UNDERSTANDING INFRASTRUCTURE IMPACTS BASED ON AUTOMATED VEHICLE DEMONSTRATIONS

DRAFT FINAL REPORT

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ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(359)

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16. Abstract

Automated vehicle (AV) demonstrations are becoming more widespread, however the infrastructure changes and needs required for AVs may not be clear to transportation agencies. To help ENTERPRISE agencies prepare for future AV demonstrations and operations, this project captured insight from agencies that have conducted low-speed AV shuttle demonstrations and identified the likely impacts of AVs on infrastructure operations. Specifically, this effort focused on low-speed AV shuttles with the intent to understand whether infrastructure changes and the roles of agency and private-sector stakeholders are representative of needs and roles in future, long-term AV deployments.

Information was collected through a literature review and interviews with 12 AV deploying agencies in the United States and Canada. It was found that identified impacts to agency infrastructure and staff vary greatly depending on the use case and AV shuttle provider. The types of infrastructure changes for AV shuttle deployments include pavement markings, signage, roadside units, traffic signal timing adjustments, charging stations, secured parking areas, vegetation management, and modifications to construction schedules. The results of this project include discussion on the nature of these impacts, as well as a discussion on the reasons these impacts may be greater for some agencies than others.

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The cover page image is courtesy of the Minnesota Department of Transportation.

Project Champion

Elise Feldpausch, Michigan Department of Transportation and Cory Johnson, Minnesota Department of Transportation, were the ENTERPRISE Project Champions for this effort. The Project Champions serve as the overall leads for the project.

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Project Input

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- Maryland Department of Transportation State Highway Administration
- Maryland Department of Transportation Motor Vehicle Administration
- Maryland Transportation Authority
- Metropolitan Transit Authority of Harris County
- Michigan Department of Transportation
- Minnesota Department of Transportation
- North Central Texas Council of Governments
- Ohio Department of Transportation DriveOhio
- Southland (representing deployments in Alberta and British Columbia, Canada)
- University of Alberta
- Virginia Department of Transportation

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1.0 Introduction

Automated vehicle (AV) demonstrations are becoming more widespread, however the infrastructure changes and needs required for AVs may not be clear to transportation agencies. To help ENTERPRISE agencies prepare for future AV demonstrations and operations, this project captured insight from agencies that have deployed low-speed AV shuttles and identified likely impacts of AVs on infrastructure and operations.

The primary focus of this effort was the deployment of low-speed AV shuttles, such as the EasyMile ez10 shown in Figure 1 with its characteristics (e.g., driverless and electric shuttle, connected), with the intent to understand whether infrastructure changes and the roles of agency and private-sector stakeholders are representative of needs and roles in future, long-term AV deployments. This effort is not intended to be a comprehensive state of practice, but instead provides a detailed view on infrastructure impacts of AV shuttle deployments by 12 different agencies. This project reveals a wide variety of approaches for deploying low-speed AV shuttles, including varying expectations and demands on agency involvement and resources.

This project revealed a wide variety of approaches for deploying low-speed AV shuttles, including varying expectations and demands on agency involvement and resources.

This report includes the following sections:

- 2.0 Project Approach – Describes the research approach and how information was gathered.
- 3.0 Infrastructure Impacts from AV Shuttles – Presents a high-level overview of various types of infrastructure impacts from low-speed AV shuttles and a summary of findings from individual deployments, followed by a detailed look at infrastructure impacts from 12 individual AV shuttle deployments.
- 4.0 Broader Infrastructure Implications for AV Deployments – Describes conclusions and a summary of key AV infrastructure characteristics based on the project findings.
- 5.0 Summary – Summarizes key project findings.
- Appendix: Agency Interviewees and Interview Discussion Questions – Provides contact information for agency interviewees and questions discussed during the interviews.

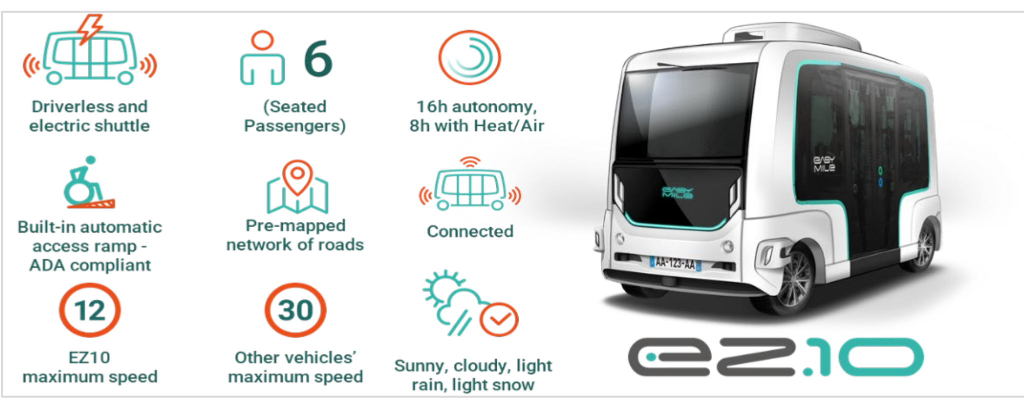

Figure 1. Example of low-speed AV shuttle, the EasyMile ez10 and its characteristics
Source: EasyMile

2.0 Project Approach

This project was structured to identify impacts of low-speed AV shuttle deployments for helping ENTERPRISE agencies to understand broader infrastructure impacts for any AV deployment.

The project completed the following activities:

- **Research Findings from AV Demonstrations.** This included an initial review of findings from a survey of AV shuttle demonstrations conducted by the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Operations (CTSO) Cooperative Automated Transportation (CAT) Working Group and CAT Coalition Infrastructure-Industry Working Group. These findings were used as a starting point for identifying agencies to contact for conducting interviews. Additionally, a review was conducted to identify published findings from agencies that completed or were in the process of completing AV shuttle deployments. See Section 3.1.
- **Conduct Phone Interviews.** Using the research findings, key contacts from agencies in the United States and Canada that conducted low-speed AV shuttle demonstrations were contacted to supplement the findings and gather more information. Twelve interviews were conducted and with the exception of the Utah deployment that used a final report identified in the literature review. See Section 3.4.
- **Synthesize Findings and Identify Likely Operations Impacts.** Findings from the review and phone interviews were stratified into broader, potential operations impacts in order to help understand if these impacts would transfer to other AV deployments. This included a discussion of candidate impacts and descriptions of what may cause them, who may be affected, and how the impacts may be mitigated. See Section 4.0.

2.1 Description of AV Shuttle Demonstrations

Overall, this project incorporates findings from 13 locations that deployed low-speed AV shuttle demonstrations, which are summarized in Table 1 and described in more detail in Section 3.4. Specifically, these demonstrations are defined by three parameters:

- **Route type.** AV shuttle deployments primarily take place either in:
    - *Closed campus* settings, such as a university, includes non-public roads, trails, or sidewalks where the AV shuttle operates in the presence of pedestrians and bicyclists but without interacting with other vehicles.
    - *Mixed traffic* settings, such as parking areas and local roads, which include streets and parking areas where the AV shuttle interacts with and operates alongside other passenger vehicles, as well as pedestrians and bicyclists.
    - Note that mixed traffic settings may or may not include *signalized intersections*, where a traffic signal may be used to control traffic at a cross street or rail crossing.
- **Duration**. AV shuttle deployments may be a relatively fast demonstration or take place for multiple years:

- *Short-term* AV demonstrations are defined here as lasting up to one year; some demonstrations may last only for several days at a given location.
- *Long-term* AV deployments are defined here as lasting over one year.

- **Status.** AV shuttle deployments are classified here for being:
  - *Multiple projects / phases* which may involve expanding the routes or demonstrating new capabilities of an AV shuttle (e.g., to use the AV shuttle in more complex situations involving more interactions with other vehicles and/or with signalized intersections), or to test or deploy different vehicle models of AVs.
  - *Ongoing* are defined as demonstrations that have been ongoing since 2021.

Table 1. Summary of AV shuttle deployments described in this report

Location	Route Type			Duration		Status		Notes
	Closed Campus	Mixed Traffic	Signalized Intersection(s)	Short-Term, up to 1 year	Long-Term, >1 year	Multiple Projects / Phases	Ongoing as of 2021	
Delaware		■			■	■	■	Agency purchased 2 shuttles in 5-year agreement
Maryland		■	■	■		■	■	3 phases lasting 2 weeks to 3 months each
Michigan		■	■	■		■		Multiple projects around the state
Minnesota		■	■	■			■	12-month project
Ohio		■	■	■		■		2 projects, each 1 year
Texas (Arlington)	■	■	■	■		■	■	3 phases, ranging from 6-12 months
Texas (Frisco)		■	■	■				8-month project
Texas (Harris County)	■	■	■	■		■	■	2 phases, first on closed campus, second in mixed traffic
Utah	■	■	■*	■		■		Deployed at 8 sites over 17 months. *Traffic signal integration tested in a closed area.
Virginia		■	■		■		■	Utility purchased AV shuttle as part of grant
Alberta / British Columbia	■	■	■	■	■	■		15 projects, including both short- and long-term demonstration
Ontario (Ottawa)	■	■		■		■		2 projects, each <2 weeks

3.0 Infrastructure Impacts from AV Shuttles

This section first provides a high-level overview of the types of infrastructure impacts in AV shuttle deployments. Subsequent subsections summarize and then provide the specific details from individual AV shuttle deployments, as identified from the literature review and agency interviews.

3.1 Literature Review Findings

The literature review identified several documents that were helpful in establishing a high-level overview of the nature of infrastructure changes for AV shuttle deployments. While these documents generally did not provide sufficient details regarding infrastructure impacts, the content was valuable for identifying agency contacts to interview about specific AV shuttle deployments and provides additional information that may be of interest to readers. These documents included:

- *Current AV Deployment and Shuttle Initiatives in the United States* (American Association of State Highway and Transportation Officials, https://transportationops.org/sites/transops/files/I-I%20AV%20Synthesis%20Report%20061120%20with%20disclaimer.pdf) summarizes survey findings provided by AV shuttle deployers. Survey questions focused largely on policy and lessons learned, but identified agency individuals to contact for interviews in this project.
- *Best Practices for Automated Vehicle Trials in North American Municipalities – Final Report* (CAVCOE, formerly the Canadian Automated Vehicles Centre of Excellence, https://www.toronto.ca/wp-content/uploads/2019/10/9014-TS_CAVCOE_City_Tor_AV_Trials_final_rpt.pdf) summarizes best practices identified from AV demonstrations across Canada.
- *Impacts of Automated Vehicles on Highway Infrastructure* (Federal Highway Administration, https://www.fhwa.dot.gov/publications/research/operations/21015/21015.pdf) highlights the potential impacts that AVs have on infrastructure and possible changes or upgrades agencies may need to make to prepare for AVs. This readiness document focuses broadly on all types of AV deployments and infrastructure preparedness.

