements (summarized):

1. Provide Autonomous Solutions (as defined by supplier expectations) option that can transport passengers along a low-speed, controlled roadway on a dedicated lane.

2. Provide to JTA real-time and readily available technical assistance/expertise.

3. Provide a plan for third-party operations of the Autonomous Solution. Supplier will allow JTA to operate the vehicle when minimum operator requirements are met.

4. Provide reports on how safe boarding/alighting of passengers at predefined stop locations with level curbside boarding would be facilitated. Alternatively, Supplier to present a method to allow mobility-impaired individuals to access and egress the vehicle. Path towards ADA compliance should be submitted as part of the proposal.

5. Identify vulnerable road user types (e.g., pedestrian, bicyclists) and describe how those road users would be protected.

A.5 AMD #5: Houston University District AV Transit Circulator

Project Site Data

AV/AMD Site No.	AMD #5
Location	Texas Southern University, Houston, TX
Dates in Service	June 2019–November 2019, Demo Deployment, Phase 1

Ownership Data

Owner/Contracting Authority:	Houston METRO
Programmatic Lead:	Houston METRO
Technical Lead:	Houston METRO

Other Sources/References	Texas Southern University

AMD Project Description

The University District AV Transit Circulator is being deployed in two initial phases. The first is a half-mile long shuttle with one vehicle along the Tiger Walk pedestrian facility in the middle of Texas Southern University's campus. Phase 2 is being planned to extend the route a half-mile off campus on city streets to reach a nearby light-rail transit station.

Cooperating Agencies	Texas Southern University, City of Houston, Houston-Galveston Area Council (metropolitan planning organization)

Type of Deployment

Initial Deployment Phase:	Demonstration Pilot – 6 months
Subsequent Phases:	Phase 2 planned for extension to a light-rail transit station, and with a planned Phase 3 ultimate extension to a major transit center.

Status of Project Implementation

Funding Committed?	Yes. Houston METRO committed funding in 2018 for Phase 1.
Procurement/Contract?	RFP June 2018, Contract December 2018
Operational Status?	Service Startup in June 2019, Delays occurring with the delivery of new vehicle from factory

Time Frame for Project

Date of Funding:	October 2019
Date of Procurement:	June 2018
Date of Award:	November 2018, Contract executed in January 2019

Date of Service Initiation:	June 2019, Initial Demonstration Period
Date of Service Completion:	November 2019, Initial Demonstration Period
Date of Line Extension:	TBD, 2020 Contract Option

Contracted Parties

Technology Vendor:	EasyMile
Service Operator:	First Transit
Maintainer:	First Transit

Operational System

System Type (1) (2):	Low-Speed Shuttle
Hours of Operation:	8 a.m.–2 p.m. and 5 p.m.–8 p.m. Monday–Friday; Scheduled tours only, Saturday
Max. Operating Speed (mph):	8, in consideration of pedestrian environment
Propulsion (EV, Hybrid, Conv.):	Electric Vehicle
System Configuration (Linear/Loop):	Linear
Number of Dedicated Stops:	4, the two intermediate stops served in each direction
Round-Trip Distance (Miles):	1
Total Vehicle Fleet Size (Veh.):	1
Peak Period Vehicles in Service (Veh.):	1
Dedicated Control Center (2):	No, Control Center is in France, with monitoring in Colorado
Operational Analysis Modeling (2):	No

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	EasyMile
Vehicle Model:	EZ10 Gen2
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	6
Number of Doors:	1
Maximum Passenger Capacity:	12
ADA Features:	Auto-deployable wheelchair ramp with push button; No wheelchair securement
Onboard Passenger Communication:	Onboard attendant

Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length: 13.19, Width: 6.56, Height: 9.42
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF controller with two asynchronous motors
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability
Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	6 hours typical with high-voltage charging station
Sensor Array Types:	LIDAR, stereo cameras, odometry, IMU

Communications/V2I

Technology(ies):	TBD – DSRC, 4G and/or 5G telecom
Localization Method(s):	GPS with LIDAR/video-detectable markers in some locations

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Texas legislation permits AV operations
Federal Regulations/Approvals:	NHTSA approval of operations in mixed traffic
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	TBD from Contractor records
Vehicle Performance:	TBD from Contractor records
System Operations:	Schedule monitored by METRO through First Transit contract
Passenger Service Level:	TBD

Passenger Data Collection

IRB/CITA Certification:	Surveyors certified by IRB
Boarding/Fare Requirements:	Free service, but limited to only Texas Southern University students and faculty
Onboard Surveys:	Yes, with final report planned in February 2020
Other Data Collection Methods:	Boarding data by station

Lessons Learned

The obtaining of vehicles from factories overseas inherently induces unexpected delays, with the shipping by cargo vessels and the customs delays of the port of entry. The impact can be months of time in delay.

