On-demand Microtransit and Paratransit Service Using Autonomous Vehicles: Gaps and Opportunities in Accessibility Policy

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ABSTRACT

Autonomous vehicle (AV) technology can help disabled Americans achieve their desired level of mobility. However, realizing this potential depends on vehicle manufacturers, policymakers, and state and municipal agencies collaborating to accommodate the needs of disabled individuals at different stages of trip making through information system design, vehicle design, and infrastructure design. Integrating accessibility at this stage of the AV revolution would finally allow us an opportunity to develop a transportation system that treats accessibility as a guiding principle, not as an afterthought. This paper documents accessibility considerations for disabled individuals followed by a review of relevant Americans with Disabilities Act (ADA) regulations. The review of regulations is followed by a review of nine case studies, five corresponding to the on-demand microtransit service model and four corresponding to the paratransit service model. These case studies are essentially different prototypes currently being deployed on a pilot basis. Each of these specific case studies is then evaluated for its ability to provide potential accessibility features that would fulfill the requirement set forth by relevant ADA regulations in the absence of an operator/driver. Based on this review of relevant research, ADA regulations, and case studies, recommendations are provided for researchers, private firms, policymakers, and agencies involved in AV development and deployment. The recommendations include better collaboration and adoption of best practices to address the needs of individuals with different disability types (e.g., Cognitive, Visual, Auditory). ADA regulations should be used as one of the tools in addition to universal design principles and assistive technologies in order to maximize accessibility.

Keywords: accessibility; paratransit; autonomous vehicles; policy; ADA; law; microtransit

INTRODUCTION

Nearly 1 in 5 people in the US have a disability (more than 57 million), and people with disabilities use the automobile as a travel mode at significantly lower rates than people without disabilities (*Travel Patterns of American Adults with Disabilities | Bureau of Transportation Statistics*, n.d.). For example, people aged 18 to 64 with disabilities make 28% fewer trips per day (2.6 v. 3.6 trips) on average than people without disabilities. The disparity is even more significant for non-workers. These statistics highlight the notable technological, design, and policy failings in today's transportation system - that disabled individuals have considerable suppressed demand for travel that is currently not being met. Even among people who are able to take the trips, a significant proportion of people with disabilities rely on modes of transportation that were not explicitly designed for their needs (*Travel Patterns of American Adults with Disabilities | Bureau of Transportation Statistics*, n.d.).

Though the technology to substitute conventional cars with the much talked about autonomous vehicles (AVs) is not entirely ready, some existing technologies might be helpful for persons with disabilities. That said, several companies are creating prototypes of AVs specifically designed to cater to the travel needs of disabled individuals. Once autonomous vehicle technology is sufficiently mature, they have the potential to help disabled Americans achieve their desired level of mobility - assuming developers accommodate varieties with different mobility needs (Claypool et al., 2017).

This paper aims to identify gaps and opportunities for researchers, policymakers, and state/local agencies to best address accessibility in AV developments—particularly for microtransit and paratransit applications. Paratransit is an on-demand shared-ride public transportation specifically for people with disabilities that complements fixed-route transit service provided by the transit agency operating in an area. Paratransit generally covers the same service area and service times as the transit service (Miah et al., 2020). On-demand microtransit provides shared rides in a van or minibus to any passenger. Microtransit has the potential to improve the flexibility of paratransit operations by allowing users to request service in real-time through a smartphone application (Volinski, 2019).

The paper is organized as follows: The next section provides a review of background research that includes a cautionary tale about treating accessibility as an afterthought, a discussion on accessibility organized by trip-making stages, and the state of policy and research on accessibility consideration for the AV environment. Conclusions from the Background research are then followed by the case for focusing on microtransit and paratransit service models. Nine different prototypes and pilot deployments are reviewed to assess if/how these deployments are addressing accessibility requirements for various disability types in the absence of an operator/driver. Recommendations for future policy research are provided in the Conclusions section.

BACKGROUND

Lessons from ADA and the 20th century

The disparities between the travel experience of the able-bodied and disabled individuals continue to persist today, three decades since the passage of the Americans with Disabilities Act (ADA). This state of affairs is partly due to the fact that the automobile revolution that dominated the mobility trends in the 20th century preceded the ADA by several decades. As a result, accessibility was treated as an afterthought in the nation's transportation system. The passage of the ADA created general awareness about the needs of individuals with different ability levels. It has led to welcome changes in the nation's transportation system, but making those changes to an established system has been cumbersome and expensive. Integrating access at this stage of the AAV (Accessible Autonomous Vehicles) revolution as it unfolds provides an opportunity to develop a transportation system that treats accessibility as a guiding principle, not *an afterthought*.