Additionally, a project report prepared by the Utah Department of Transportation on their AV shuttle demonstration was identified during the literature review process and is summarized in Section 3.4.

A challenge during the literature review was finding documentation of AV shuttle deployments that included sufficient detail about infrastructure impacts. For instance, while news releases on planned or newly operational AV shuttle deployments are more common, these generally did not provide the level of information desired for this report.

3.2 Categories of Infrastructure Impacts in AV Shuttle Deployments

In general, the most common infrastructure changes required for AV shuttle operations that were identified by deploying agencies fall within six categories, as described below.

- *Signage*. All deploying agencies reported the need to install signage to support AV shuttle deployments. This included signage for AV shuttle stops, localization signage to be recognized by the AV shuttle to support navigation along the route, and static or dynamic signage to inform other vehicles and travelers (e.g., bikers and pedestrians) about the presence of the AV shuttle.
- *Pavement Markings*. Some agencies reported the need to touch up existing pavement markings and/or add new markings to support the AV shuttle. Temporary deployments may also require additional agency effort to remove added pavement markings at the end of the pilot period.
- *Traffic Signal Timing Changes*. When the AV shuttle route included a signalized intersection, traffic signal timing adjustments were frequently needed. This included solutions like the use of transit signal priority or adjusting the signal phase, such as extending the green phase for the minor cross street to provide the low-speed AV shuttle sufficient time to traverse the intersection.
- *Roadside Units*. Some agencies used roadside units to broadcast signal phase and timing (SPaT) and vehicle location information to support the AV shuttle at signalized intersections using vehicle-to-infrastructure (V2I) communications, and supplement other AV sensor systems.
- *Charging Stations and/or Secure Parking Areas*. AV shuttles require a charging station at a secure location when not in use. These accommodations are often provided by the deploying agency. Charging stations may require electric upgrades for faster charging times. The parking area location may need to be indoors or require additional security than typically at the site. Ideally, the parking area is near the route to minimize time or challenges for transporting the AV shuttle to and from the route.
- *Vegetation Management.* Many agencies cited the need for significant vegetation management, requiring a higher level of effort than anticipated. This included more frequent mowing grass than normal or a great deal of tree trimming to reduce the number of times the AV shuttle would make unexpected and sudden stops.
- *Road or Sidewalk Changes / Maintenance.* Agencies reported various adjustments along AV shuttle routes, including modifying a trail under a bridge to increase the clearance, new concrete landing pads at AV shuttle stops, pothole repairs, and straightening sidewalks.

Other adjustments to agency operations, which agencies noted below identified, included:

- *Adjusted Construction Schedules:* Texas (Frisco, Harris County), Virginia. Permitting and construction schedules were examined and altered, as needed, to accommodate AV shuttle operations.
- *AV Maintenance:* Texas (Harris County). A tow truck was needed to take the AV shuttle for repairs, which caused unforeseen costs.

- *Curbside Management:* Texas (Frisco). Fire lanes in front of restaurants were sometimes blocked with delivery trucks or delivery services, which disrupted AV operations, leading the city to re-examine curbside management.
- *Media and Public Outreach:* Utah. While likely not unique to Utah of the deployments interviewed, Utah acknowledged staffing and resources to provide informational materials to the public and conduct surveys.
- *Notification of Events:* Texas (Frisco) and Ohio. The agencies notified the AV provider when an alternate route was needed due to a special event.
- *Operational Changes for Weather and Road Conditions:* Minnesota, Utah. Environmental conditions that impacted AV shuttle operations include blowing dust, blowing leaves, snow accumulation, and rainfall, which can impact agency decisions regarding route selection, road weather management, and the AV shuttle schedule and operations.
- *Traffic Signal Brightness:* Texas (Arlington). The brightness of traffic signal beacons had to be increased to be more visible to the AV shuttle.

3.3 Summary of Infrastructure Impacts from Individual AV Shuttle Deployments

Table 2 summarizes the infrastructure needs for the AV shuttle deployments documented in this effort.

Table 2. Summary of infrastructure impacts from individual AV shuttle deployments documented in this effort

Location	Signage	Pavement Markings	Traffic Signal Timing Changes	Roadside Units	Charging Stations / Secure Parking	Vegetation Management	Road or Sidewalk Changes / Maintenance	Notes
Delaware	■			■	■	■		Roadside units (RSU) are deployed for a future phase and not yet used on the demonstration route.
Maryland	■			■				Signage included portable dynamic message signs to inform travelers.
Michigan	■		■					Signal timing adjusted at only one location due to complex series of intersections.
Minnesota	■		■	■	■	■		More staff effort than expected for this effort.
Ohio	■	■	■	■	■	■	■	Roadside units included camera and sensors; removed pavement markings; installed landing pads at stops; notify AV provider to take alternate routes due to events.
Texas (Arlington)	■	■				■	■	Had to lower trail under bridge and move landscaping features; had to make traffic signals brighter; re-stripe markings.
Texas (Frisco)	■					■		Curbside management issues with illegally stopped vehicles.
Texas (Harris County)	■	■			■	■		Removed pavement markings at end of demonstration.
Utah	■			■	■	■	■	Sidewalk modifications.
Virginia	■	■	■	■	■	■	■	More staff effort than anticipated for this effort. Adjusted construction schedule.
Alberta / British Columbia	■	■	■	■		■	■	Added flexible barriers and speed bumps; dust management on gravel trail was a major issue.
Ontario (Ottawa)	■	■			■	■	■	Pothole repairs; adjusted parking locations to accommodate the AV shuttle.

3.4 Detailed Infrastructure Impacts from Individual AV Shuttle Deployments

This section provides details of infrastructure and operational impacts identified in interviews and the literature review. For each deployment, a general deployment summary and agency actions is provided, followed by changes to infrastructure and the extent of changes, responsibility, and needs for future deployments. Details are provided in the subsections below for the following deployment locations:

- Delaware;
- Maryland;
- Michigan;

- Minnesota;
- Ohio;
- Texas (Arlington);
- Texas (Frisco);
- Texas (Harris County);
- Texas (North Central Texas Council of Governments);
- Utah;
- Virginia;
- Alberta and British Columbia, Canada; and
- Ontario, Canada (Ottawa).

Information for each deployment was gathered via interviews conducted with agency staff, with the exception of the Utah deployment that used a final report identified in the literature review. The discussion questions and agency staff contact information is available in Appendix: Agency Interviewees and Interview Discussion Questions.

3.4.1 Delaware

The Delaware Transit Corporation (DART First State), an operating division of the Delaware Department of Transportation (DelDOT) purchased two AV shuttles under a 5-year import agreement. The AV shuttles were accepted in October 2020 and have not been officially launched into service due to COVID-19. Instead, the AV shuttles have been operating at a single location in Dover shared by the DelDOT headquarters, a Department of Motor Vehicles (DMV) office, Delaware Transit Corporation facility, and an on-site regional maintenance facility. All roads at this location are operated and maintained by the state, as are 90% of the roads in Delaware. More information on DelDOT's AV shuttle program can be found at: https://deldot.gov/Programs/avshuttles.

Changes to Infrastructure and Operations

- *Signage.* DelDOT updated signage to lower the speed limit from 30 mph to 15 mph to better accommodate the low-speed AV shuttle, as well as "watch for AV shuttle" signs. There is no curb on some roads, so some delineation was required in certain areas, which was addressed by adding localization signage.
- *Roadside Units.* RSUs are nearby at signalized intersections and the AV shuttle can detect them. The functionality to receive SPaT messages and use them to proceed through an intersection with an RSU was tested using a test signal near the current shuttle route. The AV shuttle does not currently go through a signalized intersection, but this is a future next step.
- *Charging Stations / Secure Parking.* Two chargers were purchased for charging the shuttle to capacity.
- *Vegetation Management.* The route was pre-programmed with the EasyMile 10 Gen 3 vehicle in February 2021 and vegetation changed in the interim period leading up to deployment (e.g., grass grew 10 inches, foliage flourished). This was easy to address given DelDOT ownership and maintenance of roads.

Extent of Changes, Responsibility, and Needs for Future Deployments

- All infrastructure changes were relatively easy due to DelDOT ownership and control of the route.
- DelDOT and DART were responsible for these infrastructure changes. DART has a strong agency relationship with DelDOT divisions.
- In more urban locations fewer issues are anticipated. For example, the curb is always present, and sidewalks will help reduce vegetation issues caused by tall grass. The current AV shuttle location is a partially forested location. Storage and securing the vehicle in a location with a minimum level of heat and cooling may be a greater challenge for a different location that is not a DelDOT facility.

3.4.2 Maryland

The Maryland deployment was private-sector driven by AV provider Olli without funding from Maryland DOT or local agencies. Olli worked with Maryland DOT and local agencies to deploy the AV shuttle. The demonstration objective was for the private company to show they could operate with minimal changes to the infrastructure. The DOT role was to inform the public that the AV shuttle demonstration was occurring. Maryland did not want to do a lot of infrastructure changes, and the key was having a vendor that does not rely on pavement marking changes, QR codes, or other similar infrastructure.

Maryland DOT found that outreach was critical and spent a lot of time prior to the deployment on route selection and identifying potential challenges. Maryland DOT staff walked the route with Olli staff several times to discuss issues (e.g., right turn on red is allowed, but the shuttle cannot see around obstacles and will not turn on red on its own) and understand what traffic control devices might be needed for the AV shuttle to respond to correctly without relying on infrastructure changes. Understanding that the AV shuttle (or company) may be gone in a year, Maryland DOT worked to identify the safest route that also had minimal infrastructure changes.

Olli proposed phases for deployment, starting with a shorter route in Phase 1 and a slightly expanded route in Phase 2, each of which lasted 2-3 weeks. Phase 3 is a longer and is a circulator route between various points of interest that includes signalized intersections and is expected to occur for 2-3 months. Agency teams reviewed the various deployment phases, including intersections, stop signs, traffic volumes, and other transit in the area to make adjustments to the suggested routes (e.g., avoiding roadways with closely spaced intersections, right turns at signalized intersections). Monthly reviews were conducted with the full Maryland DOT and Olli team to examine manual override situations and ask if infrastructure or vehicle adjustments were warranted. Olli found alternate solutions to integrate into the software and future generations of the vehicle when issues were encountered, iteratively taking small steps toward bigger and more complex situations.

Changes to Infrastructure and Operations

- *Signage*. Maryland DOT made portable dynamic message signs (PDMS) available to display messages like “automated vehicle testing in this area.” However, these signs were not used on the initial shorter Phase 1 and Phase 2 routes. PDMS are anticipated to be used in Phase 3. The intent of the PDMS was to inform drivers but not change driver behavior. Approved Manual of

Uniform Traffic Control Devices (MUTCD) blue and white static signs about AV testing on the right-of-way were installed by Maryland DOT. Olli installed static signage for the bus stops.