Passenger surveys involving college students on a college campus require survey managers to obtain training under IRB guidelines, with a significant investment of time to fully comply. In addition, the use of student passengers may require a legal consent to be obtained, involving parent's consent for riders under 18 years old.

Other Notes and Information

No modeling of the Texas Southern University Shuttle or the larger University District AV Circulator has been performed. Future studies of the Phase 2 and Phase 3 system could be part of a regional transportation planning process.

The 9' 6" height of the vehicles created a challenge in finding a suitable storage and charging location near the operating route on campus, since most available spaces designed for driving large vehicles through had only a 9-ft clearance. An additional complication was finding a location within the vendor's requested 400-ft. access of the route, with an enclosed space that also provided weather protection and security for the vehicle/equipment.

A.6 AMD #6: Mcity AV Driverless Shuttle at the University of Michigan

Project Site Data

AV/AMD Site No.	AMD #6
Location	Ann Arbor, Michigan
Dates in Service	June 2018–December 2019, Passenger Service Deployment

Ownership Data

Owner/Contracting. Authority:	Mcity, University of Michigan
Programmatic Lead:	Mcity
Technical Lead:	Mcity

Other Sources/References University of Michigan

AMD Project Description

This deployment is a research project focused on challenges and opportunities with driverless shuttle and interaction of riders, pedestrians, and other vehicles. Two Navya vehicles transport the University of Michigan community on a nonstop ride between two stations on a one-mile-loop route at University of Michigan's North Campus Research Complex in mixed traffic.

Cooperating Agencies City of Ann Arbor, Michigan DOT, American Center for Mobility; Mcity Affiliate private companies include Navya and Keolis

Type of Deployment

Initial Deployment Phase:	June 2018
Subsequent Phases:	A previously-planned Phase 2 southern expansion to University of Michigan's Lurie Engineering Center will not be implemented. No further passenger service routes or operations are currently planned.

Status of Project Implementation

Funding Committed?	Yes. Funding from Mcity research initiatives
Procurement/Contract?	Contract between University of Michigan and Navya established October 2017
Operational Status?	Operation in passenger service began June 2018

Time Frame for Project

Date of Funding:	December 2016 Navya became affiliate Mcity member
Date of Procurement:	December 2017, 2 Navya shuttles delivered to Mcity

Date of Award:	Information Not Available
Date of Service Initiation:	June 2018, passenger service in mixed traffic began
Date of Service Completion:	TBD
Date of Line Extension:	TBD, new deployment sites being evaluated

Contracted Parties

Technology Vendor:	Navya
Service Operator:	Logistics, Transportation, and Parking hired through University of Michigan
Maintainer:	Mcity

Operational System

System Type (1) (2):	Navya Autonom Shuttle
Hours of Operation:	9 a.m. to 3 p.m. daily operating times Monday–Friday
Max. Operating Speed (mph):	10, per operating route speed constraints
Propulsion (EV, Hybrid, Conv.):	EV
System Config. (Linear/Loop):	Loop
Number of Dedicated Stops:	2
Round-Trip Distance (Miles):	1.1
Total Vehicle Fleet Size (Veh.):	2
Peak Period Vehicles in Service (Veh.):	2
Dedicated Control Center (2):	Yes, Local Logistics, Transportation, and Parking dispatch; Navya remote monitoring of status
Operational Analysis Modeling (2):	No, see Other Notes and Information below

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	Navya
Vehicle Model:	Navya Autonom Shuttle
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	11
Number of Doors:	1
Maximum Passenger Capacity:	15 seated and standing
ADA Features:	Manually deployable wheelchair ramp