Minimum accessibility requirements as set forth by the regulations should be treated as a subset of the inclusive design principles that the AAV revolution should aim at (See Figure 1). Ensuring access at this stage of the AV revolution is more cost-effective in the long run compared to retrofitting in light of subsequent regulations. This may be a precondition to achieving the potential of AAVs to substantially increase independent mobility for consumers with disabilities, as noted by Claypool et al. (Claypool et al., 2017). Cregger et al. (Cregger et al., 2018) recommended the development and testing of new alternatives and aids for accessibility features onboard AAVs that consider a full range of disabilities. Unfortunately, the existing literature on human factors does not provide a framework to empirically examine the inclusive design needs of the emerging AAV ecosystem (Tabattanon et al., 2019).

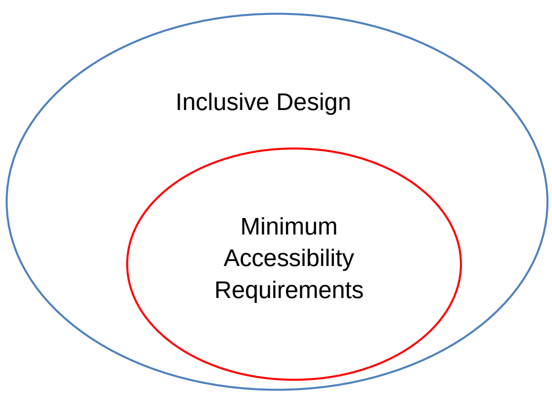

Figure 1: Minimum accessibility requirements as a subset of inclusive design principles

Accessibility: The Complete Trip

Under Title II and III of the ADA, people with disabilities legally have a right to access the same transportation opportunities as people with no disabilities (Claypool et al., 2017). In order to realize this right for all individuals, regardless of ability in the age of AVs, it is helpful to look at each trip from a passenger-centric perspective. The AAV playbook developed by the Santa Clara Valley Transportation Authority (VTA) as part of their AAV pilot project (*VTA Serving as a Model for Accessible Autonomous Vehicle Use*, n.d.) provides seven trip-making stages that may be divided into three distinct categories: Pre-trip Concierge, Wayfinding and Navigation, and Robotics and Automation.

- Pre-trip concierge (Information System Design)
    - Trip planning and booking
- Wayfinding and Navigation (Accessible Infrastructure Design)
    - Navigating to the AAV pick-up point
    - Waiting at the AAV pick-up point
    - Navigating from the AAV drop-off point to the destination
- Robotics and Automation (Vehicle Design)
    - Boarding AAV
    - Riding AAV
    - Alighting AAV

In terms of accessibility requirements, these categories involve three distinct but interconnected areas of concern. The pre-trip concierge relates to the design of information systems that will inform the travelers; wayfinding and navigation relate to accessible infrastructure design; and the boarding, riding, and alighting from AAV without any human attendant relates to the design of the vehicles themselves.

This categorization corresponds to the actionable accessibility checklist for autonomous vehicles provided by Disability Rights Education & Defense Fund (*Autonomous Vehicles (AVs), Also Known as Self-Driving Cars - Disability Rights Education & Defense Fund*, 2018). The checklist covers the three distinct areas of concern identified above: Information System Design, Infrastructure Design, and Vehicle Design. These factors have immediate feasibility for implementation by the public agencies (e.g., curb infrastructure) and private sector parties (e.g., vehicle design).

AV Policy at the Federal, State, and Local Level

Presently, there is no specific federal law that governs AVs (National Center for Mobility Management (NCMM), 2018). Though legislation has been initiated in Congress, there is still an ongoing debate within the Senate on the regulation level, safety concerns, and preemption of the state regulations. However, it is evident that a majority of both US Congress chambers are strongly in favor of passing laws that offer the automotive and tech industries the flexibility to carry out innovative vehicle tests and operate AVs on the road.

Given its jurisdiction over different transportation modes and vehicle safety standards, the US Department of Transportation (USDOT) is paying great attention to encouraging the development of AVs. USDOT has hosted stakeholder forums on AVs for modal administration and people residing all over the country. The National Highway Transportation Safety Administration (NHTSA) has also issued federal regulatory guidance on AVs, most recently in the form of the report titled "Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0" in December 2019 (*AV 4.0 | US Department of Transportation*, n.d., p. 0).

On the state level, several jurisdictions have passed laws addressing AVs. However, most of those laws support the conducting of impact studies, provide rules for AV operations on public roads, or govern the creation of committees that might explore issues on automated vehicles. Some states have provisions for automated vehicles to function on public roads, while others offer a testing framework. Some states like California have managed to establish a graduated system of regulations with a separate permit for automated vehicles to be operated without the help of a human and those that require a human driver for backup.