- *Roadside Units.* The local jurisdiction, Prince George's County Department of Public Works and Transportation, worked to integrate the AV shuttle with the traffic system by procuring and deploying Dedicated Short-Range Communication (DSRC) RSUs at locations along the deployment operational design domain (ODD). Integration and testing was successfully conducted using portable traffic lights at a test site and the same DSRC RSUs, on-board units (OBUs), and version of controllers from the route. The AV shuttle can receive MAP and SPaT data via DSRC and integrate it with vehicle software and decision-making capabilities in cognitive response of the vehicle. Olli mapped the route. The AV shuttle uses LiDAR, GPS, and cameras, so integration with the traffic light for SPaT information provides a third source of information for the vehicle to verify that the travel path is clear. This additional redundancy was shown to significantly improve rideability of the Olli shuttle. Additionally, smart transit facilities that can communicate with the AV shuttle and display the shuttle location and other transit information on a large screen were installed at stop locations.
- *Charging Stations / Secure Parking.* Olli identified the location on the route to store and charge the AV shuttle. The local jurisdiction's considerations included vehicle charge time and how long the vehicle can be on the road when fully charged, as they wanted the shuttle to be reliable and able to maintain the schedule. These are similar issues as with electric buses, which require electric charging infrastructure that would ideally be compatible with AV shuttles.

Extent of Changes, Responsibility, and Needs for Future Deployments

- The infrastructure changes were minor and one-time efforts for Maryland DOT.
- The local jurisdictions shouldered the cost and resources for changes to the infrastructure, while Maryland DOT supplied staff insights only (no funding or physical resources).
- These changes may or may not be representative of needs and roles in future, long-term deployments depending on the use case and who wants the shuttle. This demonstration was initiated by the AV shuttle provider, but the local jurisdictions hosted shelter and charging capability for a separate demonstration initiated by the agency. Maryland DOT believes that when the agency leads the effort, the agency would also likely be responsible for any necessary infrastructure changes like storage and charging infrastructure unless otherwise negotiated with the vendor. Maryland DOT is interested in efforts led by either transit agencies or as private-public partnerships but would advance deployments that includes additional funding from outside of the agency.
- An increased understanding of business cases, revenue-generation or fare collection models, and private-sector sponsorship possibilities for AV shuttles is needed to better understand needs for future deployments. The AV shuttle in Maryland does not collect a fare, and AV shuttles will likely be subsidized by businesses or agencies for maintenance and operations.

3.4.3 Michigan

A number of AV shuttles have been deployed in Michigan as part of various projects. Michigan DOT (MDOT) has worked to support these projects as much as possible, while also attempting to limit device deployment and implement modifications that are universally useful moving forward. There have been no institutionalized AV shuttles deployed long-term, so the DOT has a policy to not make changes specifically for AVs, particularly if there is no long-term value. Instead, MDOT wants to demonstrate the real-world value of AV shuttles through operations with pedestrians and in mixed traffic without specific adjustments. MDOT encourages AV providers to select routes that consider the existing infrastructure, intersections, and construction projects to minimize interactions and infrastructure modifications.

Changes to Infrastructure and Operations

- *Signage.* MDOT provided signage for directing traffic per MUTCD requirements for AV demonstrations. MDOT required the AV shuttle provider to provide any informational or promotional signage that was not also for other vehicles.
- *Pavement Markings.* MDOT conducts annual re-striping of freeways and tried to coordinate striping activities on the AV route to be completed immediately before a demonstration.
- *Traffic Signal Timing Changes.* MDOT did have to make a single traffic signal timing change for one deployment due to a complex series of intersections. Given the temporary nature of the AV shuttle deployments, MDOT does not implement transit signal priority and encourages route selection to consider intersections that will work for the AV shuttle.
- *Roadside Units.* MDOT had intended to deploy RSUs at certain intersections for an AV demonstration but it was cancelled due to the COVID-19 pandemic.
- *Charging Stations / Secure Parking.* MDOT has provided the AV shuttle provider with a nearby site to charge and store the AV shuttle. MDOT also provided storage options within a fenced area, but anything more secure than a fenced parking area had to be provided by the vendor.
- *Vegetation Management.* MDOT did not have issues with tree trimming. Vegetation management is considered during the route selection process, in part by understanding limitations of different types of AVs (i.e., shuttle bus vs. taxi style). Additionally, the demonstrations were conducted during the summer.

Extent of Changes, Responsibility, and Needs for Future Deployments

- MDOT is selective in what types of infrastructure changes were made.
- MDOT has worked in partnership with local agencies to determine who is responsible for decisions and making the changes. Sometimes MDOT deploys on the local agency road if the local agency operates and maintains the deployment, or the local agency may deploy and MDOT would buy it. These partnerships are part of a holistic agreement and demonstration.
- MDOT still works in demonstration mode with AV shuttles and expects that to stay the same for future deployments. It is hard to see where the technology is going to go, and ultimately more dynamic and flexible solutions are expected that are not constrained by a singular route. For the broader variety of solutions like traditional shuttles, robotaxis, and teleoperated shuttles, technology continues to move itself forward and expect fewer requirements.

- MDOT was able to describe a clear picture of the current environment for the procurement to help ensure that what was proposed would work for that environment. MDOT conducted workshops to talk about the deployment area and challenges before providers submitted proposals. MDOT was very clear in procurement documents and provided a variety of spreadsheets about different factors to minimize any extra, unexpected infrastructure changes.

3.4.4 Minnesota

Minnesota DOT (MnDOT) is currently working to deploy an AV shuttle with EasyMile in the city of Rochester. Infrastructure changes have been identified throughout the project by the AV provider. All "requests" are communicated as needs by MnDOT but the provider has noted some are "nice to haves." MnDOT is seeking to emphasize equity in this deployment and wants to anticipate the impacts of each request, as some may not result in equity.

Changes to Infrastructure and Operations

- *Signage.* MnDOT installed signage every 50 feet on the left and right shoulders along the route to support AV shuttle localization given concerns about operations in a rural area. MnDOT experienced challenges with sizing the signage based on the AV provider needs (e.g., a 2-foot by 4-foot sign with a 10-foot clearance). Installing this signage was a significant requirement and challenge for MnDOT but was easier along a grass boulevard. MnDOT notes that there is no formal guidance in the MUTCD on what these road-facing signs should say to be compliant. MnDOT is working to standardize messaging on these types of signs for use in similar deployments in other parts of the state.
- *Pavement Markings.* The AV provider has discussed upgrading pavement markings, but MnDOT has not done this.
- *Traffic Signal Timing Changes.* MnDOT is trying to use a transit signal priority (TSP) system with the AV shuttle that is already used with other transit vehicles, which took additional effort. MnDOT uses advanced pedestrian phasing on some signals, which was new to the AV shuttle provider (i.e., the traffic signal does not turn green for an additional 4 seconds after the walk display appears). Initially, MnDOT expected to have to reprogram the software, which would cause a 6-month delay, or change routes, but neither alternative was acceptable. Instead, MnDOT developed additional phasing to identify a solution, which reflects substantial changes from the traffic engineering perspective.
- *Roadside Units.* The initial proposal suggested V2I communications. MnDOT is trying to broadcast SPaT messaging using V2I communications for the demonstration. However, the AV provider wants SPaT information every time and this is not always possible (e.g., a thunderstorm can wipe out communications and the AV shuttle would need to revert to manual operations). MnDOT is attempting to use DSRC initially, then transition to cellular vehicle-to-everything (C-V2X) communications for point-to-point communications and use network cellular communications as a backup to help reduce demand on any one system. However, this approach requires two systems to be operational. Four signals along the route already had the required communications, but another nine needed additional backhaul communications to connect to the Transportation Management Center (TMC) for a second channel and redundancy. MnDOT had to add fiber and

point-to-point equipment from the traffic signal cabinet to the signal intersection with a field device, which required space in the cabinet and conduits and equipment on pole. The City of Rochester has advanced signalized intersection infrastructure, so the impact to cabinet and conduit spaces was minimal. Software was a bigger challenge and significant impact, including upgrading and configurating software, software integration concerns, and additional security measures. Another challenge was that the AV shuttle could get stuck in the intersection, so MnDOT built a system to not let the green light change until the AV shuttle passed through. This solution uses V2I communications and GPS location from the AV shuttle.

- *Charging Stations / Secure Parking.* The identified charging location was not initially setup to charge AVs, so MnDOT needed to install new electrical equipment, which was unexpected. However, the result is a standard electrical charging location that can be used by other vehicles at the Rochester operations garage.
- *Vegetation Management.* Tree trimming was discussed with the AV provider, but the extent and frequency that would be required was not discussed until later on. While trimming has not been substantial, the AV shuttle requirements are more aggressive in some of the requests than anticipated by MnDOT.
- *Road or Sidewalk Changes / Maintenance.* A construction project is planned in the adjacent lane along the route, but hopefully will not be too close to the AV lane of traffic to disrupt operations. One roadway on the AV route was not as smooth as others, and MnDOT received and declined a request from the AV provider to resurface it.
- *Other Impacts: Operational Changes for Weather and Road Conditions.* Snow is a challenge for the AV shuttle as it can obscure the vehicle sensors. When considering at what point (light/medium/heavy snow) the AV shuttle should revert to manual operations, the AV provider suggested an initial threshold of 14 degrees Fahrenheit. There were significant constraints to ODD that MnDOT was not initially aware of. Additional challenges included heaters on AVs and limited hours of operation.

Extent of Changes, Responsibility, and Needs for Future Deployments

- An agreement is needed to define the road environment necessary to accommodate AVs and shuttles. The AV shuttle provider for this deployment is very risk averse and wants a perfect route and scenario to avoid the risk of the shuttle making frequent stops. This indicates there is either not enough risk tolerance or capacity in the AV programming to adapt to those conditions that happen infrequently (e.g., a missing lane marking, bumps in the road, foliage).
- Currently, AV providers adapt to the DOT, but going forward more pressure will be placed on the DOT, and a big question is how much a DOT should have to adapt (e.g., frequency of painting pavement markings). The more the DOT adapts for AVs, costs will increase and get the attention of the public and legislature. This makes it more likely that AV technology will need to adapt because DOTs, cities, and counties will be unable to improve infrastructure to meet the AV provider expectations. At the same time, AV improvements have been made, and the technology continues to evolve.

3.4.5 Ohio

The Ohio DOT (ODOT) and the City of Columbus deployed two AV shuttles: the first was the Smart Circuit in a dense, urban environment downtown, and the second deployment outside of downtown was called the Linden LEAP and had more flexibility for the deployment.