Onboard Passenger Communication:	Onboard attendant
Vehicle Tare Weight (lbs.):	5,292
Vehicle Dimensions (ft.):	Length: 15.58, Width: 6.92, Height: 8.69
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with hub motors
Max. Sustained Operations (mph):	28, Propulsion max. sustained speed capability
Typical Service Time:	9 hours typical (without HVAC)
Typical Recharge Time:	4 hours (with higher-wattage charger) to overnight
Sensor Array Types:	8 LIDAR, front/rear stereo vision cameras, Odometry, IMU
Communications/V2I	
Technology(ies):	DSRC; 4G telecom
Localization Method(s):	GNSS (RTK with differential beacons)
Legal/Regulatory Issues	
Local Permitting:	University approval required (see Other Notes and Info)
State Law/Regulations:	State of Michigan legislation permits AV operations
Federal Regulations/Approvals:	NHTSA approval of operations in mixed traffic
Other Legal Challenges:	None
Technical Data Collection	
Electrical/Recharge/Facilities:	Mcity Data Acquisition System and Idaho National Laboratory
Vehicle Performance:	Mcity Data Acquisition System sensors are separate from Navya ADS sensor array
System Operations:	Mcity Data Acquisition System sensors are separate from Navya ADS sensor array
Passenger Service Levels:	Mcity Data Acquisition System sensors
Passenger Data Collection	
IRB/CITA Certification:	Yes
Boarding/Fare Requirements:	Free for University of Michigan students, faculty, employees, and their visitors
Onboard Surveys:	Link provided for survey
Other Data Collection Methods:	Onboard data acquisition system installed by Mcity

Lessons Learned
Refer to *Mcity Driverless Shuttle: A Case Study* (University of Michigan 2018)

Other Notes and Information
Operations Control Center – Mcity works with the University of Michigan Logistics Transportation and Parking department to monitor the shuttles during a shift. The shuttles have radios that talk directly to University of Michigan Transportation Dispatch. In addition to that, the shuttle conductors use an application on their phones to have direct contact with the Mcity technical team for any questions/issues that may pop up. The Mcity technical team has direct communication with the vehicle supplier for any issues that can't be easily resolved.

Pre-Deployment Operational Analysis – After extensive testing of use cases on the Mcity test track, there were several weeks of data gathering and analysis on the route without passengers prior to the launch.

Local Approval Stipulations – University approval was required after consideration and review by two research oversight committees: IRB (for research project), and Institutional Autonomous Systems Committee (IASC)

A.7 AMD #7: Rivium 3.0 AV Transit Circulator System, Rotterdam/Capelle aan den IJssel

Project Site Data

AV/AMD Site No.	AMD #7
Location	Rivium Office Park, Capelle aan den IJssel
Dates in Service	2020, 3.0 Expansion

Ownership Data

Owner/Contracting. Authority:	City of Capelle aan den Ijssel
Programmatic Lead:	City of Capelle aan den Ijssel
Technical Lead:	2getthere, a Company of ZF (Contractor)

Other Sources/References Connexxion, a Division of Transdev (Contractor)

AMD Project Description

The original Rivium system has been operating between a Rotterdam Metro station and Rivium, a nearby office park, since 1999. The system has carried over eight million riders using unmanned vehicles. For Rivium 3.0, a new third generation of larger vehicles will be deployed in early 2020, followed by an extension to reach a Waterbus terminal, with vehicle operations on streets with mixed-traffic conditions in 2021.

Cooperating Agencies Metropolitan Region of Rotterdam – The Hague

Type of Deployment

Initial Deployment Phase:	2020 with new generation vehicle design
Subsequent Phases:	Line extension in late 2021

Status of Project Implementation

Funding Committed?	Yes
Procurement/Contract Status?	Contract in place, design and manufacturing underway
Operational Status?	Second-generation vehicles continue operations until May 2019. After installation, new system in service the first quarter of 2020.

Time Frame for Project

Date of Funding:	March 2018
Date of Procurement:	Sole source procurement – City of Capelle and 2getthere
Date of Award:	March 2018

Date of Service Initiation:	3rd-generation system: Q1 2020
Date of Service Completion:	New operations contract: December 2018 to December 2033
Date of Line Extension:	2021, exact date TBD

Contracted Parties

Technology Vendor:	2getthere
Service Operator:	Connexxion, a division of Transdev
Maintainer:	Connexxion, with 2getthere as subcontractor