Overall, accessibility-related regulatory guidance issued by the states and federal government attempts to strike the right balance between seemingly competing interests of the state, interest groups, and companies working in the AV development/deployment space. For example, in their November 2020 decision, California Public Utility Commission (CPUC) did not include specific accessibility standards but required AV companies to submit Passenger Safety Plans that will outline the steps the companies will take to provide accessible service. In other words, autonomous mobility companies will be able to implement accessible service at their discretion but would only be required to submit reports that address what types of safety measures they provide and ensure that safety measures apply to all passengers, including those with disabilities ("Op-Ed," 2020).

The Endeavor Towards Autonomous Vehicles for Disabled People

In 2012, Google released a video of its automated car transporting a blind man to a taco shop as well as to his dry cleaners (Douma et al., 2017). The CEO of Santa Clara Valley Blind Center, Steve Mahan, a legally blind individual, stated that an automated vehicle could grant him the flexibility and independence to travel to places he both needs and wants to go. At the heart of his discussion lies the ability of disabled people can to access life and travel options at par with individuals without disabilities. Under the right circumstances, automated vehicles can offer a decrease in social isolation, access to vital services, and personal independence (Douma et al., 2017).

A detailed report titled "Self-Driving Cars: Mapping Access to a Technology Revolution" was produced by the National Council on Disabilities in 2015 (Henderson & Golden, 2015). It explored, in great detail, the potential of self-driving cars to transform the lives of the disabled. Nevertheless, the report also highlighted that these benefits are not guaranteed. The creation of AVs has been rather fast-paced and secretive. While developers have expressed an interest in supporting greater accessibility for AVs, there is not much information available to the public to figure out how close manufacturers and designers are to this technology. This unavailability of information raises critical questions on how self-driven vehicles might cater to the requirements of disabled people. Furthermore, while AVs are being built to curb people's need to operate vehicles, it is important to note that lack of ability to drive is not the only barrier people with disabilities face while traveling. The simple acts of entering and getting out of the vehicle might pose difficulties for many disabled people, not just wheelchair users. This makes well-thought-out considerations for people with disabilities essential at the early stages of design and development.

AV Research on Accessibility

Inclusive Mobility Design Lab (IMDL) at the University of Michigan provides an interactive portal (*Task-User Matrix*, n.d.) to document existing research and identify knowledge gaps in the context of accessibility of AAVs (specifically a low-speed Autonomous Shuttle (LSAS)). The portal categorizes 66 studies along two dimensions, i) tasks associated with using AAV as a travel mode and ii) disability type. The tasks, categorized here by the distinct areas of accessibility concerns, include information systems design factors (e.g. plan route, pay fare, identify correct vehicle or station) and vehicle design factors (e.g. boarding, securing seats/passengers, stop identification, vehicle ingress/egress).

These tasks may be mapped to the seven trip-making stages identified earlier in the paper based on the VTA's AAV pilot (*VTA Serving as a Model for Accessible Autonomous Vehicle Use*, n.d.). However, this list from the IMDL portal does not address the elements of infrastructure design of transportation facilities, including sidewalks, curbs, and street crossings (Tabattanon et al., 2019). Hence, the portal does not adequately cover three of the trip-making stages, Navigating to the AAV pick-up point, Waiting at the AAV pick-up point, and Navigating from the AAV drop-off point to the destination.

The disability types discussed in the review provided by IMDL are quite comprehensive and include: cognitive and/or developmental disability; auditory impairment; visual impairment; wheeled mobility devices; ambulatory impairment; older adults; extremes of size and weight.

In general, wheeled mobility devices and ambulatory impairments have significant literature addressing the challenges, whereas research on cognitive and developmental disabilities is sparse. The combinations of disability type and trip-making stages for which no research is documented on the portal are listed below:

- Trip planning and booking stage: Auditory Impairment
- Boarding AAV stage: Cognitive and/or developmental Disability; Auditory Impairment; Extreme Size and Weight
- Riding AAV stage: Auditory Impairment; Visual Impairment
- Alighting AAV stage: Cognitive and/or developmental Disability; Auditory Impairment;

It should be noted that almost all of the research listed on the IMDL portal is conducted on traditional transit modes because a very limited set of studies exist on paratransit shuttles.