Changes to Infrastructure and Operations

- *Signage*. For the Smart Circuit deployment, new signage was provided for AV shuttle stop locations; ODOT fabricated the signs and the city installed them. This type of signage is not addressed in the MUTCD, so there was a lot of discussion on what information the signs could or should say. The signs were also designed in a way such that if the route had to be closed, the sign could hinge open to display alternate information to make alterations appear more intentional (i.e., not the fault of the AV that it is closed). This design was informed by a lesson learned from Michigan, ODOT staff traveled to view an AV shuttle deployment in Michigan which was not operating at the time. ODOT observed signs with sheet protectors over them that were smeared from the rain, and ODOT did not want to replicate the situation. For the Linden LEAP deployment, the city fabricated and installed new advisory signs to provide additional information not found on a traditional sign and “share the road” signs for the AV shuttle (similar to signs used for bikes) in addition to station signs.
- *Pavement Markings*. The first deployment required pavement marking removal (i.e., a hashed-out area going from one to two lanes where a station was being installed). The city noted it would be illegal for vehicles to drive over that area, so stripes were removed to indicate that vehicles were allowed to pass. Originally the planned route for the second deployment was a 35-mph roadway with parking lane lines utilized as a traffic calming measure to narrow the optics and slow drivers down; however, the route was modified to a roadway with a slower speed limit where these measures were not needed.
- *Traffic Signal Timing Changes*. One signal in the first deployment did not have an advance phase because the volumes did not meet traffic signal warrants, but the AV shuttle did not have sufficient time to navigate the intersection, so a short lead-phase was implemented. This was a minor change.
- *Roadside Units*. Devices from May Mobility were used in the first deployment, which differed from traditional connected vehicle (CV) RSUs, as it used a camera with a 4G modem that sends a signal to an operations center for analysis to then send back the signal phase. These devices were attached to existing infrastructure and required power via a different power supply than what was available there. Although the required power supply was available in adjacent signal cabinets, the city did not want them to access the cabinet. As a result, May Mobility swapped batteries in the units to keep them powered. The second deployment had CV RSUs in the area, but since the AV did not cross intersections, there was no need to integrate them with the AV shuttle.
- *Charging Stations / Secure Parking*. Both procurements included turnkey service, so the onus was on the vendor to provide charging stations. The first deployment, Smart Circuit, leveraged stakeholder connections to secure a new charging location, given limited alternatives in the urban setting; the new location was more desirable to them and nearer to the route than the place

initially arranged by ODOT. The provider left the charging infrastructure located near the route for the public to use. The second deployment, the Linden LEAP, utilized two EasyMile AV shuttles and rented a parking garage from a route stakeholder that also was a station location – St. Stephen's Community House. The site had several driveways, but the grade coming out of the preferred driveway combined with the cross-slope of the intersecting road was viewed by the AV shuttle as an obstacle, so a different driveway had to be used. The next generation EasyMile vehicle has added sensors/capabilities to address this issue. It was important to have the charging station as close to the route as possible. The Smart Circuit vehicles could travel to a storage location further from the route because they could be driven manually at full speed. However, it was not desirable to operate the EasyMile AV shuttle manually as it was very slow. One AV deployment that the project team visited towed the vehicle every day off route, which ODOT and the City did not want because of the potential for bad optics.

- *Vegetation Management.* The Linden LEAP deployment required overhead branches to be removed. An unexpected need was that brush growing on a fence needed to be cleared.
- *Road or Sidewalk Changes / Maintenance*. Concrete landing pads were installed at the Linden LEAP stations to provide a level boarding area for the AV shuttle stop using available city resources. In one location for the Smart Circuit, there was discussion about how to get people from the curb across a grassy area to the sidewalk. A plastic pad with bumps on it was considered as an option, but with snow and slush that did not seem like a great solution. Instead, the agencies opted out because it did not seem like an improvement, especially for a one-year project.
- *Other Impacts: Notification of Events.* The agencies coordinated with all stakeholders on the Smart Circuit route for planned/unplanned events in order to ensure an alternate AV shuttle route was used. Alternate route options were available for AV shuttle services during planned/unplanned events. While there were not many unplanned events, there was a festival almost every other weekend during the warmer months (prior to the COVID-19 pandemic) that required route adjustments. Since the Linden LEAP required National Highway Traffic Safety Administration (NHTSA) approval for route operations, no alternate routes were proposed and there were not any significant route impacts that would have required rerouting.

Extent of Changes, Responsibility, and Needs for Future Deployments

- Most infrastructure changes were relatively small efforts, but only because of the major coordination, planning, and organizing that took place in advance. Otherwise, more extensive changes may have been required.
- The city and ODOT worked together on the infrastructure changes described above, which was a mutually beneficial collaboration.
- These infrastructure changes are likely representative of future AV deployments. AV technology is evolving and getting better and additional lessons learned will help. For example, a USDOT Better Utilizing Investments to Leverage Development (BUILD) Grant and second Federal Transit Administration (FTA) Grant will support a deployment of AV Shuttles in Youngstown, Ohio. Both deployments concluded with a report to document lessons learned, including deployment playbooks for the Smart Columbus and Linden LEAP deployments.

- The BUILD Grant application written in 2019 for the Youngstown deployment was hard to scope and procure with companies not knowing what the companies or landscape would look like in 2022 given that AV shuttles are part of a fast-changing industry.

3.4.6 Texas (Arlington)

The City of Arlington, Texas has had three AV shuttle deployments, which are described below. The first AV deployment started in 2017 and used an EasyMile AV shuttle. The route was an off-street, closed circuit and represented the first local government AV deployment available to the public. This deployment was operated for one year only, as the city opted not to pursue a second year. All infrastructure changes described for this deployment were made by the City of Arlington. City staff were very hands on for this deployment and even had a city employee certified as an AV shuttle operator.

A second AV deployment began in 2018 with Drive.ai using a retrofitted Nissan van. This AV operated on-street in the same entertainment district as the first AV deployment. This deployment was intended to last for two years but was shut down after only six months when Drive.ai was bought by Apple.

The third deployment is a one-year pilot supported by a grant that integrates the on-street AVs as an on-demand, shared service into the Via transportation application platform. This deployment includes five Lexus RX450 AVs that operate downtown and in the University of Texas-Arlington area, which is about one square mile. Four of these AVs are autonomous, and two provide wheelchair service using Polaris GEM. May Mobility worked with Via to establish a fully integrated process for booking rides and payment.

Changes to Infrastructure and Operations – First Deployment (EasyMile AV Shuttle)

- *Signage.* Signage was installed at AV stop locations and a lot of vertical elements were installed to help with navigation. Additionally, although not explicitly signage, trash cans and boulders were relocated and new boulders and birdhouses were placed along segments that required additional visual cues (note that these changes are included in this category as other deployments installed signage as a solution to fill this need).
- *Vegetation Management.* A lot of changes were needed to the environment along the shuttle route because it went through a heavy vegetation park with tall grass right up to the trail. Blowing grass or tree limbs would trigger the AV shuttle to come to a sudden stop, so continuous maintenance with mowing and tree trimming was necessary. The AV provider informed the city when the AV shuttle was having too many issues at a particular location.
- *Road or Sidewalk Changes / Maintenance.* The AV shuttle used a 10-foot trail that had to be lowered where it passed under a bridge to increase the vertical clearance.

Changes to Infrastructure and Operations – Second Deployment (Drive.ai retrofitted Nissan van)

- *Signage.* Signage was installed at stop locations.
- *Pavement Markings.* Some lane lines needed to be re-striped to be more visible.
- *Vegetation Management.* Minimal vegetation trimming was needed.
- *Other Impacts: Traffic Signal Brightness.* The brightness of traffic signal beacons had to be increased to be more visible to the AV.

Changes to Infrastructure and Operations – Third Deployment (Lexus RX450 AVs)

- *Pavement Markings.* Some re-striping of lane lines was needed for a very small part of the service area.
- *Vegetation Management.* Minor vegetation trimming was needed for visibility.

Extent of Changes, Responsibility, and Needs for Future Deployments

- The city learned a lot through the initial deployment and tries to be intentional with selecting providers to minimize the level of effort. Arlington does this by structuring the request for proposals (RFP) to be very turnkey.
- Arlington is not interested in deploying CV infrastructure and prefers AVs to operate on the streets as they are to avoid infrastructure installation and costs. That said, a separate department in the City of Arlington is looking at CV testing with sensors and infrastructure for equipped passenger vehicles.

3.4.7 Texas (Frisco)

The City of Frisco, Texas deployed an AV shuttle with Drive.ai. This deployment was conducted at no cost to the city and incurred minimal impacts to infrastructure, even though the AV operated on the street and crossed a signalized intersection. More information on this deployment is available at: https://www.friscotexas.gov/1573/Driverless-Car-Pilot-Program.

Changes to Infrastructure and Operations

- *Signage.* Signage was installed to designate the pickup points outside various buildings for riders and users. The city provided signs, the AV provider installed them, and the transit authority (Denton County Transportation Authority, DCTA) handled any required easements on private property.
- *Roadside Units.* The city was initially interested in experimenting with DSRC, and while the AV provider was willing to integrate this, they did not want the AV shuttle to depend on DSRC or roadside infrastructure for communications.
- *Charging Stations and Secure Parking.* Off-site parking requirements were managed by Drive.ai. There was no need for charging stations, as these were gas-powered AVs. Gas-powered AVs were chosen since the speed limit on the AV route was 40 mph and neighborhood electric vehicles can only operate on roadways with speed limits of 35 mph or less, per state laws.
- *Vegetation Management.* The AV provider ran the route with the AV and identified areas that vegetation needed to be trimmed. Some plantings in medians that had grown too high and obstructed visibility were trimmed.
- *Other Impacts: Adjusted Construction Schedules.* The city examined utility construction that was underway to determine if it would impact the route, worked with utilities to make any needed changes, and incorporated this into right-of-way permitting along the AV shuttle route.
- *Other Impacts: Curbside Management.* The purpose of the AV was to transport employees from retail areas to lunch and activities areas. Fire lanes in front of restaurants were sometimes blocked with delivery trucks or delivery services (e.g., DoorDash), which disrupted AV operations. The city worked with the Fire Marshall to help keep the fire lanes clear and Drive.ai adjusted their start

times. Note that Drive.ai first focused on the proof of concept, but later focused more on proof of service and wanted to minimize manual operation times requiring the driver to take over operations. As a result of this experience, the city is now considering how parking lots and loading zones should be configured to provide better access for shuttles and deliveries. Additionally, the Fire Marshall indicated they were willing to give citations for blocked fire lanes to help make the AV demonstration work.

- *Other Impacts: Notification of Events.* The city was responsible for alerting the AV provider when large events were happening in the geofenced service area.