Operational System

System Type (1) (2):	Moderate-Speed Shuttle
Hours of Service:	15 hrs per day
Max. Operating Speed (mph):	25
Propulsion (EV, Hybrid, Conv.):	EV
System Configuration (Linear/Loop):	Linear/Loop
Number of Dedicated Stops:	9
Round-Trip Distance (Miles):	3
Total Vehicle Fleet Size (Veh.):	6
Peak Period Vehicles in Service (Veh.):	6
Dedicated Control Center (2):	Yes, refer to Other Notes and Information
Operational Analysis Modeling (2):	Yes, refer to Other Notes and Information

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	2getthere
Vehicle Model:	GRT
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	8
Number of Doors:	2
Maximum Passenger Capacity:	22
ADA Features:	Level boarding with precision docking at stations
Onboard Passenger Communication:	Intercom
Vehicle Weight (lbs.):	9,920 tare weight
Vehicle Dimensions (ft.):	Length: 19.83, Width: 6.90, Height: 9.13

Vehicle HVAC:	Yes
Electric Propulsion:	AC Motor, with rear axle differential
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability
Typical Service Time:	Up to 3 hours typical (without HVAC)
Typical Recharge Time:	0.2 hours typical (30% to 80%)
Sensor Array Types:	LIDAR, radar and high-definition camera pairs, ultrasonic

Communications/V2I

Technology(ies):	Wi-Fi and Wi-Fi-P for vehicle-to-everything
Localization Method(s):	Artificial reference points

Legal/Regulatory Issues

Local Permitting (2):	Safety being validated by an Independent Safety Assessor
State Law/Regulations:	Not required
Federal Regulations/Approvals (2):	New law allows unmanned vehicles
Other Legal Challenges:	None

(2) Provide additional details in Other Notes and Information section

Technical Data Collection

Electrical/Recharge/Facilities:	Multiple charge locations – stations and maintenance
Vehicle Performance:	Contractor records
System Operations:	Contractor records
Passenger Service:	None planned

Passenger Data Collection

IRB/CITA Certification:	N/A
Boarding/Fare Requirements (2):	Fares paid by national transit smart card
Onboard Surveys:	Under development, planned to implement Q1 2020
Other Data Collection Methods:	Boarding data by station

(2) Provide additional details in Other Notes and Information section

Lessons Learned
Particular challenges for safe operations are: (1) Vehicle operating speed; (2) Access to operating lane by other vehicles/pedestrians; (3) Human behavior/misbehavior; and (4) Roadway intersections. These elements may require system-level design provisions.

Other Notes and Information
Metropolitan Region of Rotterdam – The Hague is the Transit Authority that awarded the concession to Connexxion. Connexxion as the operator is the customer of 2getthere. The Transit Authority is a cooperation between different cities in the region of Rotterdam, amongst whom is the city of Capelle aan den IJssel. The Transit Authority is involved in the steering group for Rivium 3.0, receiving updates once every two months.

Federal government provisions in accord with a pending Dutch "experimentation law" will allow remote monitoring of the vehicles rather than an onboard steward. "Experimenteerwet" passed by the Dutch government on July 1, 2019. The experimenteerwet refers to ISO-26262 and other international standards.

National fare system of the Netherlands (OV-chipcard) requires passengers to check in and out at stations, providing data records of boarding and alighting activity.

Passenger boarding/alighting currently monitored by "check-in" and "check-out" to determine ridership. Smart camera detection is an option for the future.

Analytical studies of the system performance and operations were conducted prior to the final contracting to validate the business case and to support the establishment of operating subsidies.

A.8 AMD #8: Denver Peña Station – RTD 61AV

Project Site Data

AV/AMD Site No.	AMD #8
Location	Denver, Colorado
Dates in Service	January 2019–July 2019

Ownership Data

Owner/Contracting. Authority:	Regional Transportation District (RTD)
Programmatic Lead:	Regional Transportation District (RTD)
Technical Lead	Transdev (Contractor)

Other Sources/References EasyMile (Contractor)

AMD Project Description

RTD operated an EasyMile autonomous electric shuttle as a new route called 61AV, which served people who park and live near the 61st and Peña commuter rail station. The service was fully integrated into the RTD transit service offering, as 61AV schedules were coordinated with A-Line train schedules and all 61AV information was included in all RTD information sources (online trip planner, automatic vehicle locator system, real-time information feeds, General Transit Feed Specification (GTFS) data feeds to third-party information suppliers, etc.).