Accessibility Considerations: Information System Design

According to the National Center for Mobility Management, even though ADA predates the internet, smartphones, apps, and emerging transportation modes, the regulatory framework developed for other laws, e.g., the Telecommunications Act and subsequent judicial interpretation, have extended accessibility mandates to the newest technology (National Center for Mobility Management (NCMM), 2018). The courts have held that the websites are effectively places of public accommodation, and commercial websites are required to comply with ADA regulations. The Telecommunications Act (47 USC §§255, 716, and 718) requires telecommunications equipment and services (now including smartphones, apps, and text messages) to be accessible to and usable by individuals with disabilities “where readily achievable.” Further, Section 508 of the Rehabilitation Act of 1973 (29 USC § 794 (d)) requires federal agencies to make their electronic and information technology accessible to all people with disabilities. Complying with these regulations will undoubtedly support the accessibility of interfaces developed for wayfinding, ride-hailing, and requesting transportation services through AAVs. Many existing MaaS tools use native iOS and Android accessibility features to accomplish this in the ride request rides, and it is probable that this pathway could provide a comparable standard of service for mobile application/information systems UX design.

Accessibility Considerations: Vehicle Design

Many of the onboard issues for people with sensory and cognitive impairments are currently addressed with help from the vehicle operator (e.g., availability of a vacant seat, expected arrival time to the destination stop). Absent a human driver or operator, AAVs will increase the need for providing onboard information to such passengers. Furthermore, even when compliant with federal accessibility standards, the interior configuration of vehicles presents a wide variation in challenges experienced by passengers with disabilities (Tabattanon et al., 2019). In a driverless environment, the vehicle design will need to address these challenges.

The vehicle design elements for boarding the AAV include the walking surfaces, ramps and bridge plates, slopes, lifts, level boarding, doorways, and illumination. While onboard the vehicle, the key design elements include walking surfaces, passenger access route, maneuvering through the vehicle, securement location, and means of securement (*US Access Board - Inclusive Design of Autonomous Vehicles*, n.d.). The criticality of these elements depends on the size of the AAVs. Maneuvering the vehicle while en route is less of a concern in a smaller vehicle (typical of fixed-route neighborhood circulator, on-demand microtransit, and paratransit) than for the buses used for high-capacity fixed-route transit services. Independent wheelchair securement requires significant space and designs that accommodate various mobility devices. Bharathy and D'Souza (Bharathy & D'Souza, 2018) provided an online design tool for calculating the clear floor space dimensions to accommodate the desired proportion of wheelchair users.

While riding, the haptic feedback mechanism on the vehicle and/or mobile devices may provide route guidance to visually/mobility impaired, people with cognitive disabilities, and senior citizens (Shalaik et al., 2012). Haptic feedback refers to technology that can engage people's sense of touch to enhance the interaction with onscreen interfaces (*Haptics - User Interaction - IOS - Human Interface Guidelines - Apple Developer*, n.d.). On driverless vehicles, reconfigurable spaces/seating will need to accommodate a wide range of rider needs and preferences. Sensing passenger status (appropriately located, secured, etc.) will also be necessary. Furthermore, literature shows fare payment tasks add to the challenges and should be eliminated during trips (*US Access Board - Inclusive Design of Autonomous Vehicles*, n.d.). That does not imply that costs for innovating fare payment systems should be borne solely by transit operators or contracted service providers. Eliminating points of friction to ridership should be a shared value that balances service effectiveness with economic efficiency (Appleyard & Riggs, 2018).

The ramp slope and configuration are critical for disabled individuals to independently board and alight the vehicles. Research webinars from the US Access Board in Spring 2021 (US Access Board - Inclusive Design of Autonomous Vehicles, n.d.) documented the effects of ramp slope and multi-segment ramp configuration on human performance during ramp ascent and descent. The research supports a maximum 1:6 slope for transit ramps with less severe slopes preferred to support manual wheelchair users.

The US Access Board also documented findings based on focus groups with individuals with disabilities. The major concerns relevant to the communication interface included the ability to schedule a trip, engage in a 'conversation' with the interface, the ability to secure live assistance, and design cost & availability. Communication-related concerns were paramount for individuals with sensory disabilities. For example, hearing-impaired individuals who want to talk but the voice interface may not recognize their speech may prefer a tactile interface. For the hearing impaired, visual alternatives to the vehicle's speech that provide appropriate detail and alerts are needed. The audio provided must be compatible with the hearing devices (*US Access Board - Inclusive Design of Autonomous Vehicles*, n.d.). A key research priority would be vehicle interface design with a robust yet limited set of gestures and signs for command & control.

In terms of cognitive disabilities, the challenge is that they are often combined with other disabilities, including vision (low vision, blindness), hearing (Hard of hearing or aphasia), speech disability (non-vocal, dysarthria, aphasia, stutter/stammer, etc.). Many of the 'general' solutions won't work for these individuals. Therefore, the design needs a spectrum of interface solutions within each person's abilities (*US Access Board - Inclusive Design of Autonomous Vehicles*, n.d.).