Extent of Changes, Responsibility, and Needs for Future Deployments

- Most infrastructure changes were a minor, one-time effort.
- Changes were the responsibility of both the city and AV provider, Drive.ai.
- The City of Frisco focused on making the infrastructure changes that were needed for human drivers anyway (e.g., improved signage and visibility, pavement marking maintenance).
- Most changes related to parking and future development patterns (e.g., parking space, curbside drop-off locations). The city needs to be as flexible as possible to adapt as needed for the future. The City of Frisco is a relatively "new" city with infrastructure that is only 20 years old or less.
- Drive.ai was a good partner as they had a desire to work with the city. Other companies might not be willing to work with the city, as doing so could be cost prohibitive and local regulations may not require them to do so. As such, it is important for agencies to understand whether laws are in place that require companies to work with the public agency.
- The AV industry and technology changes quickly. Federal funds were not used for this effort, but is it important to note with using federal funds the process required can increase the project duration.
- Drive.ai had to add a two-stage crossing to the algorithms for the AV to cross a divided arterial with a wide median at a non-signalized intersection. If the AV route were expanded to other areas, locations where similar geometries occurred that could challenge the AV would need to be considered. Left turns at a signalized intersection could specifically create a challenge about how the AV would handle a permitted left turn or if it would get pre-emption.
- Personal Delivery Device (PDD) operations in a suburban location also create a challenge for traversing signalized intersections with actuated pedestrian signals, since they are not able to activate the crossing. The agency could require PDDs to use only non-actuated intersections or require a connection to activate the signal; the solution might be different for each location as signal operations and vendors are all different, and may not be interoperable for all locations.

3.4.8 Texas (Harris County)

The Metropolitan Transit Authority of Harris County (Metro) deployed an EasyMile Gen2 AV shuttle on a 1-mile closed loop on the Texas Southern University (TSU) campus. EasyMile performed route mitigation activities with the AV shuttle along the route alignment, including identification of hazard spots like a bike trail, and Metro was responsible for the necessary infrastructure changes. Following Phase 1 of the deployment, Metro developed an AV Operations Manual and "Lessons Learned" report that created a blueprint for agencies entering into deployments from shuttle delivery to closing.

Metro has now begun Phase 2 of the AV deployment that has been funded by the FTA Accelerating Innovative Mobility grant. Metro has partnered with Phoenix Motorcars (vehicle manufacturer), EasyMile (automation lead) and AECOM (engineering/testing lead). Metro will be the first transit agency to develop a vehicle prototype for a Class 4 mid-size, medium duty, shared, zero emission, Level 4 AV that is compliant with Federal Motor Vehicle Safety Standards (FMVSS), Buy America, and ADA regulations.

In Phase 2, the AV shuttle will operate in mixed traffic and cross a rail line and Metro's Operations team will install agency automatic passenger counters (APCs), and equipment to support "Where's My Bus" capabilities so that the AV shuttle can mimic a bus. Metro's Safety team conducted a risk analysis for the potential Phase 2 route along with EasyMile' s Site Visit Report, which was also provided during Phase 1 of the AV deployment. This document highlighted the importance of safety and addresses any safety mitigations before the shuttle arrives for deployment, such as trimming trees, signage, and traffic mitigation. Metro will continue to engage their partners during the Phase 2 deployment.

Changes to Infrastructure and Operations – Phase 1 Deployment

- *Signage.* Yield signs and signage for shuttle stops was added.
- *Pavement Markings*. Some new lane markings were needed, none of which were needed for other entities or projects. These were identified by working with EasyMile to bring visibility to the AV shuttle on a high-traffic loop. This was part of a high level of effort focusing on safety to keep both the AV shuttle and vulnerable populations safe. While AV lane marking sounds simple, there are costs to install and also to remove pavement markings at the end of a pilot. Additionally, reflectors on the pavement kept coming off during Phase 1 due to the surface not being smooth and heavy traffic along the alignment. Painted lane markings were considered as an alternative, but would serve as a more permanent option that would be harder to remove after the pilot.
- *Charging Stations / Secure Parking.* EasyMile had storage requirements, including upgrades to lighting and security at the storage facility. Additionally, the agency had to upgrade the capacity of the electric outlet.
- *Vegetation Management*. Tree trimming was required along the route at the beginning of the Phase 1 deployment.
- *Other Impacts: AV Maintenance.* There were two incidents with the AV shuttle where a tow truck was needed to take the AV shuttle for repairs. These costs were not foreseen, but costs were covered by a 10 percent contingency for added costs that were not budgeted for. Metro now has a maintenance plan in place for future deployments.

Changes to Infrastructure and Operations – Phase 2 Deployment

- *Traffic Signal Timing Changes.* The AV shuttle will be crossing a light rail line in Phase 2. The AV shuttle will have an operator on board, and the AV shuttle will operate in manual mode while crossing the rail line. TSP was identified as an option, but will not be incorporated into the Phase 2 deployment due to the project timeline. Metro will continue having conversations with the city about TSP for future projects.

- *Vegetation Management*. Tree trimming will be required along the route. EasyMile will notify Metro if vegetation needs to be trimmed.
- *Other Impacts: Adjusted Construction Schedules.* Metro is communicating with the city about future construction that may be taking place along the route alignment to avoid any disruptions or delays to service. Phase 2 route options will be modified if there are any upcoming construction projects.

Extent of Changes, Responsibility, and Needs for Future Deployments

- Metro's experience is expected to be representative of the infrastructure and operations needs of AV shuttles. Metro worked with Metro's safety team to identify lane markings, reduce the AV shuttle speed at crossings, and assign a traffic engineer to conduct a traffic capacity study before operating in mixed traffic. This effort is not large scale, but integrates the AV shuttle with the existing system.
- The AV shuttle will be retained by Metro after the pilots, so Metro has the ability to do more and mimic full-service mode (e.g., make the AV shuttle look and operate like a bus, let passengers request rides through an app, install APCs to collect passenger counts, and/or use fare cards).
- Metro continues to consider alternative modes to meet the growing demand for transportation among a diverse group of riders, and also address shortages of drivers and mechanics and increasing community and political pressure to move to low or no carbon vehicles.

3.4.9 Texas (North Central Texas Council of Governments)

The North Central Texas Council of Governments (NCTCOG) is the Dallas-Fort Worth area metropolitan planning organization (MPO) that supported the AV shuttle deployments in the City of Arlington described in Section 3.4.6 and the City of Frisco described in Section 3.4.7 deployments. This section describes the perspective from NCTCOG in supporting the Arlington and Frisco deployments.

Extent of Changes, Responsibility, and Needs for Future Deployments

- Access to SPaT data is useful for AVs to operate without visual cues from traffic signals, to optimize left turns, and to allow AVs that operate on sidewalks and paths to trigger pedestrian calls. The cloud is already sufficient for sharing most of this information with vehicles, and this may supersede the need for roadside equipment.
- Agencies do not want to be liable for the AV driving task because of the risk. As such, agencies share data with the AV shuttle to support operations, but with no warranty for accuracy. This delineates a division for the deployment as the infrastructure is not directly responsible for driving tasks.
- The traditional approach for deploying intelligent transportation system (ITS) is morphing as vehicles use sensors and communicate to each other via the cloud, thus displacing infrastructure responsibilities. At some point, original equipment manufacturers (OEMs) may supply information to assist vehicles navigating the road environment (e.g., work zones) as their vehicles harvest real-time conditions and make information available to each other via the cloud.
- AV shuttles may be more useful if they evolve and are able to be on streets with speeds of 35 mph.

- The environment in Texas is unfavorable to revenue raising. Agencies have to rely on the private sector to figure out deployments with minimal changes. Instead, agencies are looking at investments that benefit all users like those recommendations that are proposed for the 11th edition of the MUTCD.
- NCTCOG is interested in exploring a slow lanes concept, which is an infrastructure approach to accommodate AV shuttles, PDDs, and bikes as part of an operating environment to help AVs and other forms of micromobility.

3.4.10 Utah

The AV shuttle pilot in Utah was conducted jointly by the Utah DOT (UDOT) and the Utah Transit Authority (UTA). The project team deployed and evaluated an EasyMile EZ-10 Gen2 AV shuttle at eight temporary sites across the state over approximately 17 months. UDOT was responsible for preparing physical routes for the shuttle prior to deployment at each site, including any infrastructure modifications, and assisting with daily operations. UDOT operates a connected vehicle network in Utah and tested the V2I and V2V communications capability of the AV shuttle. The goal of the pilot was to operate the AV shuttle on pre-existing roadways, as it was not realistic to get roads built or significantly modified for the project period, although minor investments are still necessary.

The project team learned the best types of environments for AV shuttles as well as the level of interest from local communities, which will help shape next steps for UDOT and UTA take in their programs. While no significant infrastructure changes were made for this temporary pilot project, minor investments were required, as described below. Specific challenges included securing the necessary government approvals, balancing the needs and priorities of many project stakeholders, overcoming the limitations related to CAV technology itself, and getting real-time data on the vehicle's location.

A full report documenting Utah's Automated Shuttle Pilot Project is available at: https://transportationtechnology.utah.gov/what-were-learning.

Changes to Infrastructure and Operations

- *Signage.* Signage was deployed at all deployment sites to advertise the presence of the AV shuttle (i.e., inform), increase safety by alerting other drivers and pedestrians to its presence (i.e., warn), and aid shuttle navigation (i.e., localization). Designing the localization signs was challenging. EasyMile specified a sign that was 5 feet in height and at least 24 inches wide, situated next to the roadway centered 10 feet above the roadway. These localization signs were only for the purpose of the shuttle using LiDAR to "see" waypoints along a route when there are not many vertical objects. Tall Telespar poles were needed to make the height work, while maintaining proper clearance on the bottom of the sign. For a permanent deployment, the project team would recommend revisiting the sign color scheme and conducting more evaluation to determine the best category to align the color scheme appropriately. Utah noted that signs take a significant amount of effort to deploy and clean up on each service day; specifically, daily set-up of approximately one person-hour and one person-hour to take down the signs was required if signs are not able to be kept outside during nonservice hours. Utah noted the need for a variety of stands to place and hold the signs, a truck to transport the signs, and a warehouse to store the signs. Further, having more signs on site than a project team anticipates using is a good strategy to ensure that if more signs are needed, there is no significant delay in acquiring them. Examples of the roadside signs used in Utah to alert other roadway users of the presence of the AV shuttle are shown in Figure 2.

Figure 2. Example signage used in Utah to alert road users about the AV shuttle.