Cooperating Agencies City of Denver, Colorado Autonomous Vehicle Task Force, Denver International Airport

Type of Deployment

Initial Deployment Phase:	Loop
Subsequent Phases:	TBD

Status of Project Implementation

Funding Committed?	Yes
Procurement/Contract?	Yes
Operational Status?	Demonstration pilot completed as of the end of July 2019

Time Frame for Project

Date of Funding:	Information Not Available
Date of Procurement:	Information Not Available
Date of Award:	Information Not Available
Date of Service	Initiation: January 2019
Date of Service Completion:	July 2019
Date of Line Extension:	N/A

Contracted Parties

Technology Vendor:	EasyMile
Service Operator:	Transdev
Maintainer:	Transdev/EasyMile

Operational System

System Type (1) (2):	Low-Speed Shuttle
Hours of Operation:	Monday–Friday: 10 a.m. to 6 p.m.
Max. Operating Speed (mph):	12
Propulsion (EV, Hybrid, Conv.):	EV
System Configuration (Linear/Loop):	Loop
Number of Dedicated Stops:	3
Round-Trip Distance (Miles):	1
Total Vehicle Fleet Size (Veh.):	1
Peak Period Vehicles in Service (Veh.):	1
Dedicated Control Center (2):	Vendor provided, but not local
Operational Analysis Modeling (2):	Not required for Demonstration Pilot

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	EasyMile
Vehicle Model:	EZ10 Gen1
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	6, Safety Operator occupies one seat
Number of Doors:	1
Maximum Passenger Capacity:	12
ADA Features:	Auto-deployable wheelchair ramp with push button, no wheelchair securement
Onboard Passenger Communications:	Onboard attendant
Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length: 13.92, Width: 4.63, Height: 6.08
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with two Asynchronous motors
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability

Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	6 hours typical with high-voltage charging station
Sensor Array Types:	LIDAR, stereo cameras, Odometry, IMU

Communications/V2I

Technology(ies):	DSRC, 4G; DSRC not required for this project
Localization Method(s):	GPS with video-detectable markers in some locations

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Colorado legislation permits AV operations
Federal Regulations/Approvals:	NHTSA waiver obtained
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	TBD from Contractor records
Vehicle Performance:	TBD from Contractor records
System Operations:	TBD from Contractor records
Passenger Service Levels:	15-min. headways

Passenger Data Collection

IRB/CITA Certification:	Information Not Available
Boarding/Fare Requirements:	Information Not Available
Onboard Surveys:	Information Not Available
Other Data Collection Methods:	Information Not Available

Lessons Learned

Stakeholder alignment in terms of shared purpose and coordination of effort is of key importance, especially when the group is large and has no history of working together. Communication of stakeholder goals and project roles is essential.

Federal (NHTSA) FMVSS regulation waivers are required, and subject to each project's unique attributes. The new State of Colorado laws governing AV deployments established an Autonomous Mobility Task Force to review deployment requests. These federal and state approval processes take time and are subject to delays.

RTD prepared a project final report, which is accessible by the following link:

https://www.rtd-denver.com/sites/default/files/files/2019-09/61AV-project-recap-aug2019.pdf

Other Notes and Information

Proactive marketing and public awareness communications initiatives have a great bearing on the way the project is perceived. The multi-stakeholder nature of the project initiative made this alignment of marketing content difficult to resolve and a dedicated steering committee is recommended.

Signage infrastructure (in accord with the stakeholder instructions), vehicle storage and battery charging facilities, and time required to manage steering committees and marketing initiatives must all be covered in the project budget.

Identification of the metrics and data requirements desired by each stakeholder must be established at the outset of the project planning process. Examples of the diverse data needs included on-time performance and vehicle reliability data (RTD), roadway safety and traffic incidents (City and County), and automated driving system disengagements (EasyMile).

A.9 AMD #9: Gainesville AV Shuttles

Project Site Data

AV/AMD Site No.	AMD #9
Location	Gainesville, Florida
Dates in Service	January 2019 to May 2021

As of October 29, 2019, NHTSA waiver for testing expired on October 2. However, NHTSA approval of Phase 1 service is pending. RTS is hopeful to start operations soon.

Ownership Data

Owner/Contracting. Authority:	Gainesville RTS
Programmatic Lead:	Gainesville RTS
Technical Lead:	Transdev (Contractor)

Other Sources/References City of Gainesville, Florida

AMD Project Description

The Gainesville AV Shuttle deployment will serve as a public transit supplement on a new route connecting passengers from the University of Florida to Downtown Gainesville. Four EasyMile EZ10 Gen2 vehicles will be operated by Transdev. The project is being called the AV Shuttle Pilot Project, and is planned for four progressive stages of deployment with increasing operational complexity.