Accessibility Considerations: En-route changes and Privacy

If there is a need to change the trip plan en-route, the task is cognitively more complex. The solution to en-route problems would potentially involve an on-call human attendant. The most difficult cases may include designs and interface options that need to cover travelers who may have no memory, be easily confused, or cannot give clear instructions. A trained-human-in-the-loop option may be required for such scenarios. A hands-free, voice-activated tool to communicate with Dispatch or Customer Service should be a prerequisite for providing service. Providing human-in-the-loop may require data collected on disabled individuals. However, any data collected about users with special accommodations have the potential to be used to harm the traveler. The potential harms include discrimination, identification as a target for fraud, robbery, etc.

This privacy issue may require all data sharing on users' abilities to be overseen by an external third-party regulatory body that serves as a data ethics council. In the case of government regulators at the state or federal level governing this council may represent a conflict of interest. It may be most appropriate that this data council serve as an independent, similar to the concept of the Facebook Oversight Board (*Oversight Board | Independent Judgment. Transparency. Legitimacy.*, n.d.), and providing an independent assessment of complex issues such as privacy, surveillance, individual expression, and data sharing.

Relevant ADA Regulations Following the review of the existing resources on the needs of disabled individuals in the context of AAVs, a rigorous background of how the Americans with Disabilities Act and relevant research could inform trends of autonomous vehicles—particularly autonomous microtransit and paratransit. A detailed review of the Americans with Disabilities

Act of 1990 and Section 504 of the Rehabilitation Act of 1973 was conducted with special emphasis on the following regulations:

- 49 CFR Part 37 -Transportation Services for Individuals with Disabilities (ADA)
- 49 CFR Part 38 - Americans with Disabilities Act Accessibility Specifications for Transportation Vehicles
- New Final Rule: Reasonable Modification of Policies and Practices (Federal Transit Administration Office of Civil Rights)

A careful review of various documentation from pilot projects, as well as a review of 49 CFR Sections 37 and 38, helped determine if they are applicable to future AAV fixed route or paratransit systems and review the applicability of accessibility policy to following potential platform / technological innovations:

1) Fixed-route neighborhood circulators;
2) On-demand microtransit;
3) Paratransit;
4) High-capacity fixed-route transit services.

These services and vehicles are regulated under Title 49 CFR Part 37, Transportation Services for Individuals with Disabilities, and Title 49 CFR Part 38, Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles.

Building on this background, a rating framework was developed to evaluate how and to what extent technological frameworks and vendors (itemized as Case Studies in the next section) address accessibility requirements. It is used to provide insights beyond an assessment of a specific project or technology and allows for a detailed exploration of the gaps and opportunities for these advancing technologies.

Conclusions from Background Research

Based on background research and literature, at full vehicle autonomy resulting in the absence of an onboard operator, tasks such as ingress-egress, securement of passengers and carry-on items, and the communications with passengers will need to be safe, efficient, and independent. The biggest challenge in this area may be the need to handle these tasks for a wide range of disability types, most currently supported by the vehicle operator.

To ensure that the disabled individuals are appropriately served at each trip-making stage identified by the VTA pilot, the design of transportation facilities, sidewalks, and street crossings is also essential to consider (Tabattanon et al., 2019). The environmental facilitation that may support easier boarding and alighting includes deploying ramps to curbs at corners or sidewalks with enough clear space and standardization of pick-up and drop-off conditions. (*US Access*

Board - Inclusive Design of Autonomous Vehicles, n.d.). This presents an opportunity for better curb management and collaboration between agencies/entities in using limited curb space.

Applicability of AAV Vehicle Capacity by Service Model

In this context of Information System Design, Vehicle Design, and Infrastructure Design, various platforms can meet service standards based on different standard service models governed under Title 49 CFR Part 37. We considered four other service models that may have distinct accessibility considerations: fixed-route neighborhood circulator, on-demand microtransit, paratransit, and high-capacity fixed-route transit services.

The most straightforward service model to be deployed using autonomous technology would be fixed-route circulators or high-capacity fixed-route transit services. Automation of these services on fixed guideways using standard ADA-accessible vehicles was piloted as early as 1980 during the Los Angeles Olympics (Kellerman, 2018). Yet, as automated technology has progressed, most vendors have been primarily focused on microtransit and paratransit services, given the efficiency and cost-effectiveness of operations and increased reliability and convenience of the model (Riggs & Beiker, 2019). As a result, research indicates that these two will be the primary business models of these technologies. Hence, we have focused on these two service models in our case study review.