- *Traffic Signal Timing Changes.* While no traffic signal changes were made as part of the pilot, a significant effort was spent pursuing service at a location that was ultimately not pursued because of the need to cross a signalized intersection.
- *Roadside Units.* An original goal of the project was to test the capability of the shuttle to wirelessly communicate with traffic signals using DSRC V2I technology. This capability was tested in a UDOT parking lot with a portable signal controller and roadside unit, and then further demonstrated at the UDOT Test Track, where a fixed traffic signal was used to send stop and go commands to the shuttle's onboard unit. These tests successfully showed that DSRC communication and responses by the EZ10 shuttle were accurate and reliable if properly set up.
- *Charging Stations / Secure Parking.* The AV shuttle needs to be stored on site very close to its route, preferably less than a mile away. The parking location is preferably indoors, especially if hot or cold weather is expected, and requires a plug; although any type of plug will work, the type available will impact charging time. Each site in the Utah pilot needed to have a secure storage and charging location, some of which were outdoors and others were indoors. Since the shuttle requires 10 feet of vertical clearance, most traditional parking garages, with only 8 feet of clearance, are not suitable for storage. To maintain charging efficiency, all charging locations had to maintain an overnight temperature of 40° Fahrenheit or higher, so sites with outdoor storage locations were scheduled for summer deployments. Agencies planning to deploy automated shuttles need to consider how to provide maintenance, repair, cleaning, charging, and other services to AVs at remote locations. Usually, the AV shuttle is driven manually to its storage location, but this route could also be programmed in if it were short enough and within technological capabilities. For now, accessing the storage location in automated mode would probably mean having a dedicated lane and/or educating other drivers that the AV shuttle has the right-of-way.

- *Vegetation Management.* There was a need to mow grass and trim trees more often than usual as vegetation growth was sometimes identified by the AV shuttle as a potential hazard.
- *Road or Sidewalk Changes / Maintenance.* A minor sidewalk modification was made in one location to straighten out the AV shuttle travel path. Additionally, LiDAR detections on slopes can limit the ability to detect actual objects, especially at grade changes and transitions to flatter or steeper slopes where the LiDAR detects pavement surfaces ahead and the algorithms identify the pavement as an obstacle, which either required a manual override without modifications to the roadway or sidewalk grade.
- *Other Impacts: Operational Changes for Weather and Road Conditions.* The AV shuttle had problems operating in windy or dusty conditions as well as other previously known weather limitations such as rain and snow. This did not impact agency personnel, but would impact the shuttle operations and create a need for increased manual operations. Sensitivity of the LiDAR system algorithms causes the AV shuttle to stop for minor obstacles, including rain droplets and snowflakes. In general, the filtering software used to determine what the LiDAR sensors detected is not advanced enough to prevent abrupt stops for tumbleweeds, insects, and other minor obstacles. This created an unacceptable safety risk at higher speeds but was functional and safe at lower speeds of 5 mph or under.
- *Other Impacts: Media and Public Outreach.* When the AV shuttle was deployed near an indoor location, like a conference center, Utah DOT set up an informational booth inside the venue to provide informational materials. Additional materials included tablets for staff to solicit survey responses, a kiosk and/or umbrella, if staff were standing outside, and cleaning supplies.

Extent of Changes, Responsibility, and Needs for Future Deployments

- Combining UDOT's expertise in CAV technology, traffic management, and road infrastructure with UTA's knowledge of customer needs, daily operations, and vehicle performance standards made the project team well equipped to plan and oversee the project.
- AV shuttles currently need a very simple environment to run safely. Private roads with low speeds and not much through traffic are the best environments. Other environments, like parking lots, are not always a good fit (e.g., larger vehicles that stick out of a normal parking stall). Given current limitations of AV shuttles, UDOT criteria for future deployments include:
  - Dedicated right-of-way with nearby storage and charging stations.
  - Limited interactions with other vehicles.
  - Shuttle has priority over other traffic.
  - Prevention of obstructions from parked vehicles or delivery vehicles.
  - Limited conflicts with pedestrians, bicyclists, skateboarders, and other travelers that cause the AV shuttle to abruptly stop.
  - No construction activities in the proximity of the travel path.
- Beyond the cost for the AV shuttle itself, very little infrastructure changes are needed to operate in a simple environment when a human operator will be on board. Without an operator, more infrastructure changes would be needed. Finding an existing environment that meets the constraints of safely operating without an operator on board would be optimal from a cost perspective, as the costs to upgrade infrastructure would likely be high and possibly cost-

prohibitive. Any infrastructure improvements required to enable operations without an operator, such as physically separating a lane or smoothing the road, are additional capital costs. The cost for charging the automated shuttle is assumed to be only $2 a day, based on project results.

3.4.11 Virginia

The AV shuttle was purchased by the utility Dominion Energy and operations were supported by a grant awarded to the county through a public bidding process. Over 10 agencies and entities were engaged in the project, and it took about a year to get everything ready for the deployment. The Virginia DOT (VDOT) was called in to assist Fairfax County since VDOT operates some of the roads along the AV shuttle route. At the time, the start and end points of the route were known but the specific streets and route were not selected until after the shuttle was selected. Overall, not a lot of infrastructure changes were needed for basic AV shuttle operations, however a lot of unexpected items arose that required additional agency resources.

Changes to Infrastructure and Operations

- *Signage.* First, "Low Speed Vehicle" signage was required to communicate messages about operations for the AV shuttle. The shuttle provider, private developer, county, and VDOT coordinated about where signs were needed. In some cases permitting was required, as well as involving an engineer to identify appropriate locations for signage. Additionally, the AV shuttle required new signage approximately four feet by two feet for geolocation purposes because there were not sufficient permanent structures along the chosen route. This was not initially known and required time and debate about what the sign should look like or say. In general, there is not a lot of guidance in the MUTCD for AV shuttle-related signage.
- *Pavement Markings.* Some pavement marking adjustments were needed since the travel lane was not always wide enough, but this mostly involved touchups.
- *Traffic Signal Timing Changes.* Transit signal priority was needed at a signalized intersection because otherwise the AV shuttle did not have sufficient time to clear the intersection, given the width of the cross street and slow speed of the AV shuttle (12.5 mph).
- *Roadside Units.* RSUs were needed at signalized intersections to help the AV shuttle understand traffic signal indications.
- *Charging Stations / Secure Parking*. Charging stations needed to be added for the deployment. Note that the placement for charging stations may vary by the objective of the deployment: transit (close to the route) vs. economic development (visible to the public) vs. research (access to researchers).
- *Vegetation Management*. A lot of tree trimming was needed, because the AV shuttle would come to a complete stop if a branch was too close. It was a major effort to obtain the necessary permits since VDOT needed to engage developers, businesses, and other jurisdictions.
- *Other Impacts: Adjusting Construction Schedules*. The county needed to shift the timing for installing a new bike lane, so that the AV shuttle operations would not be disrupted after the deployment began. Otherwise, it would have required the bike route to be re-routed. Specifically, the pavement marking contract specified work was to be conducted within a 2-3 month time

period, so without changing the schedule, it would have been unknown when exactly the change might occur and disrupt shuttle operations.

Extent of Changes, Responsibility, and Needs for Future Deployments

- With current AV shuttle speeds, VDOT believes this experience would be comparable to other, similar deployments. Some changes, like the transit signal priority, would not have been necessary if the AV shuttle could operate at a higher speed.
- VDOT anticipated RSUs and pavement marking needs, but everything else was learned along the way and could provide lessons for future deployments.
- Routing is an important part that agencies may not think of, but careful planning can prevent the need for many infrastructure changes. Specifically, all decisions regarding shuttle selection and route selection should be made with a single purpose (e.g., research, transit, economic development) for consistent outcomes.

3.4.12 Alberta and British Columbia, Canada

Note that this interview was conducted with individuals from Southland, which is owned by Pacific West Transportation Group of Companies and works with Transport Canada and municipalities for AV shuttle deployments, and the University of Alberta.

Initial planning began in 2017 with a focus on battery life and a seamless rider experience to assure the traveling public that AV shuttles were safe. Required pre- and post-deployment activities for AV shuttle deployments were not anticipated. In total, the support contractor, Southland, has supported over 15 AV shuttle deployments around western Canada (including Edmonton and Calgary, Alberta; and Vancouver and Surrey, British Columbia) in cooperation with Transport Canada, ranging from demonstration to practical deployments. As government officials become satisfied with AV shuttle experiences, deployments are expanded to be more complex. The initial project did not involve interactions for the AV shuttle with traffic or pedestrians, but AVs operated on mixed traffic roads in subsequent deployments as confidence grew.

Additional information on AV shuttle deployments by Transport Canada can be found at:

- *Testing Highly Automated Vehicles in Canada – Guidelines for Trial Organizations*: https://tc.canada.ca/sites/default/files/migrated/19_ah_01_automated_vehicles_layout_en_r13.pdf
- *Transport Canada Low Speed Automated Shuttle Testing – Final Report*: https://tcdocs.ingeniumcanada.org/sites/default/files/2021-04/Transport%20Canada%20Low%20Speed%20Automated%20Shuttle%20Testing%20-%20Final%20Report.PDF

Changes to Infrastructure and Operations

- *Signage.* New signage is typically installed along the AV shuttle route to provide awareness for both pedestrians and motorists.
- *Pavement Markings.* In some instances, painted lane markings have been added for a deployment to delineate an AV shuttle lane.

- *Traffic Signal Timing Changes.* For one deployment, one of the turns from the traffic signal sequence had to be canceled so that the vehicle would have access to the green light. This change was included with a big campaign to inform the public.
- *Roadside Units.* Roadside equipment was installed for the AV shuttle to communicate with the traffic signal controller. The timing of communications between traffic and pedestrian signals and the AV shuttle caused some challenges: V2I communications integration took an additional week in one location. Timing between the OBU and traffic signals has to be part of daily service inspection in order to understand how many seconds of delay exist between the signal timing and broadcast information.
- *Charging Stations / Secure Parking*. AV shuttle storage areas were required to be secure and out of public eye to prevent potential vandalism, and also needed access to water. The area also needs charging infrastructure, keeping in mind that lower voltages will require longer charging times (i.e., fully charging the AV shuttle with 110V electricity takes 12 hours, 240V takes 6 hours, and higher voltages may only take 1-3 hours). Finally, the storage area needed to have a strong and reliable Wi-Fi signal and broadband capacity to transfer large amounts of data, AV diagnostics, and video detection and recording. For shorter demonstrations (e.g., lasting only two days), the AV shuttles are sometimes stored in tents.
- *Vegetation Management.* Environmental conditions were most challenging, which is common for any vehicle using Lidar for autonomous navigation, including dust, flying debris, and hedge and grass trimming. Long-term pilots create a learning curve for staff with every change of season. Trees require maintenance during autumn due to falling leaves and branches, which creates debris that could hit AV sensors during high winds. These things can cause the AV shuttle to disengage and stop abruptly; when the AV moves at higher speeds then AV disengagement is harsher and can potentially harm passengers.
- *Road or Sidewalk Changes / Maintenance.* Work had to be done to prepare curb heights for the AV shuttles. Additionally, when testing the AV shuttle on a gravel road in Calgary dust was a major challenge due to the dry weather. Staff applied a film/coating to the road surface to minimize dust, but this created a mud that had to be cleaned from the AV shuttle sensors; sweeping the road worked better. During snow, the AV shuttle was able to operate in 3-4 inches of snow without plowing. Note that while some AVs have challenges working in dust, fog, wind, rain, hail, and snow conditions, other AVs are specifically designed to work in cold-weather climates. Additionally, a deployment in Beaumont had three phases: flexible barriers were added in phase 1 to separate other vehicles from the AV shuttle lane, those were replaced in phase 2 with rubber speed bumps between the lanes, and finally those were removed in phase 3 and replaced with painted lane markings.