Cooperating Agencies Florida DOT, City of Gainesville

Type of Deployment

Initial Deployment Phase:	Passenger service Downtown to Innovation Square on half-mile route Subsequent Phases: From Depot Park to University of Florida on 2-mi. route

Status of Project Implementation

Funding Committed?	Yes. Florida DOT grant funding
Procurement/Contract?	Contract March 2018, three-year agreement with Transdev
Operational Status?	Passenger Service delayed until NHTSA waiver received

Time Frame for Project

Date of Funding:	Q2 2017 100% Florida DOT funded
Date of Procurement:	October 2017, Proposals received after August RFP
Date of Award:	March 2018
Date of Service Initiation:	Q2 2019, Passenger Service in mixed traffic**
Date of Service Completion:	May 2021, three-year contract completion

Date of Line Extension:	Q4 2019, University of Florida, deployment of V2I**

** Startup still pending, NHTSA waiver approved through October 2, 2019

Contracted Parties

Technology Vendor:	EasyMile
Service Operator:	Transdev
Maintainer:	Transdev

Operational System

System Type (1) (2):	Low speed, mixed traffic, on public streets
Hours of Service:	10 hrs/day, Monday–Friday
Max. Operating Speed (mph):	15
Propulsion (EV, Hybrid, Conv.):	EV
System Config. (Linear/Loop):	Linear
Number of Dedicated Stops:	TBD with final mapping and testing
Round-Trip Distance (Miles):	TBD with final mapping and testing
Total Vehicle Fleet Size (Veh.):	4
Peak Period Vehicles in Service (Veh.):	TBD
Dedicated Control Center (2):	Vendor provided
Operational Analysis Modeling (2):	To be performed during future phases

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	EasyMile
Vehicle Model:	EZ10 Gen2
Bidirectional/Unidirectional:	Bidirectional
Number of Seats:	6
Number of Doors:	1
Maximum Passenger Capacity:	12
ADA Features:	Manually deployable wheelchair ramp, no onboard wheelchair securement
Onboard Passenger Communication:	Onboard attendant
Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length: 13.19, Width: 6.56, Height: 9.42

Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with two Asynchronous motors
Max. Sustained Operations (mph):	25, Propulsion max. sustained speed capability
Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	6 hours typical with high-voltage charging station
Sensor Array Types:	LIDAR, stereo cameras, Odometry, IMU

Communications/V2I

Technology(ies):	TBD – DSRC, 4G and/or 5G telecom
Localization Method(s):	GPS with video-detectable markers in some locations

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Florida legislation permits Self-Driving AV operations
Federal Regulations/Approvals:	NHTSA approval of operations in mixed traffic
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	TBD from Contractor records
Vehicle Performance:	TBD from Contractor records
System Operations:	TBD from Contractor records
Passenger Service Level:	TBD, 10- to 20-min. headways

Passenger Data Collection

IRB/CITA Certification:	Not required
Boarding/Fare Requirements:	No fares charge during the demonstration period
Onboard Surveys:	TBD
Other Data Collection Methods:	TBD

Lessons Learned

Delivery of three of the EasyMile vehicles were held up in customs clearance for several months due to NHTSA's refusal to provide waivers, and the project has been delayed well beyond the planned startup.

Due to the lack of FMVSS requirements for steering wheels and other such equipment, "waivers" were required from NHTSA for operations on public streets. Over nine months of schedule slip has resulted from NHTSA's internal delays in issuing the waivers, with NHTSA clearance still pending as of April 1, 2019.

Other Notes and Information

Operations Control Center – A permanent operations control center that continuously monitors the EasyMile vehicles will be established within the United States, and possibly in Gainesville. Operational data and system diagnostics data will be streamed in real time to this facility, including data, video, and audio, as well as some sensor data, and, as currently, also streamed to the EasyMile headquarters in France.

Phase 4 of the deployment plan activates demand-response services along the Phase 3 route alignment, depending on public acceptance of these advanced features.