Particularly concerning their general design and operational standards, it is anticipated that these vehicles will be able to meet or exceed applicable platform and service design standards. Table 1 summarizes the required and desirable elements of accessible service (based on our review of relevant regulations and background literature) and whether the state-of-the-art microtransit and paratransit service meets the standard. As shown in Table 1, both platforms could meet most standard vehicular thresholds, but due to the nature of the service, voice control systems and drop-off orientation may need more technological development or additional service specifications through on-demand or on-call help services. These services are sometimes referred to as trained-human-in-the-loop. These onboard issues for people with visual and hearing impairments are currently addressed with help from the transit vehicle operator. These will be critical for policymakers and vehicle service providers to address in the AAV context.

Table 1. Applicability of AAV Technology to On-demand Microtransit and Paratransit Services

	Accessible Safety Features	**Wheel Chair Stowage / Tethering**	**Voice Controlled Systems**	**Pick Up Point Orientation**	**Drop Off Point Orientation**	**Location, weather, route info etc.**
AAV On-Demand Microtransit	Meets Standards	Meets Standards	May Need Additional Development	Meets Standards	May Need Additional Development	Exceeds Standards

AAV Paratransit	Meets Standards	Meets Standards	May Need Additional Development	Meets Standards	May Need Additional Development	Exceeds Standards

On-Demand Microtransit Cases

<u>Case 1 – Prototype of a Wheelchair-Accessible AV</u>

One company has started working on a wheelchair-accessible prototype of an autonomous shuttle car and has completed its initial round of collecting feedback from community members in the region of Columbus, Ohio, and Grand Rapids, Michigan, where the shuttle will be operating (*May Mobility Reveals Prototype of a Wheelchair-Accessible Autonomous Vehicle | TechCrunch*, n.d.). The design will provide space for exit and entry, along with securing the wheelchair for a passenger once it is brought on board some time during the entire trip phase. The company realized the need for design improvements from an initial round of feedback. Specific enhancements suggested in the feedback were increasing the length of the mounting ramp to offer steadier boarding and alighting and optimized drop-off and pick-up points. The company planned to make these improvements prior to deployment.

<u>Case 2 – Customized Minivans</u>

A leading autonomous driving technology development company recently announced that it would be including 100 customized hybrid Chrysler Pacifica minivans in its experimental fleet of automated cars. These minivans will be customized in partnership with one of the leading providers of wheelchair vehicles and mobility solutions (*Automated Vehicles & People with Disabilities*, n.d.). This venture aims to demonstrate that the automation technology does not have to be utilized only in pod-like vehicles that could never accommodate a ramp for wheelchairs. Individuals with disabilities could use automated cars in their everyday lives if they collaborated with more oversized vehicles, allowing passengers of all types.

<u>Case 3 – A Luxury Concept Car</u>

The concept car from one of the German automakers is one of the more luxurious autonomous vehicles reviewed here as a case study. It was first introduced in 2017 as a public transportation option, but as of 2020, it is being marketed for private use or carsharing. With its tall roofs and wide doors, wheelchairs can easily fit, although no details are available on access and securement logistics. The automaker is collaborating with the National Federation of the Blind, the Disability Rights Education & Defense Fund, and the National Association of the Deaf in its Inclusive Mobility initiative (*Volkswagen Developing Mobility Solutions for People with Disabilities – Newsroom*, n.d.). This collaboration initiative will help the automaker incorporate feedback into their autonomous car design to ensure that they meet mobility requirements for underserved disabled populations.

Case 4 – An Urban Robo-taxi

First introduced in 2018, this concept vehicle from another European automaker has level 4 autonomy (Savov, 2018). The concept vehicle has been developed to serve as an urban "robo-taxi" that can be hailed using a phone application or from a designated city station. This communal taxi service will operate similarly to pooled options in Transportation Network Companies (TNCs) such as Lyft or Uber. The vehicle features a large door opening with an adjustable ramp and claims that it is wheelchair and stroller-accessible and there are straps for securing the wheelchair or stroller inside.

Case 5 –A Single-occupancy Design

This case study describes an accessible automated car design initiated in Eastern Europe (Templeton, n.d.). The vehicle is small, hollow, and for one-person best suited for city travel. With self-drive and electric power, it is convenient to develop a car with a hollow shell and a flat floor. The vehicle is wheelchair accessible, allowing users to roll in their chairs more easily than someone walking and getting into the car. Once a user is inside, they can clamp down the chair, strap on the belt and start the ride, which is a lot more convenient than cars with handles and seats or vans that have lifts. According to reports, wheelchair users have provided positive feedback for this vehicle.