Extent of Changes, Responsibility, and Needs for Future Deployments

- AV shuttle infrastructure needs will continue to get better and less intensive. AVs are evolving to rely on multiple systems to provide a seamless experience for navigation. Some AV providers are investing more to build on existing capabilities that are 80-90% “there” in order to get to full operations.

- Currently, fixed routes and locations need to be mapped to provide a lot of knowns and allow for a higher degree of certainty. As such, current AV shuttle technology is suited for testing and demonstrations, not full operations.
- AV operations must plan for environmental impacts 24/7 in all conditions, and agencies will need to focus on the adequacy of infrastructure for AV deployments and operations moving forward (e.g., to move obstacles that sometimes block the view of traffic signals and install devices to support vehicle intelligence). As long as a human operator is required for AVs, there are no cost efficiencies. As such, infrastructure investment is needed to address the remaining issues because it will not be possible to simply rely on autonomous driving.

3.4.13 Ontario, Canada (Ottawa)

The first AV shuttle pilot project operated in 2019 for four days on a golf course with the Aurrigo Pod AV to gain understanding of how the vehicle operated in a live but protected environment with a tunnel, bridges, and grade changes. This helped build an understanding of what was needed to minimize challenges and make future deployments successful. The city then undertook a preliminary review of potential sites that could be used for future deployments based on the learnings from this initial project.

A second deployment in the Fall of 2020 was part of a testing program with Transport Canada to understand AV shuttle capabilities, battery requirements and navigational constraints. Using the preliminary review results as a baseline, route selection was part of a four-month planning process with EasyMile that included a lot of site assessment. The route was chosen largely due to the 20 mph posted speed limit, the connection to a light rail station, and limited infrastructure changes required to the route, minimizing the number of new variables to account for. The stop locations had to be adjusted +/- 20 feet to ensure that accessibility ramps could properly deploy due to curb heights (e.g., one location had a storm sewer drain with a dip that prevented the accessible ramp from being deployed due to the dip, in another location the curb height was too low with two shuttles back-to-back).

The AV shuttle underwent a week of operational test scenarios in a private facility to ensure stakeholders were comfortable with the safety provisions of the shuttle before performing site calibration runs for a week on the pilot project route with no passengers. The AV shuttle then operated for about two weeks in November 2020 on a larger boulevard that had streetlights in the median and many trees and Canadian geese along the roadway. Challenges with the deployment included:

- The AV shuttle would stop due to Canadian geese that did not always move.
- Impatient drivers would speed or try to pass the AV shuttle.
- Parked vehicles triggered the AV shuttle and required manual operations. This occurred both for angled parking spots with a long vehicle and with parallel parking spots when the lanes are narrow and a car is parked far from the curb.

A full report on this deployment is available at: https://tcdocs.ingeniumcanada.org/sites/default/files/2021-04/Transport%20Canada%20Low%20Speed%20Automated%20Shuttle%20Testing%20-%20Final%20Report.PDF.

Changes to Infrastructure and Operations

- *Signage.* "Watch for shuttle" signs about the size of chevron signs were placed along the route at all entrance roads. Additionally, three localization panels were needed to assist the vehicle in positioning due to the wide boulevards.
- *Pavement Markings*. Minor line painting was needed. Additionally, because the route has many pedestrian crossings, some parking spaces were blocked out to ensure the AV shuttles had a clear line of sight as they approached.
- *Traffic Signal Timing Changes.* Traffic signals were avoided during the route selection process to support an incremental, "baby steps" approach toward more challenging conditions.
- *Charging Stations / Secure Parking.* AV shuttles were parked and charged in the site's power station garage through connections directly to the breaker panel.
- *Vegetation Management.* The first several days were very windy and blowing leaves created issues; after the leaves blew away and were cleaned up by crews, there were no issues for the rest of the deployment.
- *Road or Sidewalk Changes / Maintenance.* The location required minor pothole repairs.

Extent of Changes, Responsibility, and Needs for Future Deployments

- The effort to address the pilot needs was relatively minor. Future, new pilots will likely be longer and deployed in more complex situations, such that the agencies will be able to take the lessons learned and incorporate them into any implementation.
- Deployments need to currently avoid overly challenging situations in order to ensure success and instill public confidence.
- There is still a question of whether AV shuttles need to operate in a protected lane or can operate in mixed traffic, which will largely depend on the existing operating speed of the traffic in those lanes and the capabilities of the shuttle. While AV shuttles can travel faster, most operate around 10-12mph, so route selection is critical.

Ottawa is planning for another future possible pilot in a more populated area on a longer route to determine passenger interest and understand utility versus the "novelty factor" (e.g., similar to e-scooters).

4.0 Broader Infrastructure Implications for AV Deployments

This section summarizes a variety of lessons learned and recurring themes described by the AV shuttle deployments in Section 3.4, which can be extrapolated to inform agencies that are either planning any type of AV deployment for the first time or looking to expand existing AV deployments or new use cases. That is, agencies deploy AVs for a variety of reasons including any of the following:

- Public outreach and education efforts to expose local residents and travelers to AVs.
- Wanting to gain experience with new technologies and better understand how AVs will interact with existing infrastructure and any changes that may be required.
- Wanting to expand transportation options for the traveling public to address gaps or make existing transit operations more efficient.

This chapter builds on the individual AV shuttle deployment findings described in Section 3.4 to more broadly help agencies plan for AV deployment and operations.

4.1 Agency Involvement in Deployment

Agencies that have deployed AV shuttles shared one of three philosophies that greatly inform the magnitude of agency resources and involvement in the deployment. The following three approaches range from the highest to lowest in terms of requiring agency resources and infrastructure changes.

- *Collaborate with the provider to integrate AVs with infrastructure.* Agencies are sometimes very interested in understanding the full potential of AVs and potential benefits of V2I communications that may be achieved by integrating the AV with existing infrastructure and agency operations. These communications can also provide redundancy to improve safety, particularly at signalized intersections. However, this level of integration can require a significant commitment of agency resources (e.g., challenges to upgrade infrastructure, software, and communications, challenges to staff who do not have a lot of experience in this area). Similarly, even without major upgrades to integrate AVs with infrastructure, a number of agencies deploying AVs for the first time are doing so as a demonstration to gain experience and are willing to commit more staff time and resources than for a typical deployment to ensure success and meet the needs of the AV provider.

- *Implement universally useful changes.* Agencies may be willing to make investments to improve existing infrastructure or implement new infrastructure, however the agency may limit these investments to items that are useful for all road users, rather than specific to the AV. This approach may accommodate changes for roadway striping, new signage, or charging stations, for example, while limiting investments in new technologies or infrastructure changes like roadside units to reduce risks (e.g., the AV provider going out of business) or expenditures that will only be used for a limited demonstration or specific to a certain type of AV. Additionally, this approach has a benefit of demonstrating real-world value of AVs to operate in mixed-use traffic without specific infrastructure changes.

- *Place responsibility on the AV provider to make changes or adapt to the existing environment.* Sometimes AV deployments are private-sector driven (e.g., a provider may approach an agency about implementing an AV deployment), and the agency may have a minimal or mostly observational role. At other times, the agency may solicit proposals for a new AV deployment and clearly share the state of existing infrastructure with potential AV providers, as well as potential challenges and constraints so that the AV provider is able to accommodate all of the challenges and needs in a proposal without requiring any additional effort by the agency. Generally, this approach may have a similar outcome as the previous approach, since the AV provider may adapt the vehicle and route rather than implement many changes to infrastructure.

Other considerations also affect the level of agency resources and infrastructure changes that are needed. For example, an AV deployment in a closed environment with no or minimal interactions with traffic like a university campus will generally have less impact than an AV deployment on a route that includes mixed traffic and signalized intersections. Additionally, as AV technology continues to improve and evolve there may be a reduced need in future deployments for as many infrastructure changes.

4.2 Potential Long-Term Deployment Impacts of AV Shuttles

This section identifies some likely impacts to agencies and changes that may be observed by travelers where AVs may be deployed for long-term and ongoing deployments.

- *Signage*. Deploying agencies will likely require some signage to support AV deployments. At a minimum, this may include signage to alert travels that AVs are operating in an area or to help identify AV pickup/dropoff or stop locations. Depending on the type of AV and state of technology, localization signage may still be needed to help the AV with navigation along the route.
- *Pavement Markings*. Deploying agencies may need to modify pavement marking programs to ensure that lane markings on routes used by AVs are adequately maintained.
- *Traffic Signal Timing Changes*. Agencies may wish to avoid signalized intersections during route selection processes to simplify AV deployments. Otherwise, depending on the state of the AV technology, the agency should anticipate some work to adjust traffic signal timings at intersections where AVs will operate. This may include the deployment of roadside units or technology to broadcast SPaT information to the AVs.
- *Roadside Units*. Agencies may wish to consider deploying roadside units or other technologies to support AV operations at signalized intersections with V2I communications, in order to supplement other AV sensor systems and increase safety.
- *Charging Stations and/or Secure Parking Areas*. Agencies may consider wider deployment of charging stations that support AVs, as well as electric vehicles used by the traveling public. Charging stations may need to be located in a secure parking area to reduce the risk of vandalism or meet requirements (e.g., weather) of the AV provider.
- *Vegetation Management.* Agencies may need to adapt schedules for vegetation management, such as more frequently mowing grass.

- *Road or Sidewalk Changes / Maintenance.* Similar to pavement markings, agencies may need to be more proactive about road maintenance on routes used by AVs to reduce the presence of potholes, for example.

Long-term and ongoing AV deployments will also require some other adjustments and accommodations that may affect agency operations, such as:

- *Operational Changes for Construction or Special Events:* Construction activities or special events like a street festival will periodically close certain lanes or roads that are typically used for AV operations. Agencies will need to coordinate with the AV provider for providing notifications about these activities and also to make plans for alternate routes that can be used by AVs when these kinds of activities take place.
- *Operational Changes for Weather and Road Conditions.* Agencies will need to consider how environmental conditions will impact the deployed AV technology and whether operations will be able to occur year-round and not be interrupted by weather events. As an example, agencies may need to modify winter maintenance activities, for instance, to clear and treat routes used by AVs to ensure continuity of AV operations during inclement winter weather.