A.10 AMD #10: Babcock Ranch Self-Driving Shuttles

Project Site Data

AV/AMD Site No.	AMD #10
Location	Babcock Ranch, Florida
Dates in Service	March 2018–Present, Passenger Service Deployment

Ownership Data

Owner/Contracting Authority:	Babcock Ranch Transportation Services
Programmatic Lead:	Kitson & Partners
Technical Lead	Transdev (Contractor)

Other Sources/References Easy-Mile (Contractor)

AMD Project Description

The self-driving electric shuttle began with demonstration rides from Founder's Square most weekends. The self-driving shuttle demonstration is operated by Babcock Ranch Transportation Services as the first phase of Babcock Ranch's long-term mobility plan to integrate smaller shared, self-driving vehicles.

Type of Deployment

Initial Deployment Phase:	Fixed route in mixed traffic on private development roads
Subsequent Phases:	Service area being expanded as the development grows in size, with demand-response service becoming the common operating mode.

Status of Project Implementation

Funding Committed?	Yes
Procurement/Contract?	N/A
Operational Status?	Passenger Service for school children disallowed by NHTSA

Time Frame for Project

Date of Funding:	2017
Date of Procurement:	2017
Date of Award:	2017
Date of Service Initiation:	March 2018, date of NHTSA approval
Date of Service Completion:	N/A
Date of Line Extension:	Continual expansion with development

Contracted Parties

Technology Vendor:	EasyMile
Service Operator:	Transdev
Maintainer:	Transdev

Operational System

System Type (1) (2):	Low-Speed Shuttle
Hours of Operation:	Information Not Available
Max. Operating Speed (mph):	12
Propulsion (EV, Hybrid, Conv.):	EV
System Config. (Linear/Loop):	Network – one route for each origin/destination being served
Number of Dedicated Stops:	17
Round-Trip Distance (Miles):	7 miles – currently mapped routes
Total Vehicle Fleet Size (Veh.):	2
Peak Period Vehicles in Service (Veh.):	2
Dedicated Control Center (2):	Vendor provided, but not local
Operational Analysis Modeling (2):	Not required for Demonstration Pilot

(1) Low-Speed Shuttle, Moderate-Speed Shuttle, Demand Response Service, Mixed-Traffic Operations, etc.
(2) Provide additional details in Other Notes and Information section

AMD Vehicle Technology

Vehicle Technology/Supplier:	EasyMile
Vehicle Model:	EZ10 Gen2, 12 mph max. cruise speed
Bidirectional/Unidirectional:	Bidirectional, 25 mph max. propulsion capability
Number of Seats:	6
Number of Doors:	1
Maximum Passenger Capacity:	12
ADA Features:	Auto-deployable wheelchair ramp with push button, no wheelchair securement
Onboard Passenger Communication:	Onboard attendant
Vehicle Tare Weight (lbs.):	4,079
Vehicle Dimensions (ft.):	Length: 13.19, Width: 6.56, Height: 9.42
Vehicle HVAC:	Yes
Electric Propulsion:	Yes, VVVF Controller with two Asynchronous motors

Max. Sustained Operations (mph):	N/A, Propulsion max. sustained speed capability
Typical Service Time:	10–12 hours typical (without HVAC)
Typical Recharge Time:	6 hours typical with high-voltage charging station
Sensor Array Types:	LIDAR, stereo cameras, Odometry, IMU

Communications/V2I

Technology(ies):	4G telecom**
Localization Method(s):	GPS with LIDAR-detectable markers in some locations

**Gen2 vehicles are DSRC capable, but not used at Babcock Ranch

Legal/Regulatory Issues

Local Permitting:	Not required
State Law/Regulations:	State of Florida legislation permits Self-Driving AV operations
Federal Regulations/Approvals:	NHTSA approval of operations for temporary demonstration
Other Legal Challenges:	None

Technical Data Collection

Electrical/Recharge/Facilities:	TBD from Contractor records
Vehicle Performance:	TBD from Contractor records
System Operations:	TBD from Contractor records

Passenger Data Collection

IRB/CITA Certification:	Information Not Available
Boarding/Fare Requirements:	Information Not Available
Onboard Surveys:	Information Not Available
Other Data Collection Methods:	Information Not Available

Lessons Learned

Clear communications of operating intent with NHTSA are very important. Consultation should always occur with NHTSA before any potential variance from the strict wording describing the operating plan as it is documented in the waiver agreement.

Other Notes and Information

On-demand service accommodated by unique routing between each origin/destination pair creates a large operating system with 7 route miles and 17 station stops currently mapped, and growing over time as the Babcock Ranch development expansion continues.