Paratransit Cases

Case 6 – Detroit Medical Campus Shuttle

The Detroit Medical Center Heart Hospital campus automated shuttle Evo was unveiled in August 2020. It has been previously deployed in downtown Las Vegas, the University of Michigan campus, the Texas A&M campus, and Oslo, Norway (*Autonomous Vehicles*, n.d.). The electric shuttle can fit fifteen people and run for nine hours. This hospital shuttle service was designed to be accessible for paratransit and elderly riders thanks to the custom addition of an ADA wheelchair ramp. Although the shuttle is self-driving, there is always a human safety operator on each shuttle at this stage of prototype deployment.

Case 7 – US Army Catapult

In an experiment by the US Army with vital implications for American service members and people of the nation, a driverless shuttle is being piloted at Fort Bragg. The shuttle will aid wounded soldiers, especially ones suffering from traumatic brain injuries, to reach hospitals and clinics to make medical appointments (*Driverless Shuttle at Fort Bragg Is "Army's Future" - News - The Fayetteville Observer - Fayetteville, NC*, n.d.). The US Army Tank Automotive

Research, Development, and Engineering Center (TARDEC) is operating specifically equipped Cushman Shuttles that are essentially remodeled golf carts. The shuttles receive injured soldiers from their barracks and carry them to the medical center about half a mile away.

Case 8 – JTA/Olli 2.0

The Jacksonville Transportation Authority (JTA) is testing the Olli 2.0 autonomous vehicle from Beep, Local Motors by LM Industries, and Robotic Research LLC. The testing is being conducted under the umbrella of the 4-phase Ultimate Urban Circulator (U^2C) program. JTA developed Golden 20 along with an extensive test protocol for the AVs being deployed and tested for use by the transit agency under this program (*AVs Pave the Way for Future Mobility*, 2020). JTA specified "Full ADA compliance" as the first of the "Golden 20" requirements in the Request for Proposal issued in October 2019 for AV solutions appropriate for the U^2C Project.

Case 9 – ELATE project and VTA Service at VA Palo Alto

The Enhancing Life with Automated Transportation for Everyone (ELATE) project will support the goals of the Federal Transit Administration's (FTA's) Accelerating Innovative Mobility (AIM) initiative by successfully demonstrating a purpose-built, high automation common-spec Accessible Automated Electric Vehicle (AAeV) in two locations with varying climates: Youngstown, OH and Santa Clara, CA. The VTA Service will be from the Veterans Administration Palo Alto Health Care System to the Palo Alto transit center. The average trip of 4.5 miles is expected to take no more than 15 - 20 minutes. Due to the number of buses, shuttles, and trains using the Palo Alto transit center, the project will require the development of a transit center curb management solution. VTA plans to leverage the innovative tech industry by utilizing the latest in passenger management technologies such as interactive speech and video analytics. VTA will work with microtransit software providers to develop an accessible mobile app and web and phone backend system.

In Table 2 below, each of these case studies is evaluated on the ability to provide potential accessibility features needed in the absence of a driver/operator.

Table 2. Accessibility Features by Case Study

	Microtransit Case Studies					Paratransit Case Study		
Accessibility Features	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Staff manually adjusts vehicle to curb height and curb gap at stop and adjusts suspension to match if possible	N	N	N	N	N	N	N	Y
Exterior Button to deploy ramp	Y	Y	Y	Y	Y	Y	Y	Y[1]
Interior Button to deploy ramp	Y	Y	Y	Y	Y	Y	Y	Y[1]
Steward Screen to deploy ramp	P	P	P	P	P	P	P	Y
Ample lighting in the interior when boarding	Y	Y	P	P	P	Y	Y	Y
Audio announce door opening	Y	Y	N	N	N	Y	Y	Y
Vehicle opens door	Y	Y	N	N	N	Y	Y	Y
Vehicle deploys ramp manually	N	N	Y	Y	Y	N	N	Y
Safety attendant manually assists passengers with wheelchair securement	P	P	P	P	P	P	P	Y
Audio announce to wear seatbelts for all	Y	Y	P	P	P	Y	Y	Y
Ramp interlocked with door position (only deploy ramp if door open)	Y	Y	Y	Y	Y	Y	Y	Y
Ramp interlocked with vehicle drive system (vehicle moves only if ramp is stowed)	Y	Y	Y	Y	Y	Y	Y	Y
Audio announce door closing	Y	Y	P	P	P	Y	Y	Y
Ample lighting in the interior when riding	Y	Y	P	P	P	Y	Y	Y
Ability to store video for more than 30 days to evaluate incidents	Y	Y	Y	Y	Y	Y	Y	Y
Audio announce next stop when vehicle starts moving at current stop	Y	Y	P	P	P	Y	Y	Y
Audio announce next stop 35 m before vehicle arrives there	Y	Y	P	P	P	Y	Y	Y
Audio announce stop when vehicle arrives there	Y	Y	P	P	P	Y	Y	Y
Audio announce in different languages	Y	Y	P	P	P	Y	Y	N
Video display information in different languages	P	P	P	P	P	P	P	Y[2]