4.3 Lessons Learned for Successful Deployments

The following are a series of lessons learned and themes from various AV shuttle deployments that may be instructive for a variety of broader AV deployments.

- *Collaborate with a broad group of stakeholders.* Most AV shuttle deployments cited a broad stakeholder team that was key to mutual understanding with the AV provider and a successful deployment. This included coordination across different state agencies, local agencies, law enforcement, universities, and private-sector developments or businesses.
- *Route selection is critical.* Several deploying agencies cited the importance of route selection in the planning process to help reduce the need for infrastructure changes or resources. Careful consideration of available route alternatives may help avoid the need to re-time signals, re-pave or re-stripe roadways, install navigational signage, reduce speed limits, or re-route the AV due to construction or special events. Selection of some routes may even reduce or eliminate a need for additional vegetation management activities. Additionally, routes near parked vehicles or through parking lots can also negatively impact AV shuttle operations.
- *Maintain existing infrastructure well.* While this is not specific to an AV deployment, agencies with robust programs for maintaining pavements and lane markings will find themselves better prepared for AVs, which may otherwise require changes to minimize AV disruptions.
- *Clearly specify expectations in requests for proposals and contracts.* Agencies generally benefit from providing clear provisions in proposals and contracts about the current state of available infrastructure, what the agency is willing to provide, and what is expected from the AV provider.

- *Plan for the unexpected.* As with any type of deployment that an agency is doing for the first time, there will be times when unexpected delays, costs, or resource needs occur that were not initially planned for. AV shuttle deployments provide a glimpse into various needs that required additional resources that were not initially planned for (e.g., new navigational signage that does not have clear MUTCD guidance regarding content or placement, increased vegetation management activities, towing the AV shuttle for repairs).
- *Anticipate typical AV needs.* Many types of AV deployments will require infrastructure elements that were common in the AV shuttle deployments, such as charging stations and signage to inform other road users, identify AV-specific stops, or assist in AV navigation.

5.0 Summary

This effort focused on the deployment of low-speed AV shuttles with the intent to understand whether infrastructure changes and the roles of agency and private-sector stakeholders are representative of needs and roles in future, long-term AV deployments. This report provides a detailed view on infrastructure impacts of AV shuttle deployments by different agencies across the United States and Canada (i.e., in Delaware, Maryland, Michigan, Minnesota, Ohio, Texas, Utah, and Virginia, as well as Alberta, British Columbia, and Ontario in Canada) through agency interviews and a literature review.

The AV shuttle deployments that were documented revealed a number of infrastructure and operational impacts, as well as a wide variety of approaches for deploying low-speed AV shuttles, including varying expectations and demands on agency involvement and resources, as outlined below.

- *Signage*. All deploying agencies reported the need to install signage to support AV shuttle deployments. This included signage for AV shuttle stops, localization signage to be recognized by the AV shuttle to support navigation along the route, and static or dynamic signage to inform other vehicles and travelers (e.g., bikers and pedestrians) about the presence of the AV shuttle.
- *Pavement Markings*. Some agencies reported the need to touch up existing pavement markings and/or add new markings to support the AV shuttle. Temporary deployments may also require additional agency effort to remove added pavement markings at the end of the pilot period.
- *Traffic Signal Timing Changes*. When the AV shuttle route included a signalized intersection, traffic signal timing adjustments were frequently needed. This included solutions like the use of transit signal priority or adjusting the signal phase, such as extending the green phase for the minor cross street to provide the low-speed AV shuttle sufficient time to traverse the intersection.
- *Roadside Units*. Some agencies used roadside units to broadcast signal phase and timing (SPaT) and vehicle location information to support the AV shuttle at signalized intersections using vehicle-to-infrastructure (V2I) communications, and supplement other AV sensor systems.
- *Charging Stations and/or Secure Parking Areas*. AV shuttles require a charging station at a secure location when not in use. These accommodations are often provided by the deploying agency. Charging stations may require electric upgrades for faster charging times. The parking area location may need to be indoors or require additional security than typically at the site. Ideally, the parking area is near the route to minimize time or challenges for transporting the AV shuttle to and from the route.
- *Vegetation Management.* Many agencies cited the need for significant vegetation management, requiring a higher level of effort than anticipated. This included more frequent mowing grass than normal or a great deal of tree trimming to reduce the number of times the AV shuttle would make unexpected and sudden stops.

- *Road or Sidewalk Changes / Maintenance.* Agencies reported various adjustments along AV shuttle routes, including modifying a trail under a bridge to increase the clearance, new concrete landing pads at AV shuttle stops, pothole repairs, and straightening sidewalks.

Other adjustments to agency operations, which one or more agencies noted, included:

- *Adjusted Construction Schedules*. Permitting and construction schedules were examined and altered, as needed, by several agencies to accommodate AV shuttle operations.
- *AV Maintenance*. A tow truck was needed at one deployment location to take the AV shuttle for repairs, which caused unforeseen costs.
- *Curbside Management*. One agency noted that fire lanes in front of restaurants were sometimes blocked with delivery trucks or delivery services, which disrupted AV operations, leading the city to re-examine curbside management.
- *Media and Public Outreach*. Agencies may use staffing and resources to provide informational materials to the public and conduct surveys.
- *Notification of Events*. Two agencies notified the AV provider when an alternate route was needed due to a special event.
- *Operational Changes for Weather and Road Conditions.* Environmental conditions that impacted AV shuttle operations include blowing dust, blowing leaves, snow accumulation, and rainfall, which can impact agency decisions regarding route selection, road weather management, and the AV shuttle schedule and operations.
- *Traffic Signal Brightness*. The brightness of traffic signal beacons had to be increased at one deployment location to be more visible to the AV shuttle

The extent of these infrastructure and operational changes often reflect differences in agency philosophies regarding AV deployment and generated a variety of lessons learned for future AV shuttle deployments as well as AV deployments in general.

The findings in this report may be used to inform agencies that are either planning any type of AV deployment for the first time or looking to expand existing AV deployments or implement new use cases.

References

American Association of State Transportation and Highway Officials (AASHTO) Committee on Transportation Systems Operations (CTSO) Cooperative Automated Transportation (CAT) Working Group and CAT Coalition Infrastructure-Industry Working Group. *Current AV Deployment and Shuttle Initiatives in the United States*. June 2020. Accessed Aug 2021: https://transportationops.org/sites/transops/files/I-I%20AV%20Synthesis%20Report%2006112%20with%20disclaimer.pdf.

CAVCOE (Formerly the Canadian Automated Vehicles Centre of Excellence). *Best Practices for Automated Vehicle Trials in North American Municipalities – Final Report.* October 2019. Accessed Oct 2021: https://www.toronto.ca/wp-content/uploads/2019/10/9014-TS_CAVCOE_City_Tor_AV_Trials_final_rpt.pdf.

City of Frisco. *Driverless Car Pilot Program.* Accessed Oct 2021: https://www.friscotexas.gov/1573/Driverless-Car-Pilot-Program.

Delaware Department of Transportation. *DelDOT AV Shuttles.* Accessed Oct 2021: https://deldot.gov/Programs/avshuttles.

Federal Highway Administration. *Impacts of Automated Vehicles on Highway Infrastructure.* Publication Number FHWA-HRT-21-015. March 2021. Accessed Oct 2021: https://www.fhwa.dot.gov/publications/research/operations/21015/21015.pdf.

National Research Council of Canada. *Transport Canada Low Speed Automated Shuttle Testing – Final Report.* March 2021. Accessed Oct 2021: https://tcdocs.ingeniumcanada.org/sites/default/files/2021-04/Transport%20Canada%20Low%20Speed%20Automated%20Shuttle%20Testing%20-%20Final%20Report.PDF.

Transport Canada. *Testing Highly Automated Vehicles in Canada – Guidelines for Trial Organizations*. 2018. Accessed Oct 2021: https://tc.canada.ca/sites/default/files/migrated/19_ah_01_automated_vehicles_layout_en_r13.pdf.

Utah Department of Transportation. *Utah Autonomous Shuttle Pilot – Final Report.* April 2021. Accessed Oct 2021: https://transportationtechnology.utah.gov/what-were-learning.

Appendix: Agency Interviewees and Interview Discussion Questions

The table below lists the agency contacts who were interviewed and the 2021 date of the interview.

Contact	Agency	E-mail Address	Date
U.S. Shuttle Deployments			
Lyndsay Mitchell	City of Arlington (Texas)	lyndsay.mitchell@arlingtontx.gov	6/18
Kerin Smith	City of Frisco (Texas)	ksmith2@friscotexas.gov	8/3
Brian Moen	City of Frisco (Texas)	bmoen@friscotexas.gov	
Nathan Attard	Delaware Transit Corporation	nathan.attard@delaware.gov	6/30
Nanette Schieke	Maryland DOT Motor Vehicle Administration	nschieke@mdot.maryland.gov	6/24
Carole Delion	Maryland DOT State Highway Administration	cdelion@mdot.maryland.gov	
Roxane Y. Mukai	Maryland Transportation Authority	rmukai@mdta.state.md.us	
Jamila Gomez	Metropolitan Transit Authority of Harris County	jamila.gomez@ridemetro.org	6/18
Elise Feldpausch	Michigan DOT	feldpausche1@michigan.gov	7/28
Kristin White	Minnesota DOT	kristin.white@state.mn.us	7/8
Clint Hail	North Central Texas Council of Governments	chail@nctcog.org	7/6
Tom Bamonte	North Central Texas Council of Governments	tbamonte@nctcog.org	
Cynthia Jones	DriveOhio	cynthia.jones@drive.ohio.go	6/22
Jeffrey Kupko	Michael Baker (for Ohio)	jeffrey.kupko@mbakerintl.com	
Amanda Hamm	Virginia DOT	amanda.hamm@vdot.virginia.gov	3/15
Canadian Shuttle Deployments			
Omar Choudhry	City of Ottawa	omar.choudhry@ottawa.ca	7/7
Gerardo Moreno	Southland (for Alberta and British Columbia)	gerardom@southland.ca	7/8
Tony Qiu	University of Alberta	tony.qiu@ualberta.ca	

Each interviewee received the following four questions in advance via email to guide discussion during the phone interview:

- What infrastructure (and DOT operations) changes were required? What did these changes entail?
  - (e.g., roadside units, charging stations, pavement markings, signage, traffic signal adjustments / transit signal priority, tree trimming, adjusting construction schedules, other)
- What was the extent of these changes?
  - (e.g., major or small effort, one-time or ongoing effort, other)
- Who was responsible for these changes?
  - (e.g., local agency, state agency, private entity, others)
- In your opinion, are these changes representative of needs and roles in future, long-term deployments?