Y = has feature N = does not have feature P = feature possible

[1] Ensure access to the button for persons using mobility device
[2] Multilingual (English and Spanish)

DISCUSSION AND CONCLUSIONS

As this evaluation illustrates, AAVs offer a considerable promise of mobility to the disabled population through increased service with new forms of on-demand passenger travel options. However, to realize this promise, a careful review of the regulatory regime and guidance on potential changes to the rules is required.

Many of the standard features in vehicles have the potential to be enhanced and improved with automation. AAV may also increase the significance of providing onboard information to such passengers. And these technologies are being deployed globally. For example, Stockholm has recently introduced the prototype of an automated shuttle bus. The bus, since its initiation, has been sharing the roads and functioning alongside cyclists, pedestrians, and other vehicles (*Driverless Vehicles*, n.d.). It can travel at a 24 km/hr speed and has access ramps for individuals with disabilities. Potential improvements from AAVs that can deliver multimedia content en-route to passengers include the ability to provide features such as:

- Inclusion of video/safety analytics
- Ramp deployment and actuation
- Voice warning for securing passengers, rider/stop information
- The ability for multi-lingual support

Apps and other technologies providing onboard and/or pre-trip information to the passengers should be certified as *508 compliant* (*About Us | Section508.Gov*, n.d.) for web content accessibility, and communications must be *HIPAA* (Rights (OCR), 2009) compliant. The best practices in this area also include assessing the accessibility of all content against the latest international *Web Content Accessibility Guidelines (WCAG)* (*Web Content Accessibility Guidelines (WCAG) 2.1*, n.d.).

The evaluation shows the need for refinement to the existing technology privacy considerations where a trained-human-in-the-loop may be required. Additional points of consideration include factors such as voice-controlled systems for certain operations (e.g., change route, unlock doors, lower/raise windows, etc.), orientation and access features, weather and route conditions, as well as information about the environment surrounding the vehicle (*Autonomous Vehicles (AVs), Also Known as Self-Driving Cars - Disability Rights Education & Defense Fund*, 2018).

Most vendors are assuming fares and fare boxes become digital. This should be a universal standard to eliminate fare boxes from the vehicle/vehicle vestibule. The design simplicity of vehicles must also ***account for individuals with cognitive disabilities*** with simple and intuitive layouts and system controls. Voice control systems and drop-off orientation may need more technological development or additional service specifications through on-demand or on-call help services.

The transit agencies should include exploration of slope standards in requests for qualifications from vendors. A University at Buffalo study on ADA slope requirements and wheelchair capabilities would be critical to highlight in any contracts or regulations (*US Access Board - Inclusive Design of Autonomous Vehicles*, n.d.). Over the coming years, policymakers and planners will need to ensure that vehicles are designed to accommodate roadway users (especially those with disabilities) not using or interacting with those vehicles. And most importantly establishing a dialogue with AAV developers on user experience studies and focus groups could be a valuable source of learnings for both industry as well as the concerned agencies, and establish greater informational symmetry on diverse user needs.

Similarly, local transportation agencies have an opportunity to partner with AAV developers to facilitate the ease of providing accessible service through targeted policy actions in the built environment. These efforts could include:

- Coordination with local governments on enhancing and building appropriate transit infrastructure (curb ramps, bus stops, etc.) for AAV travel, particularly for mobility-impaired riders.
- Coordination, collaboration, prioritization, and sharing of curb availability for accessible services (including, but not limited to, AAVs) can create a greater density of established pick-up and drop-off locations and more collaboration in using limited space in urban areas.
- Digitization of transit trip data to encourage greater multimodal integration of future AAV services with existing transportation infrastructure.

These items will ensure that vehicles balance safety and accommodation and that regulators are prepared so that they not only guide deployment that meets the intent of the (ADA) Accessibility Specifications but deployment that potentially exceeds them. In other words, ADA standards should be used as one of the tools in addition to universal design principles and assistive technologies in order to maximize accessibility. For AAV applications, this means using advanced solutions that provide incentives for public transit operators or contracted service providers to enhance services and amenities to better serve users in the most economically prudent and environmentally sustainable manner possible.

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